



North Central Texas
Council of Governments

Integrating Transportation and Stormwater Infrastructure

Environmental Analysis Mitigation Banking Memo

July 2026



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Integrating Transportation and Stormwater Infrastructure (TSI)

Environmental and Wetland Analysis for Mitigation Banking Considerations

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1 Executive Summary

As the TSI region develops rapidly through the year 2070, there will be significant impacts to natural stream and wetland environments. These ecosystems provide habitats for the region's plants and wildlife; however, they also provide water quality benefits, recreational opportunities, and flood storage capacity. As these streams and wetlands are impacted by development, the benefits should be maintained by providing mitigation. These mitigation efforts include protection of existing ecosystems, improvement of existing ecosystems, and construction of new stream and wetland areas. Additionally, a process of mitigation banking can be utilized, where stream and/or wetland mitigation bank areas are developed, improved, and conserved for a region and credits are purchased from the bank to offset the impacts of development or transportation projects.

Where impacts on wetlands, streams, and other aquatic resources are unavoidable due to transportation infrastructure, federal laws require transportation agencies to employ mitigation or compensation strategies. Under Section 404(b)(1) of the Clean Water Act, the preferred form of compensatory mitigation is the purchase of mitigation bank credits (NCTCOG, 2016).

The North Central Texas Council of Governments (NCTCOG) Transportation Department serves as the Metropolitan Planning Organization for the 12-county Dallas-Fort Worth region, which includes the TSI study area. As part of their comprehensive regional long-range transportation planning process, NCTCOG routinely conducts analyses of mitigation bank credit supply and demand and assesses the potential impacts on recommended transportation projects. This analysis was conducted for the most recent Metropolitan Transportation Plan for North Central Texas, Mobility 2050.

The TSI study seeks to identify innovative ways to integrate transportation and stormwater infrastructure planning to meet the region's growing demand for mitigation banking while also providing flood risk reduction benefits. This memo documents the analysis of mitigation bank credit supply and demand, the potential impacts of recommended transportation projects within

the TSI study area, and the use of hydrologic and hydraulic (H&H) outputs from the TSI study to identify potential locations and integration opportunities for stream and wetland mitigation banking. The memo also presents design criteria, ownership, funding, revenue, and long-term maintenance considerations for mitigation.

2 Mitigation Bank Credit Supply & Demand

NCTCOG's Transportation Department used the RIBITS (Regulatory In-Lieu Fee and Bank Information Tracking System) tool, developed by the U.S. Army Corps of Engineers (USACE), to identify the number of wetland and stream credits available on January 14, 2025, for the subbasins (Hydrologic Unit Code, HUC-8) within their 12-county Dallas-Fort Worth Metropolitan Planning Area. They also evaluated which subbasins may face the greatest demand for mitigation credits for the Mobility 2050 projects. Figure 1 displays the subbasins and ecoregions and Table 1 displays the results of the mitigation assessment within the TSI study area.

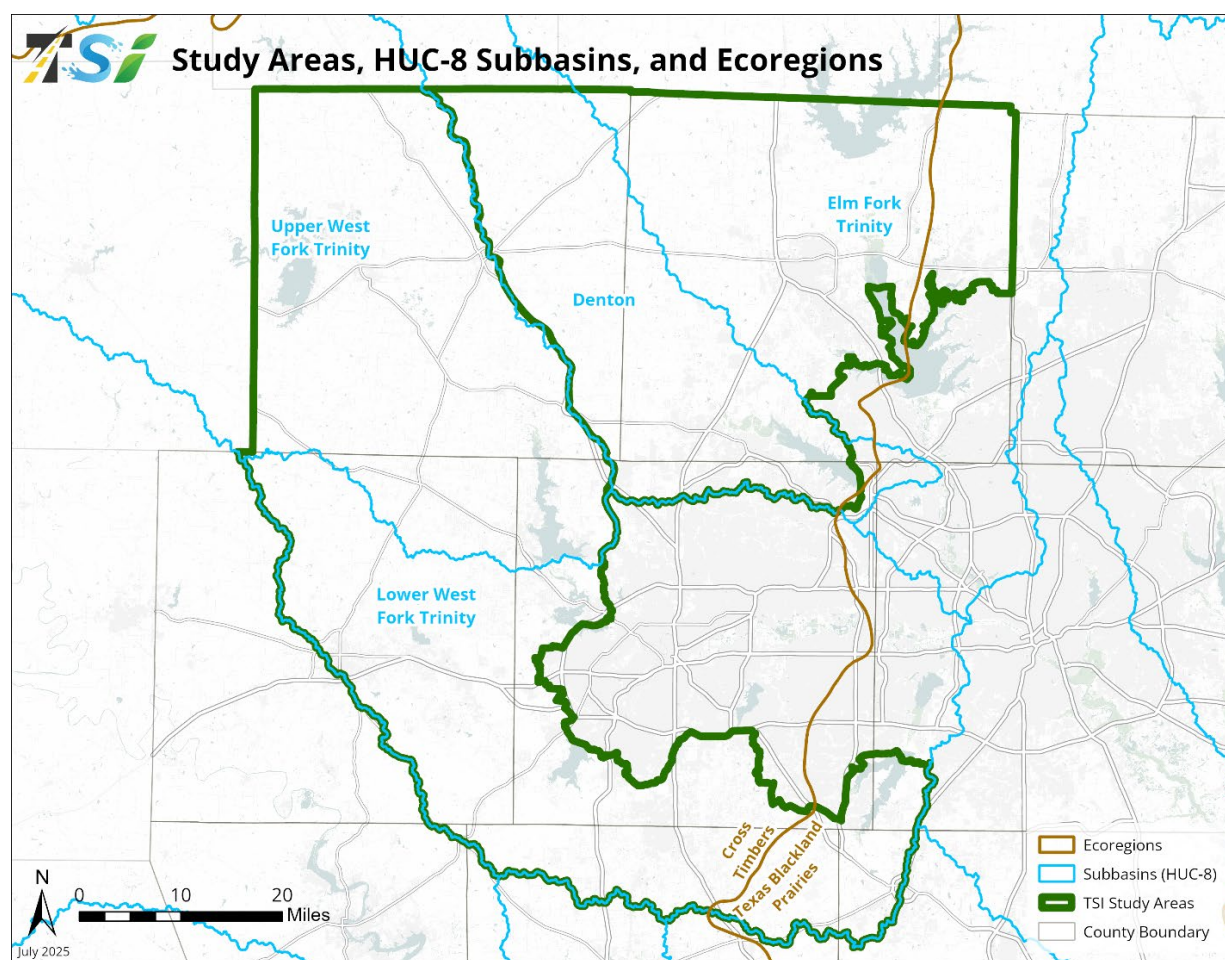


Figure 1. Subbasins and Ecoregions of the TSI Study Area

Table 1. Mitigation Assessment

Subbasin-Scale Watersheds	Ecoregion	Wetlands		Streams				Ephemeral**	General Legacy***
		Available Credits*	Potential Demand	Perennial		Intermittent		Available Credits	Available Credits
				Available Credits	Potential Demand	Available Credits	Potential Demand		
12030101 Upper West Fork Trinity	Cross Timbers	290.46	Low	0.00	Low	0.00	Low	0.00	110.25
12030102 Lower West Fork Trinity	Blackland Prairies	495.33	Medium	2240.19	Medium	9916.65	Medium	11039.71	110.25
12030102 Lower West Fork Trinity	Cross Timbers	548.43	Low	49509.19	Medium	234849.05	Low	64448.71	110.25
12030103 Elm Fork Trinity	Blackland Prairies	500.30	Medium	1688.07	High	14138.20	Medium	7565.47	110.25
12030103 Elm Fork Trinity	Cross Timbers	1222.76	Medium	0.00	Low	0.00	High	0.00	110.25
12030104 Denton	Blackland Prairies	491.76	None	1688.07	None	6488.85	None	3099.12	110.25
12030104 Denton	Cross Timbers	500.30	Low	1688.07	Low	14138.20	Low	7565.47	110.25

*Data on available credits was downloaded from the U.S. Army Corps of Engineers Regulatory In-Lieu Fee and Bank Information Tracking System on January 14, 2025 (<https://ribits.ops.usace.army.mil>).

**Potential demand for ephemeral credits cannot be estimated because data on the location of these streams is not available.

***General legacy stream credits can be used to mitigate for impacts to any kind of stream. The watersheds in which these credits are available are approximated.

Potential Demand of None indicates no projects are recommended by Mobility 2050 that impact this area.

Potential credit demand and availability were analyzed for roadway projects in Mobility 2050 that are expected to be constructed by 2035. This first interim year was chosen because it reflects the time scale on which mitigation banks operate better than the plan's horizon year of 2050. The number of available credits can change daily as credits are purchased from or made available for sale by mitigation banks; additionally, RIBITS does not reflect credits that have been purchased but are not yet associated with a permit. NCTCOG analyzes potential credit demand and availability with each Metropolitan Transportation Plan, which identifies a potential lack of credits early in the planning process and allows NCTCOG to coordinate with mitigation bankers, transportation partners, and USACE as necessary (NCTCOG, 2025).

NCTCOG Transportation Department's mitigation assessment also identified potential locations for mitigation of impacts to wetlands and streams in accordance with the Clean Water Act. With feedback from stakeholders at federal, state, and local environmental agencies, environmental factors were used to model wetland acreage and stream segments in which protection could provide the greatest ecological benefit. Potential locations for wetland enhancement and stream enhancement are identified in Figures 2 and 3 (NCTCOG, 2025).

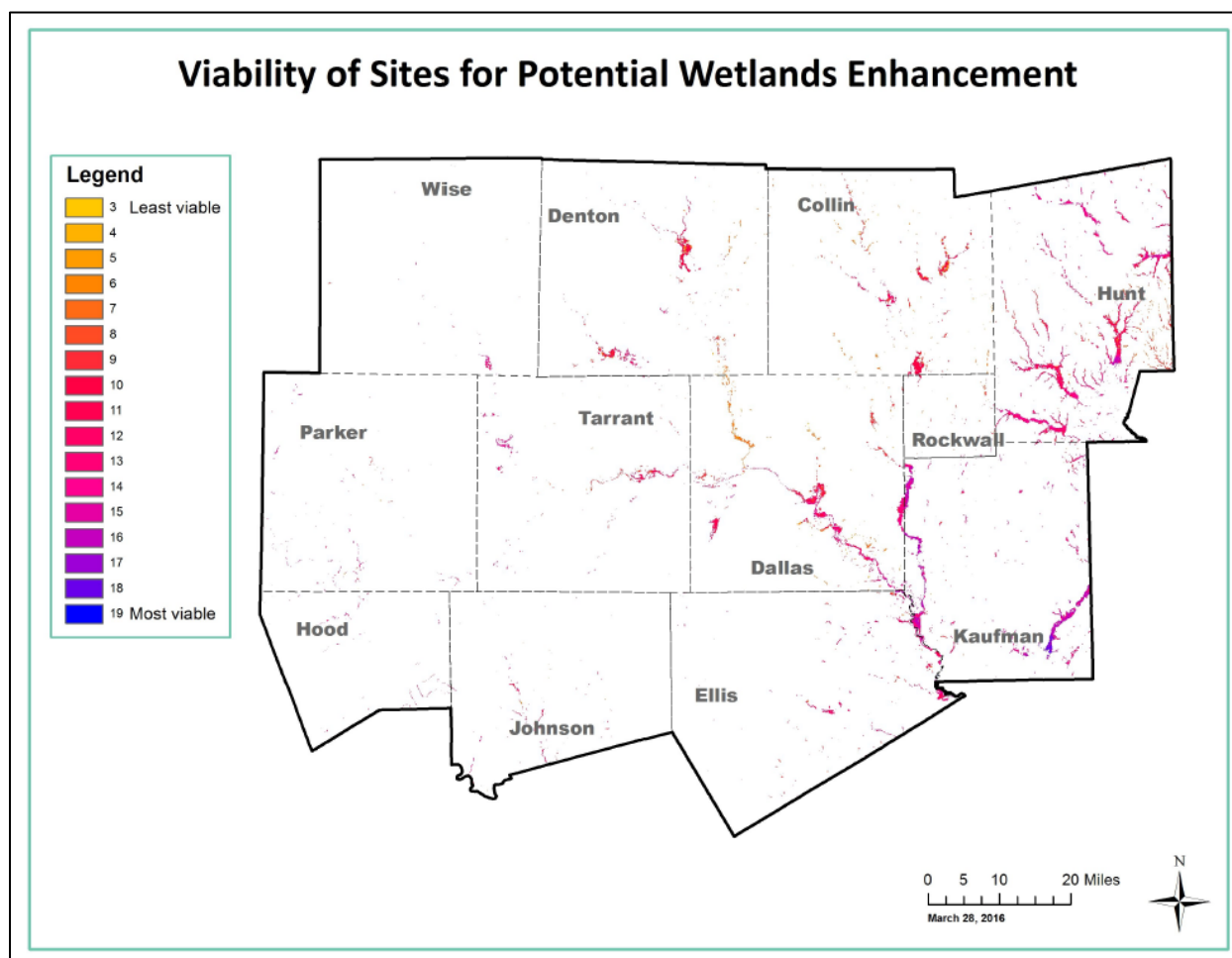


Figure 2. Potential Wetland Enhancement Sites

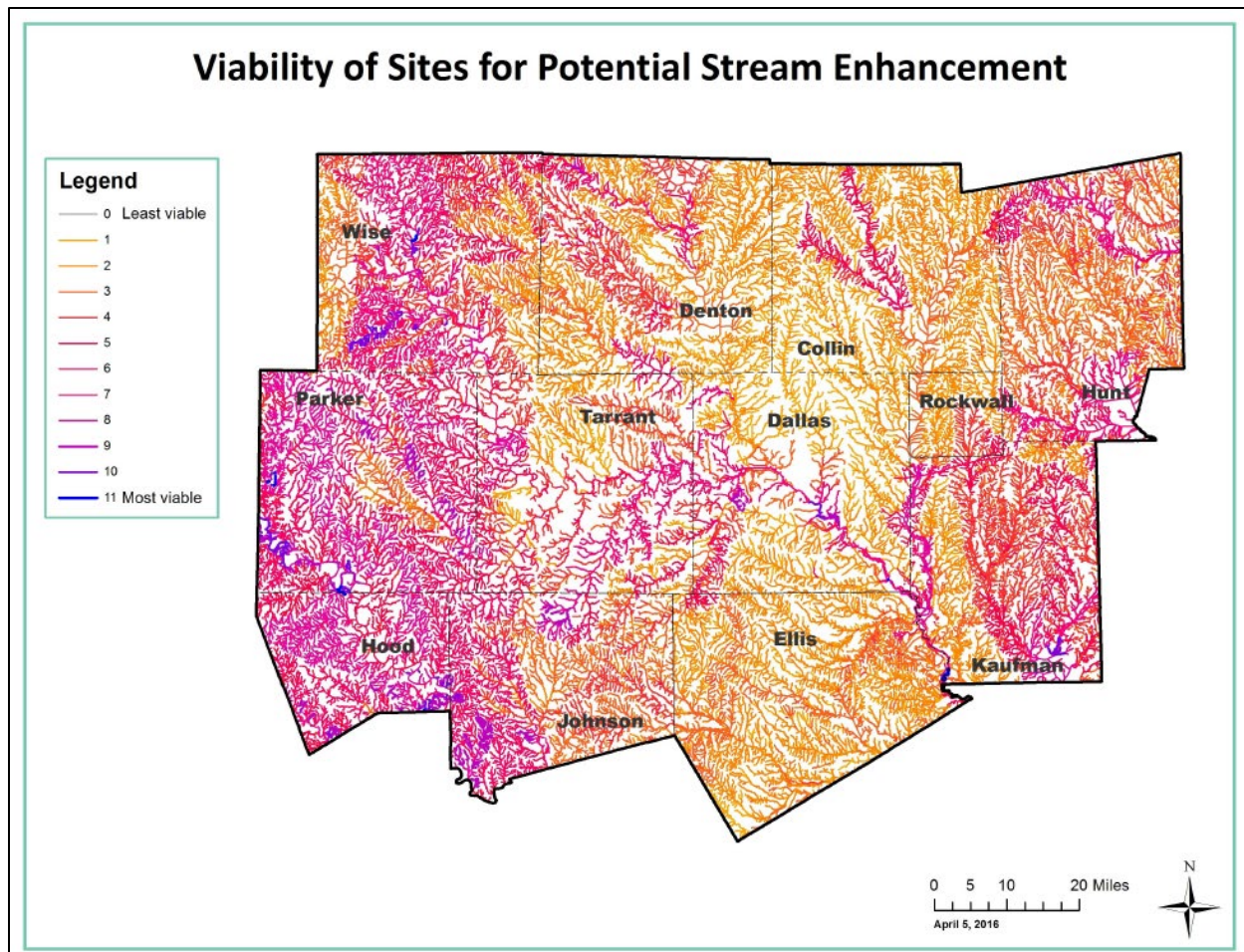


Figure 3. Potential Stream Enhancement Sites

The wetland locations and viability are scattered throughout the NCTCOG region, with the most viable wetlands for enhancement in the southeast portion of the NCTCOG region, which is outside of the TSI study area. The most viable streams for enhancement in the NCTCOG region are in the westernmost counties, Wise, Parker, and Hood counties. Wise County is entirely within the TSI study area, and the eastern half of Parker County is in the TSI study area, so these stream areas should be considered for future stream enhancements and mitigation bank developments.

3 Hydrology and Hydraulic Modeling

The data sources identified in Table 2 were used to compare H&H results from the TSI modeling to the environmental mitigation banking demands. The data includes flood inundation shapefiles generated from 1-dimension (D) and 2D USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) modeling results layers, environmental, and land use data generated by NCTCOG.

Table 2. GIS Data Sources

Data Type	Data Source	Description of the Data
Existing Structure Locations	nsi_2022_48.gpkg	National Structure Inventory database for existing structures (2022)
Existing Road Locations (2023)	YR23.shp	Locations of existing TxDOT roads with number of existing lanes
Future Road Locations (2045)	YR45.shp	Locations of future TxDOT roads with number of future lanes
Flood Inundation	Inundation_LAWO_TSI.shp	Flood inundation layers generated from TSI model of the Lake Worth watershed for the 100-year and 500-year storm events for the 2020 and 2070 land use conditions
Flood Inundation	TSI_West_Form_1DRAS.shp	Flood inundation layers generated from TSI model of the West Fork Trinity River watershed for the 100-year and 500-year storm events for the 2020 and 2070 land use conditions
Stream and Wetland Future Restore/Enhance Areas	Wetland-Stream Restoration-Enhancement Maps from Mobility 2050.mpkx	Wetland Stream Restoration Enhancement maps from NCTCOG Mobility 2050 with viability for enhancement index

As part of TSI, USACE was tasked with investigating and updating the Federal Emergency Management Agency (FEMA) generated Base Level Engineering (BLE) hydraulic models, including 1D HEC-RAS modeling in the West Fork Trinity River watershed upstream of Eagle Mountain Lake and 2D HEC-RAS modeling in the West Fork Trinity River watershed between Eagle Mountain Lake and Lake Worth (Lake Worth watershed). The 1D and 2D BLE models were enhanced according to the TSI study “West Study Region HEC-RAS Model Development Standard Operating Procedure (SOP)”, dated February 2025. The enhancements included adding hydraulic structures (bridge and culvert crossings), updating flows with TSI existing 2020 and future 2070 conditions, updating overbank reach lengths, and ineffective flow areas. Additionally, the “No As-built Process” memo by Freese and Nichols was utilized to input structures in the models where the Texas Department of Transportation (TxDOT) as-built plan information was not available.

The results of the 1D and 2D HEC-RAS models included enhanced hydraulic data and inundation layers for the various recurrence interval storm events, including the 100-year and 500-year events for the existing 2020 and future 2070 conditions. The 1D HEC-RAS models were separated by streams, however a contiguous flood inundation ArcGIS shapefile was created using the results of the various models in the West Fork watershed. The 2D HEC-RAS model for the Lake Worth watershed produced a contiguous ArcGIS shapefile for the flood inundation results in that watershed. For this mitigation banking analysis, only the 100-year storm event flood inundation layers were referenced for the existing 2020 and future 2070 conditions.

4 Mitigation Methods

Federal laws, such as the Clean Water Act, require that impacts to protected waters of the U.S. caused by transportation projects and developments be avoided, minimized, and mitigated. The 2008 “Final Rule for Compensatory Mitigation for Losses of Aquatic Resources” (USACE and

EPA) and the USACE “Fort Worth District Stream Mitigation Method”, adopted in 2013, define the parameters for minimizing impacts and mitigating impacts to streams and wetlands.

The USACE Stream Mitigation Method provides a hierarchy of mitigation methods to be employed. The first preference is for impacts to be mitigated by purchase of mitigation bank credits. Where sufficient bank credits are unavailable, in-lieu fee payments are the second preference to support future mitigation efforts. The third preference for mitigation is permittee responsible mitigation, provided either on-site or off-site via protection, restoration, or enhancement of aquatic features. In addition to this hierarchy of mitigation methods, the USACE Stream Mitigation Method shows a preference for in-kind replacement of lost aquatic functions, where wetland impacts are mitigated with wetland mitigation measures, and stream impacts are mitigated with stream mitigation measures based on the type of stream impacted (perennial, intermittent, or ephemeral).

In general, it is more viable to restore and enhance an aquatic feature, than it is to create a new aquatic feature. Creation of aquatic features can be more difficult because of incompatible soil types, hydrologic patterns, and groundwater availability. An article titled “Wetland Restoration and Creation” by Mary E. Kentula with the U.S. Environmental Protection Agency (EPA, 1996), provides greater detail about the conditions necessary for wetland restoration and creation. That article is part of the U.S. Geological Survey (USGS) Water Supply Paper 2425 and is included in the appendix of this memo for reference.

Due to the difficulty of creating new aquatic features, this memo seeks to identify existing wetland and stream features in the TSI region with the highest viability for enhancement. These existing areas will be overlaid with flood inundation results to present potential sites and alternatives to meet the TSI study area mitigation banking needs and integrate with stormwater and transportation planning.

4.1 Stream Mitigation

Transportation projects and development can cause significant impacts to streams by disrupting natural drainage paths, altering channel geometry, and increasing erosive flows. Impacts can be mitigated by a suite of natural channel design features to re-establish or enhance natural stream functions. Natural channel features seek to provide grade control along the stream to prevent erosion vertically down along the banks, referred to as downcutting. These features can retain storage areas along the streams that can be used as habitats for stream ecosystems and can provide additional flood storage along the stream during high flows. They can be constructed of rock riprap, native vegetation, and organic material from downed trees and root balls. Some of these natural channel design features include constructed riffles, log vanes, single wing deflectors, and live stakes. A more comprehensive list of stream mitigation measures was prepared by USACE and is included in the appendix of this memo, titled “Natural Channel Design Features” (Allen, n.d.). The attached list includes descriptions and images of the various stream mitigation measures.

4.2 Wetland Mitigation

As previously mentioned, it is more viable to restore and enhance existing wetlands than it is to create wetlands where there were none previously. Wetlands consist of three major

characteristics, hydrology, hydric soils, and wetland vegetation (Private Land Partnerships, n.d.), included as an appendix. The hydrology of wetlands refers to the surface and ground water sources of water into the wetland. Hydric soils are soils that hold water on or near the ground surface for at least a portion of the year. Wetland vegetation include plants that are adapted to grow in wet soils. Wetland restoration and mitigation measures seek to return some of these major characteristics to a wetland site or enhance these features. Mitigation measures can include altering drainage patterns with earthen ditches or berms to redirect water to a wetland site. Additionally, species of wetland vegetation can be selected and planted to encourage growth and establishment within a restored wetland area. These restoration measures can both enhance wetland functions and potentially provide additional flood storage capacity if provided in a floodplain fringe area. Further information about wetland mitigation measures can be found in the “Wetland Restoration Techniques” article by the Private Land Partnerships and the “Wetland Restoration and Creation” article in the USGS Water Supply Paper 2425 (1996). These references have been included in the appendix of this memo.

5 Mitigation Locations Identified Using H&H Results

Example mitigation locations have been identified by comparing NCTCOG environmental viability data, as seen in Figures 2 and 3, with the TSI H&H results. These locations should be considered for future mitigation banking sites and can be used as a reference for general criteria when selecting sites for mitigation banking. These example locations were selected to meet mitigation banking needs while integrating stormwater improvements.

5.1 Stream Mitigation Locations

To identify optimal locations for stream mitigation banking, NCTCOG cross-referenced the Mobility 2045 network with stream enhancement viability layers. This pinpointed intersections where future roadway capacity expansions overlap with high-viability stream restoration areas, presenting ideal opportunities to integrate transportation, stormwater storage, and mitigation improvements. During this evaluation, staff ensured consistency across the TSI study area by comparing the original future (YR45) capacity values against recommendations from the newly approved Mobility 2050 plan.

One example location for potential stream mitigation banking is along Silver Creek and Little Silver Creek in the Lake Worth watershed, upstream of FM 1886. This area has TSI enhanced H&H modeling results that could be leveraged for the development of the mitigation project. FM 1886 is projected to increase from two to four lanes in the Mobility 2045 plan. The FM 1886 crossings at Silver Creek and Little Silver Creek could be improved to reduce future flood risk by restricting the flow through the crossing, with storage added upstream of the crossings to reduce flows downstream. Stormwater improvements at roadway crossings could include a combination of raising the roadway embankment, cutting floodplain areas upstream, and/or installing box culverts where there was previously a bridge crossing to restrict the flow through the crossing. These stormwater improvement measures are some examples for improvements to reduce future flood risk, however a more extensive description of stormwater improvements with example projects can be found in the Alternative Analysis memos of the TSI final report. These stormwater infrastructure improvements could be integrated with transportation improvements when the FM 1886 roadway is increased from two to four lanes. The storage areas added

upstream along Silver Creek and Little Silver Creek roadway crossings could also be improved to provide stream mitigation banking. These reaches of Silver Creek and Little Silver Creek have been ranked 6 out of 11 for viability for stream enhancements in the NCTCOG environmental data, which is moderate viability.

Figure 4 shows the reach of Silver Creek and Little Silver Creek that could be utilized for stream mitigation banking. Existing structures from the National Structure Inventory are shown in red, and the stream viability ranking symbology is also included. The two crossings along FM 1886 are circled which could be improved to provide stormwater and environmental benefits. The TSI 100-year flood inundation is also included for 2020 existing conditions in blue and 2070 future conditions in red.

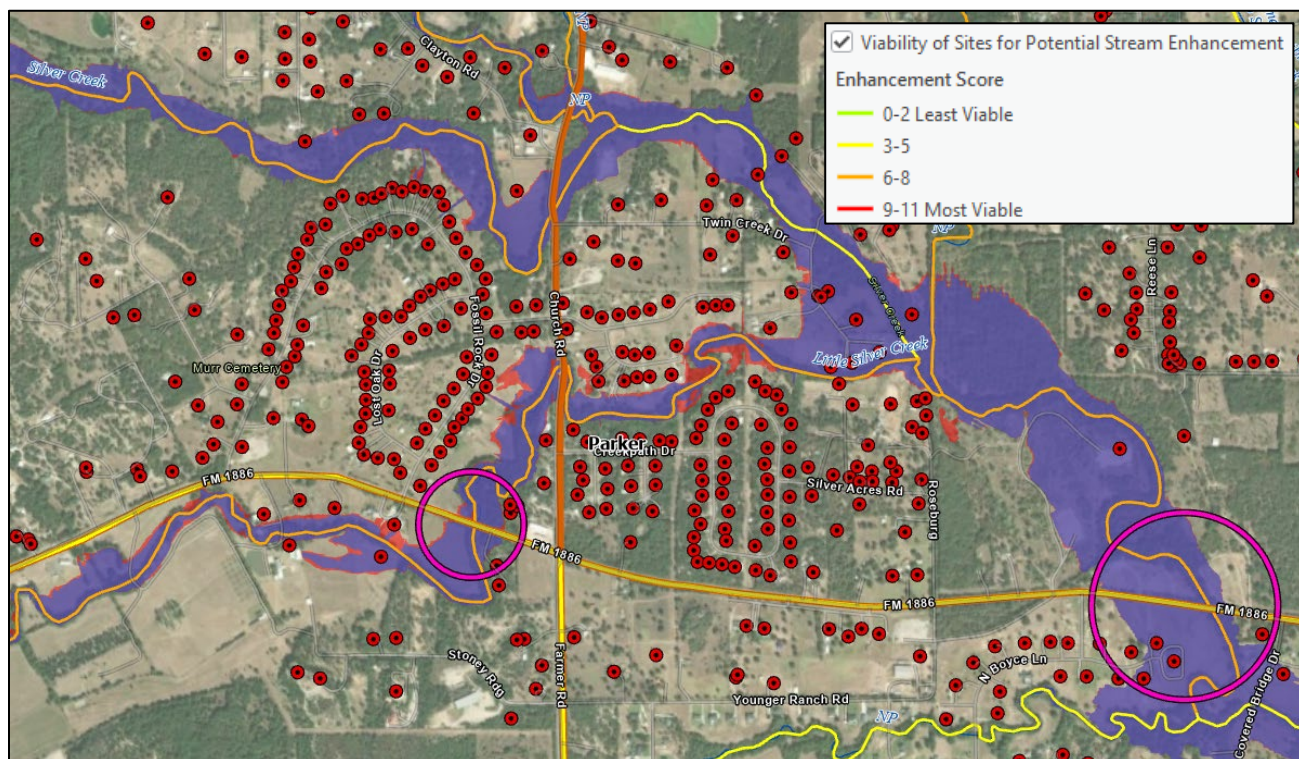


Figure 4. Potential Stream Mitigation Banking Locations

As mentioned in section 2 of this memo, there is a lack of stream mitigation credits in Wise County. There are a few streams in Wise County identified in the NCTCOG environmental data that have high viability for enhancement (Figures 5 and 6). These streams do not coincide with roadways with future improvements, but they are in areas of TSI enhanced H&H modeling, which could be leveraged for the development of the projects. These reaches with high viability for stream enhancement are Garrett Creek, upstream of the confluence with Rush Creek near CR 3655, and Big Sandy Creek, upstream of US Hwy 380. The TSI 100-year flood inundation is also included for 2020 existing conditions in blue and 2070 future conditions in red.

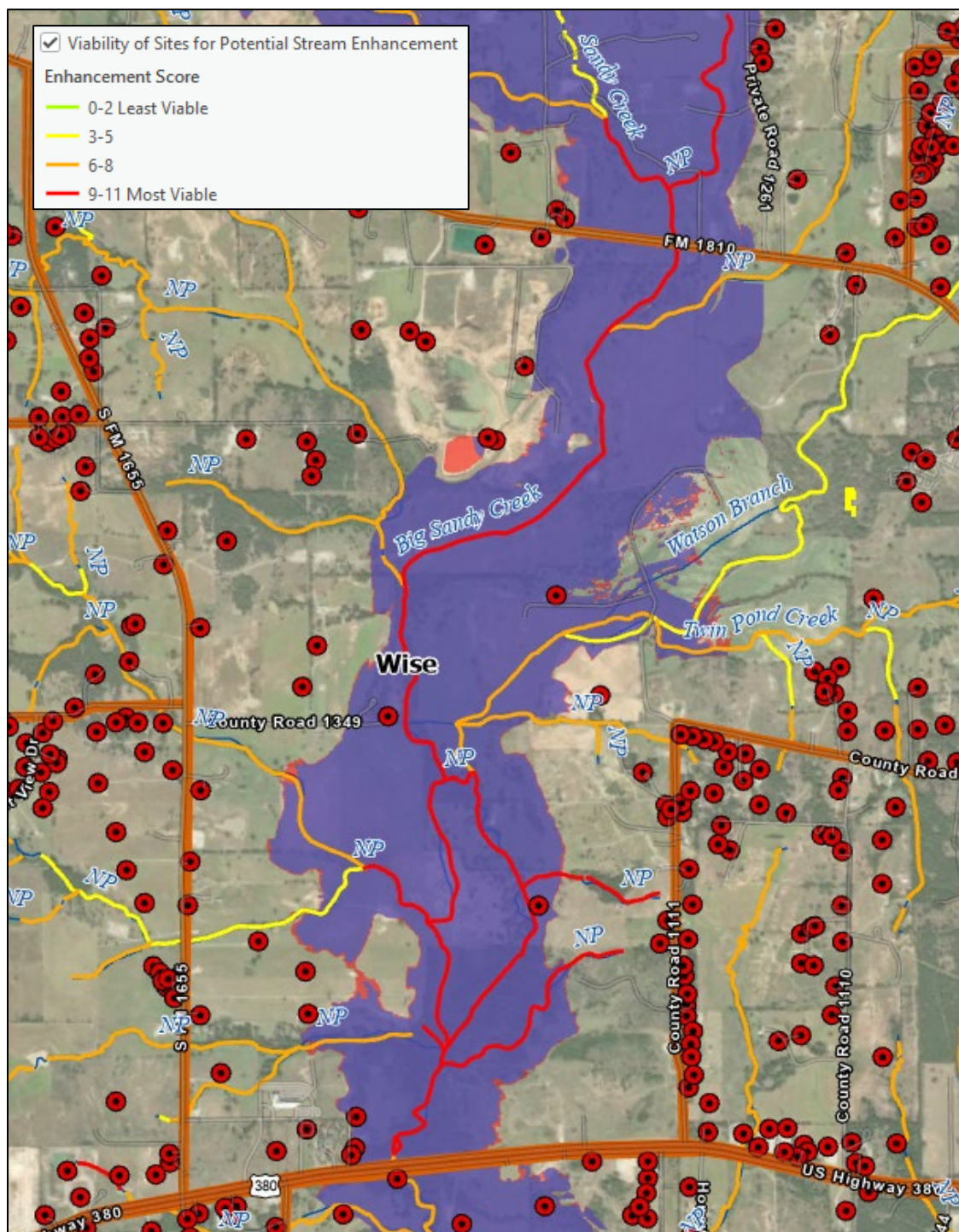


Figure 6. High Viability for Stream Enhancement Location at Big Sandy Creek

5.2 Wetland Mitigation Locations

The NCTCOG environmental data identified wetland areas with viability for restoration and enhancement throughout the NCTCOG region. Within the TSI study area, these viable wetland enhancement areas are primarily located near Eagle Mountain Lake and Lake Worth. One potential alternative for wetland mitigation banking in the TSI region would be to identify properties with increased flood risk in the 2070 future conditions and recommend buyouts of these properties. These buyouts could be strategically targeted near areas of high viability of wetland enhancement, and the properties could be used to restore and enhance the wetland areas for mitigation banking.

To identify these potential locations, the TSI enhanced H&H inundation results layers were leveraged. The 2020 existing conditions 100-year flood inundation was subtracted from the 2070 future conditions inundation, and the difference was the increase in 100-year flood inundation extent through 2070. This shapefile was intersected with the National Structure Inventory points shapefile to determine what properties would be in the increased flood inundation areas in 2070, where they were previously outside of the 2020 flood inundation. Structures within increased 2070 inundation were compared with the NCTCOG wetland enhancement shapefiles to identify areas of intersection. It should be noted that existing structures within the 2020 flood inundation will also experience increased flooding depths in the 2070 conditions, so structures in the 2020 flood inundation could also be considered for buyouts.

There were two areas identified where property buyouts could reduce future flood risk and serve as wetland restoration and enhancement mitigation bank areas. These areas were along the West Fork Trinity River, upstream of Eagle Mountain Lake, and along Silver Creek and Live Oak Creek to the west of Lake Worth. Figures 7 and 8 show existing structures from the National Structure Inventory in relation to the NCTCOG wetland enhancement viability layers. The structures which were not in the 2020 flood inundation, but will be in the increased 2070 flood inundation extent are shown in green and all other existing structures are shown in red. Buyouts for wetland mitigation banking improvements could target structures near the viable wetland enhancement areas already located in the 2020 flood inundation, since they will experience increased flood depths in 2070, or the buyouts could target structures which will be in the future 2070 flood inundation extent.

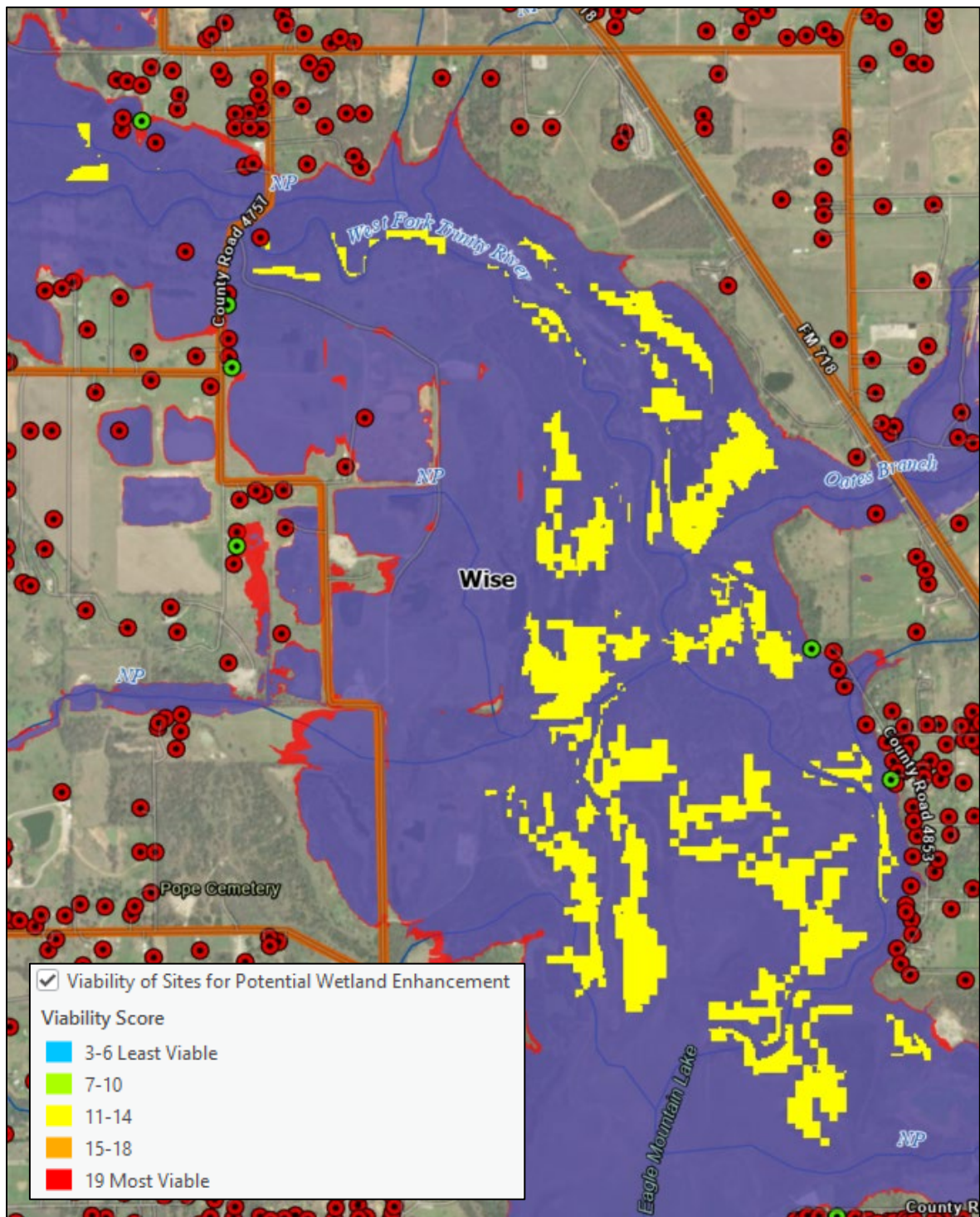


Figure 7. High Viability for Wetland Enhancement Location Along the West Fork Trinity River

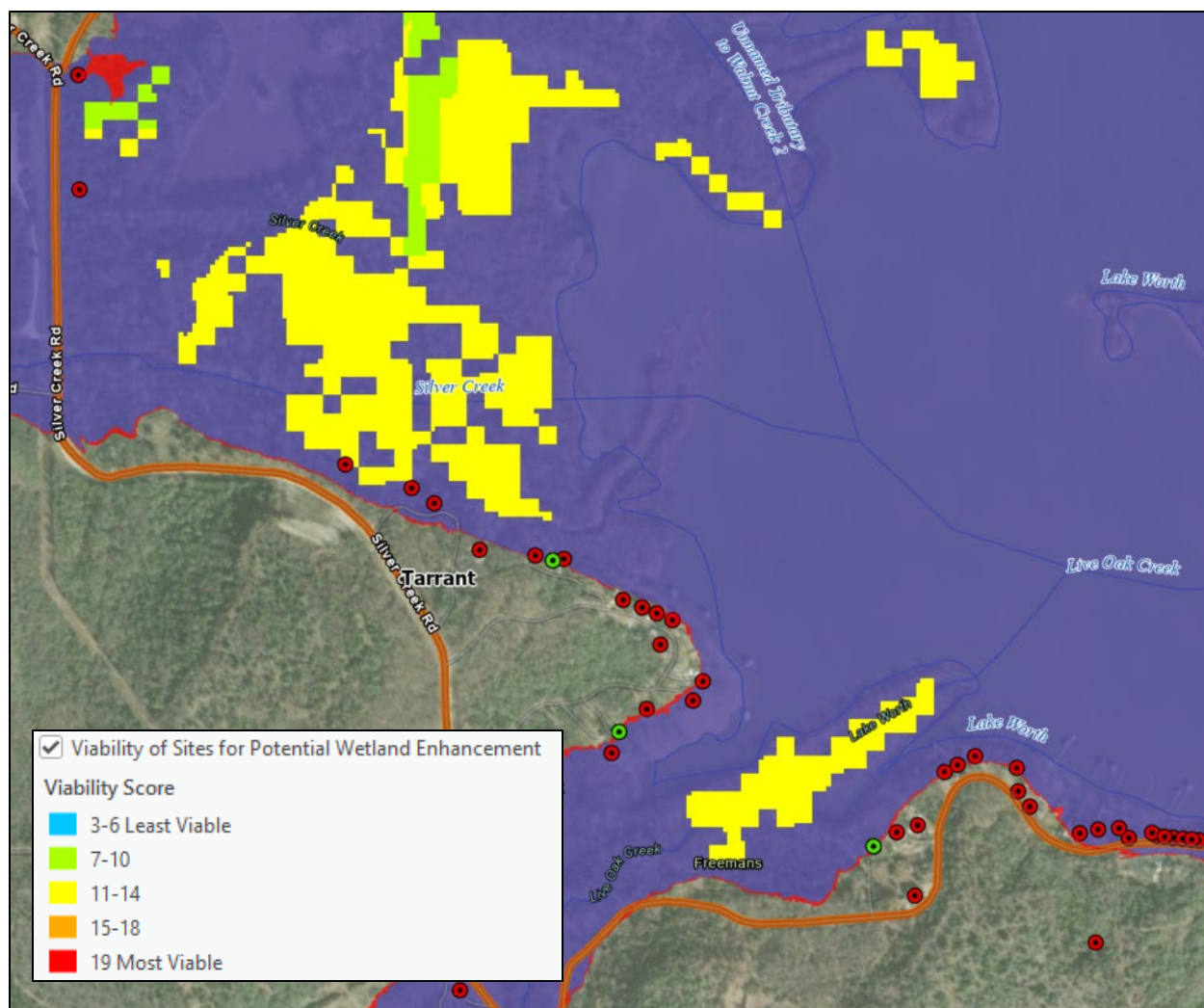


Figure 8. High Viability for Wetland Enhancement Location Along Silver Creek and Live Oak Creek

6 Design Criteria

Common design criteria for stream enhancement and restoration projects address channel stability, hydraulic function, sediment continuity, floodplain connectivity, and habitat enhancement. The features and practices used to achieve these objectives generally fall into four main categories:

1. Grade control features, such as constructed riffles, step pools, cross-vanes, and grade-control J-hook vanes, help maintain channel elevation and prevent incision.
2. Lateral stability structures, including root wads, log vanes, J-hooks, rock vanes, and toe wood, help stabilize streambanks and direct flow away from erosion-prone areas.
3. Bed form diversity structures, such as wing deflectors and cover logs, increase hydraulic complexity and enhance aquatic habitat.

4. Bioengineering techniques promote long-term bank stability through the establishment of native vegetation.

These measures may be applicable within the stream enhancement and restoration focus areas and should be selected and designed to appropriately reflect site conditions, project objectives, and anticipated hydraulic conditions.

Wetland enhancement and restoration design criteria are highly dependent on wetland type and site-specific hydrologic conditions. H&H analyses are necessary to establish the water regime needed to support the target wetland community. Water control structures, such as adjustable weirs or stop logs, may be used to manage water levels; however, their applicability, along with vegetation selection and establishment methods, depend on factors including wetland type, hydrologic regime, site topography/elevation, and target ecological functions. Compared to wetland restoration, stream restoration is generally more dynamic and offers a broader range of potential design features and techniques.

Additional stream and wetland restoration design features and techniques are included in the appendix.

7 Ownership, Funding, Revenue, and Long-Term Maintenance Considerations

The stream and wetland mitigation opportunities identified in this memo may be pursued as individual mitigation projects or incorporated into a mitigation bank. Ownership and management responsibilities vary depending on project objectives, regulatory requirements, and the implementation approach selected. Potential owners and managers of mitigation sites include private landowners, local governments, regional authorities, transportation agencies, nonprofit conservation organizations, mitigation bank sponsors, and public-private partnerships. In many cases, the entity undertaking the mitigation project is responsible for construction, regulatory compliance, monitoring, and maintenance until applicable performance standards have been achieved.

Mitigation projects may be incorporated into a mitigation bank when restoration, enhancement, preservation, or creation activities generate compensatory mitigation credits. Establishment of a mitigation bank typically requires coordination with the USACE and the Interagency Review Team (IRT), development of a banking instrument, designation of a service area, and establishment of performance standards and long-term management requirements. Once approved, mitigation credits may be released and used, transferred, or sold to offset unavoidable impacts to streams, wetlands, and other aquatic resources.

Revenue associated with mitigation banking is generally generated through the sale of mitigation credits. Credit release schedules, approved service areas, regulatory approval, market demand, and the quantity and type of credits generated all influence the financial viability of a mitigation bank. For the mitigation opportunities identified through this study, incorporation into a mitigation bank may provide a mechanism to offset implementation costs while supporting the long-term stewardship and management of restored aquatic resources.

Incorporation of a mitigation project into a mitigation bank does not necessarily change ownership of the underlying property; however, it may affect long-term management and stewardship obligations. Mitigation banks typically require formal agreements governing performance standards, monitoring, maintenance, financial assurances, site protection measures, long-term management plans, and stewardship responsibilities. Accordingly, project sponsors should consider not only the potential revenue generated through mitigation credit sales, but also the additional regulatory and stewardship commitments associated with mitigation banking.

Long-term maintenance and stewardship are important considerations for any mitigation project, regardless of whether it is incorporated into a mitigation bank. Depending on site conditions and restoration objectives, activities may include vegetation management, invasive species control, monitoring, repair and maintenance of water-control structures, adaptive management measures, streambank stabilization, and protection of conservation easements. These needs are generally greatest during the establishment period following construction but may continue periodically throughout the life of the site.

Responsibility for long-term maintenance and stewardship may remain with the project sponsor, landowner, mitigation bank sponsor, public agency, conservation organization, land trust, or another designated entity. Stewardship obligations may continue after mitigation performance standards have been achieved and regulatory monitoring requirements have ended in order to ensure the continued ecological function and protection of the site. Consequently, project sponsors should evaluate long-term maintenance obligations, stewardship responsibilities, and associated funding needs early in project planning and feasibility evaluations.

Circumstances concerning ownership, revenue, and stewardship should be evaluated alongside ecological suitability, flood risk reduction objectives, and regulatory requirements when assessing the feasibility of future stream and wetland mitigation opportunities and potential mitigation banking applications.

8 Conclusions

As the TSI region continues to develop rapidly, the lack of stream and wetland mitigation bank credits available to the region will present a challenge for environmental protection and enhancement. In general, it is easier to restore and enhance existing aquatic features than it is to create new features. This memo identifies existing aquatic features and areas that are viable for stream and wetland mitigation bank improvements. Mitigation bank locations have been identified in this memo using TSI enhanced H&H modeling data that can be integrated with transportation and stormwater improvements. Areas with future roadway improvements could be utilized as stormwater detention structures, and the upstream areas can be used for stream mitigation banking efforts. Properties with increased future flood risk could be considered for buyouts and the land could be used to restore and enhance existing wetlands for mitigation banking. The appendix of this memo includes additional resources identifying stream and wetland mitigation methods, design considerations, and restoration features that could be employed in these potential mitigation bank areas.

Development of new mitigation banks in the TSI study area will be beneficial to offset the environmental impacts of rapid development. These benefits would include reduced environmental review times, cost savings for environmental mitigation, and improved water quality and ecosystems throughout the region. If these mitigation bank areas can be integrated with transportation and stormwater improvements, costs can be shared to meet multiple needs for the region. Future stream and wetland mitigation opportunities should be evaluated not only for their ecological and flood risk reduction benefits, but also for ownership considerations, revenue potential, long-term stewardship obligations, maintenance requirements, and the feasibility of mitigation banking applications. These integrated mitigation bank recommendations should be considered by communities, planning organizations, and transportation departments to collaboratively meet these needs.

9 References

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10 Appendix

Appendix A: “Wetland Restoration and Creation,” U.S. Geological Survey

Appendix B: “Natural Channel Design Features,” U.S. Army Corps of Engineers

Appendix C: Wetland Restoration and Creation,” U.S. Geological Survey



National Water Summary on Wetland Resources

United States Geological Survey Water Supply Paper 2425

Restoration, Creation, and Recovery of Wetlands

Wetland Restoration and Creation

By Mary E. Kentula, U.S. Environmental Protection Agency

The benefits of restoration of degraded or destroyed wetlands and creation of new wetlands has only recently been recognized. As the population has expanded across the Nation during the past few centuries, wetlands have been drained and altered to accommodate human needs. These changes to wetlands have directly, or indirectly, brought about changes in the migratory patterns of birds, local climate, and the makeup of plant and animal populations. In the past, people used wetland plants and animals for shelter and food. More recently, people have become more aware of other benefits that wetlands provide: water-quality improvement, flood attenuation, esthetics, and recreational opportunities. Now, it is recognized that numerous losses are incurred when a wetland is damaged or destroyed. Restoration and creation can help maintain the benefits of wetlands and their surrounding ecosystems, and at the same time accommodate the human need for development.

Wetland restoration rehabilitates a degraded wetland or reestablishes a wetland that has been destroyed. Restoration takes place on land that has been, or still is, a wetland. A term commonly associated with restoration is "enhanced." An enhanced wetland is an existing wetland that has been altered to improve a particular function, usually at

Wetland creation is the construction of a wetland on a site that never was a wetland. This can be done only on a site where conditions exist that can produce and sustain a wetland. Consequently, creation is more difficult than restoration. A term commonly associated with wetland creation is "constructed." A constructed wetland is a wetland created specifically for the purpose of treating wastewater, stormwater, acid mine drainage, or agricultural runoff (Hammer, 1989). As used in this article, "project wetland" refers to restored or created wetlands. (For a more complete discussion of the meaning of these terms and others associated with restoration and creation, see Lewis, 1990.)

Wetland alterations have brought about changes in the migratory patterns of birds, local climate, and make up of plant and animal populations.



(Click on image for a larger version, 80K)

Figure 52. View of a restored salt marsh in the Salmon River Estuary on the Oregon coast. *(Photographs courtesy of the EPA Wetlands Research Program.)*

the expense of other functions. For example, enhancing a site to increase its use by a particular species of bird commonly limits its use as habitat for other species. (For information on functions of wetlands see the articles ["Wetland Hydrology, Water Quality, and Associated Functions"](#) and ["Wetland Functions, Values, and Assessment"](#) in this volume.)

CHALLENGES OF RESTORATION AND CREATION

Ecological issues and physical limitations are important factors to consider when planning for wetland restoration or creation. The relative merits of destroying the function of an existing wetland, or other ecosystem, in exchange for another wetland function involves the consideration of numerous questions such as: (1) Which is more important, the existing or the replacement function? (2) Will the proposed wetland increase wildlife diversity? (3) Is the increased diversity worth the loss of habitat of any endangered species? Questions of this type always arise during planning for wetland restoration and creation.

A well-documented example of a physical limitation associated with restoring a wetland can be seen along the shoreline of the Salmon River Estuary, Oreg. (Frenkel and Morlan, 1990, 1991). In the past, many high marsh wetlands along the Pacific coast were diked to remove them from tidal action. After the area was diked, the wetlands dried up and the land was used for pasture. In 1978, in an effort to restore the Salmon River Estuary to its original condition, two dikes were removed to allow the original wetlands to reestablish themselves. However, after 10 years, the resulting wetlands ([fig. 52](#)) were not typical of other high marshes along the estuary. The land behind the dikes had subsided over time, and the restored

It is difficult to make a definitive statement about the ability to replace wetland functions. Goals for restoration and creation projects seldom are stated and information on the existing functions of the wetlands seldom are documented. This is due, in part, to the difficulty and expense of quantifying wetland functions. Also, responsible monitoring during construction and after completion of the project wetland is uncommon. Most information available on project wetlands is in the form of qualitative case studies.

Restoration and creation can help maintain the benefits of wetlands and accommodate the human need for development.

wetlands were more typical of wetlands at lower elevations nearer the estuary (low marsh). Although the wetlands continue to evolve as sediments are trapped and deposited by the vegetation (thus raising the elevation), it might take another 50 years for the restored wetlands to become similar again to the original high marsh (Frenkel and Morlan, 1991). The time required and the ability to develop a fully functional soil system in project wetlands may be major determinants of the eventual acceptance or rejection of restoration and creation as management options.

DESIGNING FOR SUCCESS

Much of the written material on wetland restoration and creation deals with "project design." Project design considers a large number of site-specific, interdependent factors that determine the structure and function of a wetland. Although there is no "cookbook" for restoring or creating wetlands, documents describing general approaches to restoration and creation and the conditions conducive to project success are available (Garbisch, 1986; Marble, 1990; Pacific Estuarine Research Laboratory, 1990; Hammer, 1992; Maynard and others, 1992). Elements common to wetland project design are site-selection criteria, hydrologic analysis, water source and quality, substrate augmentation and handling, plant material selection and handling, buffer zones placement, and long-term management. A brief overview of each element is presented here in a sequence similar to that followed in project planning.

Site selection.- Sites for project wetlands often are selected on the basis of available land, or on policies that require wetlands to be restored or created to compensate for nearby wetland losses (mitigation). A wetland's structure, function, and ability to persist over time are greatly influenced by its location. Wetlands in settings with

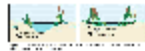
Hydrologic analysis.- Hydrologic conditions probably are the most important determinants of the type of wetland that can be established and what wetland processes can be maintained (Mitsch and Gosselink, 1993). Elements of site hydrology that are important to maintaining a wetland are inflows and outflows of ground water and surface water, the resulting water levels, and the timing and duration of soil saturation or flooding.

One factor influencing hydrology is the configuration of the basin (depression) containing the wetland. The position of the basin surface relative to the water table influences the degree of soil saturation and flooding. To ensure that standing water is present year round, many project wetlands are excavated so that the deepest part of the basin is below the lowest anticipated water level. The slope of the basin banks determines how much of the site will be vegetated and by what kinds of plants ([fig. 53](#)). This is because the slope determines how far the substrate (soil or rock material that forms the surface of the basin) will be from water and how much of the substrate has the necessary conditions of wetness for specific plant species (Hollands, 1990). The ability to maintain the desired plant

Benefits can extend beyond the wetland if care is taken in site selection.

limited human influence can differ greatly in structure and function from wetlands in settings dominated by human activities. Therefore, the present and projected land uses of the surrounding area are a consideration when selecting the site. The characteristics of existing wetlands, in the same general area, or in an area with similar land uses, can be used as models for what might be expected of the project wetland. Benefits that extend beyond the wetland itself can be derived from the placement of a wetland if care is taken in site selection. For example, restoration of riverbank wetlands between agricultural land and a stream can improve downstream water quality (Olson, 1992).

community, therefore, is ultimately dependent on the hydrology of the site. In a properly constructed freshwater marsh, the lowest point of the wetland will be inundated to a depth and for a period long enough that emergent vegetation can persist, but not so long as to destroy the plants.



(Click on image for a larger version, 59K)

Figure 53. The relative position of a basin substrate, the water table, and differences in vegetation resulting from the degree of basin slope.

Water source and quality.- Although it is commonly acknowledged that site hydrology is a major determinant of the success or failure of wetland restoration or creation, the influence of water quality often is ignored. Inputs of chemicals from the surrounding landscape can overwhelm a wetland's ability to improve water quality and can change the characteristics of the site. For example, deicing salts are used extensively along highways and, if they enter a wetland, can alter the productivity and composition of its plant community, possibly favoring nuisance species such as purple loosestrife (Niering, 1989).

Substrate augmentation and handling.- Wetlands are characterized by hydric soils, which develop as a result of an area being saturated, flooded, or ponded long enough during the growing season to develop anaerobic (oxygen-deficient) conditions (U.S. Soil Conservation Service, 1991) ([fig. 54](#)). Most of the chemical reactions in

Plant material selection and handling.- Vegetation is the most striking visual feature of a wetland. Because of the unique and stressful conditions that develop in wetlands, varying from long periods of flooding to periodic drying, plants and animals found there have developed distinctive mechanisms to deal with these stresses and conditions. It is important to recognize the constraints of this unique environment when planning a project wetland. Plant communities established in project wetlands will fare better if they closely resemble communities in similar, local wetlands. To increase the likelihood of successful colonization, Garbisch (1986) suggests that project managers:

- Select herbaceous species that rapidly stabilize the substrate and that have potential value for fish and wildlife
- Select species that are adaptable to a broad range of water depths. A

Hydrologic conditions probably are the most important determinants of wetland types and processes.

wetlands take place in the soils, where most chemicals are stored (Mitsch and Gosselink, 1993). The soils of project wetlands are receiving increased attention as studies link substrate characteristics to ecological function. Although a created wetland may be structurally similar to a natural wetland, its hydrology may differ greatly from that of the natural wetland if the permeability of the substrates differ (O'Brien, 1986). In addition to differences in permeability, soils in project wetlands commonly have a smaller amount of organic matter than soils in similar natural wetlands. Because organic matter in soils stores nutrients that are critical to plant growth (Pacific Estuarine Research Laboratory, 1990), the smaller amounts of organic matter in soils of project wetlands may limit plant growth (Langis and others, 1991). Augmenting, or mulching, the substrate of project wetlands with materials from a "donor" wetland can increase soil organic matter and provide a source of needed plant species, microbes, and invertebrates. Mulching makes the substrate more conducive to rapid revegetation by reducing the evaporation of pore water, runoff, soil loss and erosion, and surface compaction and crusting (Thornburg, 1977). Mulching also can cause problems such as the introduction of unwanted plant species.

survey of vegetation at wetlands of the type being created or restored can identify the conditions of "wetness" needed by species

- Avoid choosing only those species that are foraged by wildlife expected to use the site-muskrats and geese have been known to denude sites
- Avoid committing significant areas of the site to species that have questionable potential for successful establishment

In addition, Stark (1972) suggests the selection of "low maintenance" vegetation.



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Figure 54. Scientists checking to see if a soil sample has the unique coloration typical of wetland (hydric) soils. *(Photograph courtesy of the EPA Wetlands Research Program).*

Buffer zone placement.- Protective measures are needed for many restored and created wetlands, particularly in urbanized areas. This protection can take the form of an undeveloped, vegetated band around the wetland; a fence or

Long-term management.- Careful monitoring of newly established wetlands and the ability to make mid-course corrections are critical to long-term success. However, few project sponsors have been willing to assume long-term

Chemicals from the surrounding landscape can overwhelm a wetland's ability to

barrier; or a lake or sediment basin. This buffer between the wetland and surrounding land is desirable; however, the characteristics of an appropriate vegetated buffer are not well defined. Although composition is important, width is the most frequently cited characteristic of an adequate buffer zone. Requirements for both composition and width are dependent upon the adjacent land uses, their potential effect on the functions of the wetland, and the requirements of the animals that will use the wetland and buffer area. Buffers are used to:

- Deter predators from entering wetlands
- Trap and prevent undesirable materials from entering the wetland through runoff from the surrounding landscape
- Provide habitat for wildlife that depend on uplands in addition to wetlands for part of their life cycle

responsibility for managing these new systems (Kusler and Kentula, 1990b). Because of this, project wetlands that are designed to be self-sustaining or self-managing will have the best chance of survival. The installation of control structures, such as tide gates or pumps, that will require maintenance and are subject to vandalism could be disadvantageous to the life of the project wetland.

improve water quality.

EVALUATION OF SUCCESS

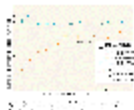
One of the most vexing aspects of wetland restoration and creation projects is defining success, primarily because there is no generally accepted definition. This is true for many reasons-lack of clearly stated objectives, lack of long-term monitoring (Kusler and Kentula, 1990b), and the subjective point of view of the definer (Roberts, 1993). The vast majority of project wetlands are ecologically young-10 years of age or less. The lack of information on ecologically mature projects limits the ability to predict whether or not the functions of project wetlands can replace the functions of natural wetlands. Nevertheless, the results of ongoing research and good professional judgment can be used to provide insight into the selection of projects that have a high probability of success.

The Wetlands Research Program of the U.S. Environmental Protection Agency (EPA) is developing an approach to establish quantitative performance criteria for project wetlands. In this approach, groups of natural wetlands serve as reference sites against which project wetlands are judged. For example, Zedler (1993) uses reference data from natural marshes being used by clapper rails (an indigenous bird species) to define criteria that can be used to judge the suitability of restored and created habitat for the birds. Older project wetlands also are used as reference sites against which to judge newer project wetlands, both to verify that development is as expected and to identify developmental patterns that may have resulted from changes in project design (Kentula and others, 1992). This approach is designed to produce results that are

Various attempts have been made to define success criteria for wetland projects. The earliest criteria assumed that if conditions were correct for the establishment of wetland vegetation, then other ecological functions would either be present or develop over time. Now, it is known that a site "green" with vegetation does not necessarily mean success, and the standards by which projects are judged are more likely to be tied to wetland functions.

regionally applicable to wetland protection and management.

One tool for comparing the characteristics of project wetlands with similar, naturally occurring wetlands is a performance curve ([fig. 55](#)). Functions in a group of restored wetlands can be expected to increase gradually with time to a point of maturity at which time the level of function has stabilized. The mean level of function in mature project wetlands is generally less than that for natural wetlands. Rate and time of maturation and functional level at maturity will differ from project to project, depending on the type of wetland being restored. The curve provides information on when to monitor, how restored wetlands typically develop, and when project goals have been met. Changes in the characteristics of project wetlands can be expected in response to the maturation process, but also in response to changes in the environment. Information on the development of project wetlands and similar natural wetlands helps managers determine whether an observed change is typical for a particular year or stage of development.



(Click on image for a larger version, 98K)

Figure 55. Typical performance curve illustrating the comparison of groups of natural wetlands and restored wetlands of the same type and similar size in the same

Over time, successful project wetlands can be expected to become similar to comparable natural wetlands. A comparison of plant diversity on project wetlands and similar natural wetlands in Oregon (Kentula and others, 1992), Connecticut (Confer and Niering, 1992), and Florida (Brown, 1991) showed that, although the level of diversity differs with each project, diversity tends to be higher on each project wetland than on its natural counterpart. The type of wetland studied was a pond with a fringe of freshwater marsh ([fig. 56](#)). If a project wetland develops as hoped and expected, after 2 to 5 years it probably will have a plant diversity greater than or equal to that of similar natural wetlands. As competition for space and resources increases and the plants more completely cover the site, the diversity usually decreases and the plant community tends to become more like that of a mature site.



(Click on image for a larger version, 110K)

Plants in project wetlands fare better if they closely resemble those in similar, local wetlands.

land-use setting. (Source: *Modified from Kentula and others, 1992.*)

Figure 56. This pond with a fringe of marsh in Portland, Oreg., is a restored wetland and is an example of the type of freshwater project wetland most common in this country. (Photograph courtesy of the EPA Wetlands Research Program.)

STATUS OF THE SCIENTIFIC KNOWLEDGE OF RESTORATION AND CREATION

Current scientific knowledge about successful wetland restoration and creation has been documented in "Wetland Creation and Restoration: The Status of the Science" (Kusler and Kentula, 1990a). Although the literature on wetland restoration and creation has increased since the publication of that book, the general assessment presented still applies. Key points from the Executive Summary (Kusler and Kentula, 1990b) are discussed below. (Additional information on restoration of aquatic systems, including wetlands, can be found in a recent publication by the National Research Council Committee on Restoration of Aquatic Ecosystems, 1992.)

The status of scientific knowledge about wetland restoration and creation differs by wetland function, type, and location. It is still uncertain if the full suite of functions provided by a particular wetland type can be replaced. Full functional replacement has not yet been demonstrated. In the case of specific functions, the most is known about replacement of flood storage and waterfowl habitat, and the least is known about water-quality-improvement and ground-water-associated functions. The more complex the hydrology and ecology of a system, the more difficult it is to restore the system. Complete restoration might be impossible in some systems.

With respect to types and locations of wetlands, the most is known about restoration and creation of intertidal salt marshes along the coasts of the United States, in particular, the tall cordgrass marshes of the Atlantic coast. However, these salt marshes comprise only about 5 percent of the total wetland area of the Nation and are only a small part of the marine and estuarine wetlands.

Much less is known about restoration and creation of inland freshwater wetlands, such as ponds, forested wetlands, or bogs and fens. Among these wetlands, most is known about restoration and creation of those dominated by open water, such as ponds, and the associated herbaceous vegetation. Much less is known about replacing forested wetlands because of the time needed for woody vegetation to mature. Experts agree, however, that the ecosystems that are least likely to be successfully replaced are bogs and fens. These are the wetlands with deep organic soils that have developed over thousands of years and that have hydrologic conditions that are difficult, if not impossible, to duplicate.

FEDERAL AGENCY RESEARCH ON WETLAND RESTORATION AND CREATION

Several Federal agencies have missions, and therefore conduct research activities, that involve wetlands. This section presents a brief overview of Federal research on wetland restoration and creation. [For more information on wetland research by Federal agencies, see the publications of the Wetlands Research Program of the U.S. Army Corps of Engineers (Corps) and the article "Wetland Research by Federal Agencies" in this volume.] The Corps has been leading an effort to provide a reference source on current wetland research being conducted by Federal agencies. The first edition (U.S. Army Corps of Engineers, Wetlands Research Program, 1992) presents information provided by the Corps, the EPA, the Soil Conservation Service (renamed Natural Resources Conservation Service in October 1994), the Forest Service, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, the Bureau of Reclamation, and the U.S. Geological Survey. The Corps surveyed over 25 agencies in 1993. To complement the Corps' reference source, the U.S. Fish and Wildlife Service is maintaining the Wetland Creation/Restoration data base to provide a current compilation of the published literature. A hard copy of the bibliographic material contained in the digital data base also has been produced (Schneller-McDonald and others, 1989).

Federal agencies' research into wetland restoration and creation generally falls into two categories-design implementation and performance evaluation. Major contributions on project design have been made by agencies involved in large-scale development, like the Corps (Maynard and others, 1992) and the Federal Highway Administration (Marble, 1990). The EPA has focused its research on evaluation to support the agency responsibilities under Section 404 of the Clean Water Act (Zedler and Kentula, 1986; Leibowitz and others, 1992). Agencies responsible for stewardship of living resources, such as the National Marine Fisheries Service, have produced information that will increase their effectiveness in management (Thayer, 1992).

The Natural Resources Conservation Service and the U.S. Fish and Wildlife Service probably will contribute the most information on practical, low-cost approaches to wetland restoration under the 1990 Farm Bill (Food, Agriculture Conservation and Trade Act of 1990- (P.L.101-624) and the Wetland Reserve Program. Under these programs, thousands of wetland acres previously converted to agriculture have been restored to wetlands. To support these efforts, both agencies have produced guidelines for their field personnel who are working with the farmers to restore wetlands (U.S. Soil Conservation Service, 1992; Wenzel, 1992). (For more information on legislation affecting wetlands, see the article "Wetland Protection Legislation" in this volume.)

Ecosystems that are least likely to be successfully replaced are bogs and fens.

CONCLUSIONS

Wetland restoration and creation is more an art than a science, and functional replacement of wetlands has not been conclusively demonstrated. At the same time, the growing body of literature and experience is increasing the ability to discern which projects have a high probability of restoring or replacing damaged or lost ecosystems. Two factors that most limit the effective use of restoration and creation are: (1) lack of information on ecologically mature restored and created wetlands, and on the maturation process; and (2) the limited number of well designed and well constructed project wetlands that can be used as models.

In general, restoration is likely to be more successful than creation. Restoration of a damaged or destroyed wetland will have a greater chance of establishing the range of prior wetland functions, including critical habitat. Also, chances are greater for the long-term persistence of a restored wetland than for one created where none existed before.

Restoration is likely to be more successful than creation.

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Natural Channel Design Features

In-stream Grade Control Structures

Constructed Riffles

Step Pools

Cross-vanes

Grade Control J-Hook Vanes

Instream Lateral Stability Structures

Root Wads

Log Vanes

J-Hook and Rock Vanes

Toe Wood Structures

Bed Form Diversity Structures

Double Wing Deflectors

Single Wing Deflectors

Large Woody Debris Cover Logs

Bioengineering

Brush Mattress and Brush Layers

Live Stakes

Geolifts

Fascines

Transplants

Erosion Control Matting

In-stream Grade Control Structures

Certain types of in-stream structures can be utilized to provide grade control in order to prevent the stream from eroding vertically downward, often referred to as down-cutting or incising. Grade control is provided naturally in stream systems by stable riffles, bedrock outcrops, and sometimes root masses associated with woody vegetation. In-stream structures intended to provide grade control are thus carefully designed and constructed to mimic these natural features. Examples of in-stream structures that are used to provide grade control include constructed riffles, step pools, cross-vanes, and grade control j-hook vanes.

Constructed Riffles

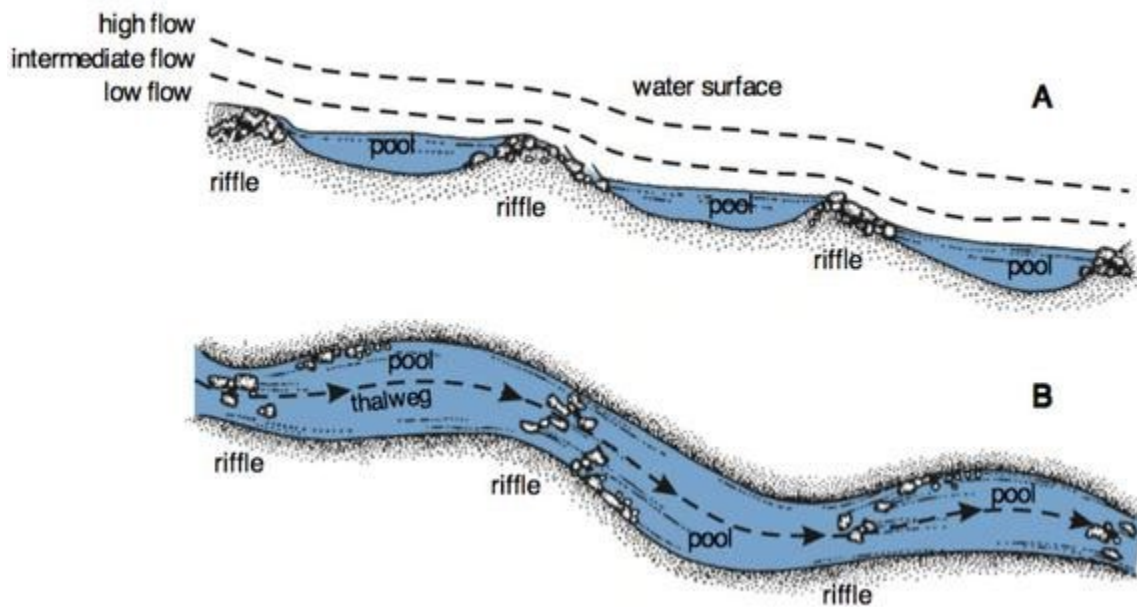
A constructed riffle is created by placing coarse bed material (gravel, cobble, and small boulders) in the stream at specific riffle locations along the profile. The purpose of this structure is to provide initial and/or permanent grade control and establish riffle habitat within the restored channel, prior to the natural establishment of an armored streambed. Constructed riffles function in a similar way as natural riffles; the gravel and cobble surfaces and interstitial spaces are crucial to the life cycles of many aquatic macroinvertebrate species. From a stability standpoint, riffles establish the overall grade for a stream reach and maintain the low water surface slopes of the upstream pools.



Constructed Riffle during Construction



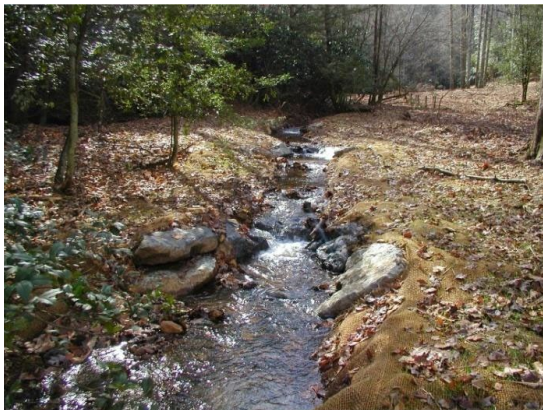
Constructed Riffle Two Months after Construction



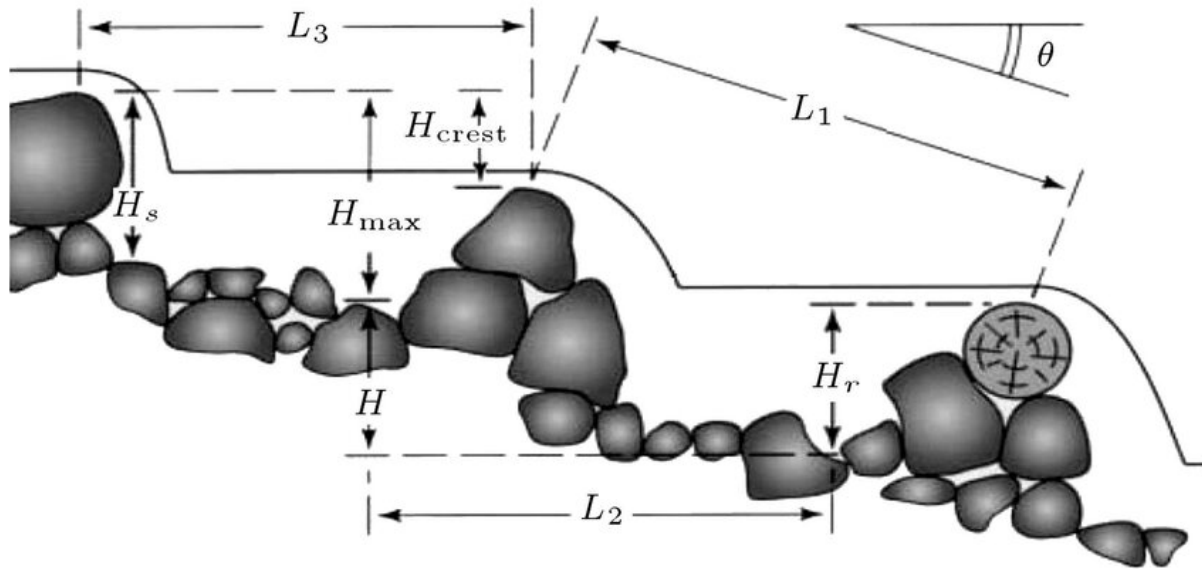
Pool/Riffle Schematic

Step Pools

Step pools are used to provide grade control and bed form diversity. Step pools are constructed by installing abutting courses of footer and header rocks in a formation of cascading or stepped, alternating pools with stepped sills in between. The sills are installed at the same elevation as the streambed but should not be installed such that they back up water in the channel like a weir. Step pool structures should be constructed out of large boulders and not riprap. The pool depth will depend on the configuration of the structure, flow velocity and gradient, and bed material of the stream.



Step Pool Sequence Examples



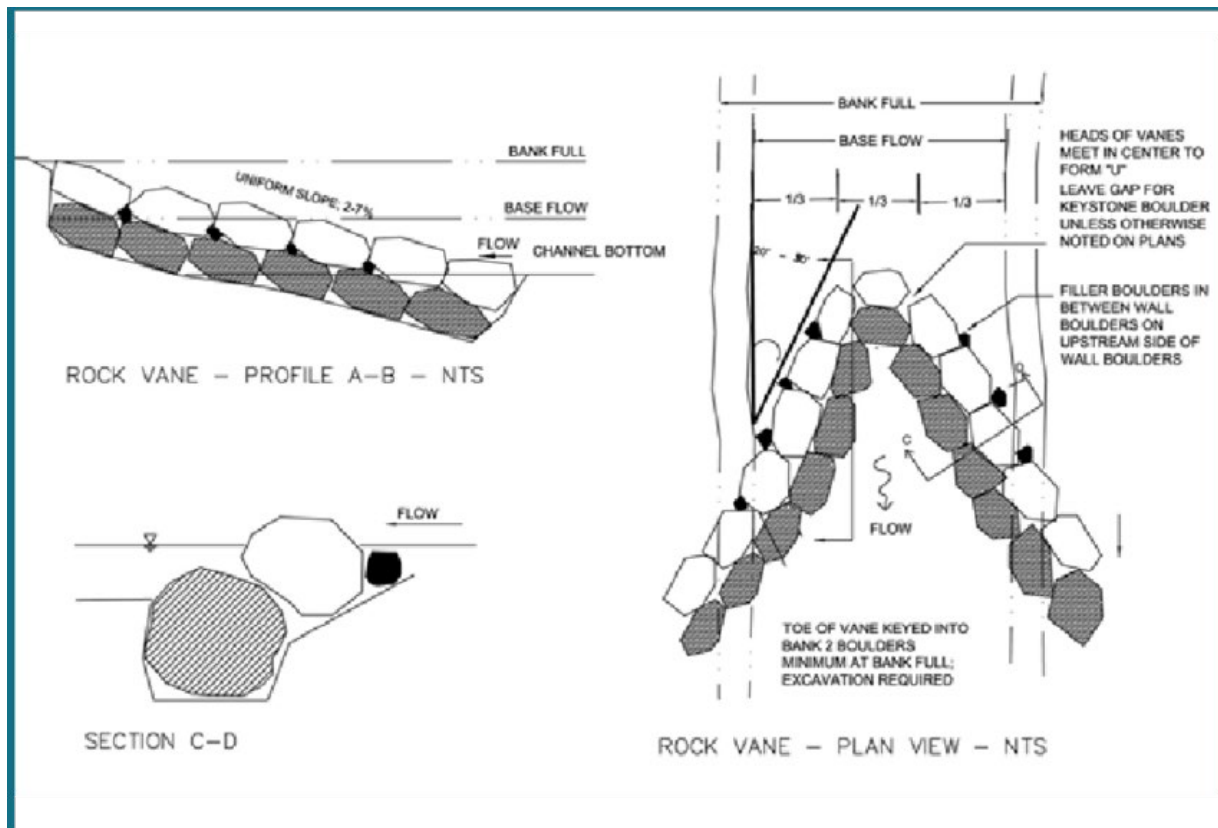
Step Pool Schematic

Cross-vanes

Cross-vanes are used to provide grade control, keep flow energies centered in the channel, and protect the adjacent stream banks. A cross-vane consists of two rock vanes joined by a center structure installed perpendicular to the direction of flow. This center structure sets the invert elevation of the streambed. Due to the increased flow velocity and gradient, scour pools form downstream of cross-vanes. Pool depth will depend on the configuration of the structure, flow velocity and gradient, and bed material of the stream. For many fish species, these pools form areas of refuge due to increased water depth, and prime feeding areas as food items are washed into the pool from the riffle or step directly upstream.



Cross Vane Examples



Cross Vane Schematic

Grade Control J-Hook Vanes

Grade control j-hook vanes are utilized to provide grade control and protect stream banks. These vanes may be constructed out of logs or rock boulders. The structure arms turn water away from the banks and re-direct flow energies toward the center of the channel. In

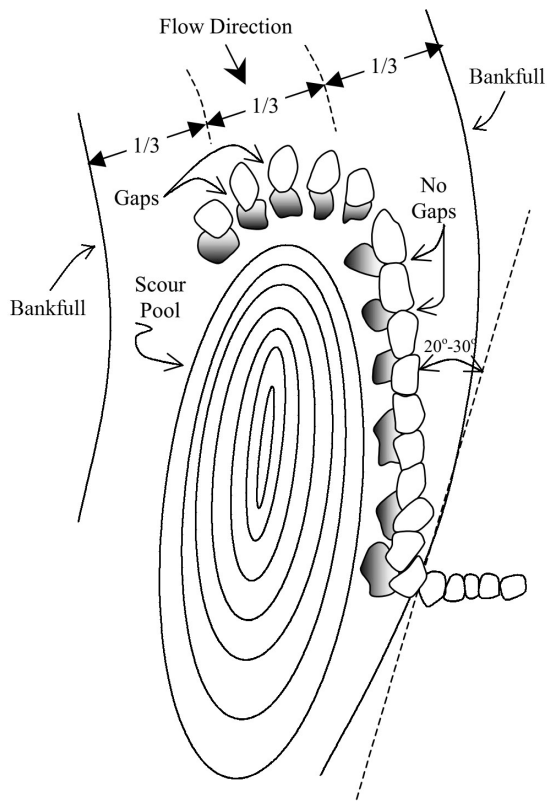
addition to providing stability to stream banks, grade control j-hook vanes also promote pool scour and provide structure within the pool habitat. Grade control j-hook vanes have two to three boulders placed in a hook shape at the upstream end of the vane. The primary difference between regular j-hooks and grade control j-hooks is the way that the “hook” part of the structure is constructed. Regular j-hooks are constructed to have gaps between the header boulders in the hook to promote flow convergence. Grade-control j-hooks do not have gaps between the header boulders in the hook and also have boulders sill built from the outside of the hook over to the opposite bank such that the structure can serve as a grade control feature. Grade control j-hooks still promote scour in the downstream pool, thus providing habitat benefit.



J-Hook Example (Wood)



J-Hook Example (Rock) (Under Construction)



J-Hook Schematic

Instream Lateral Stability Structures

Laterally stable streams resist unnatural or abnormal rates of horizontal migration. Lateral stability is directly related to stream bank stability. When stream banks are not naturally “armored” or protected by woody vegetation, lateral instability often occurs. Various in-stream structures can work to provide critical bank protection by re-directing stream flow away from the stream bank or by simply armoring the stream bank. These structures provide stability until a mature riparian buffer can be established. Similar to grade control structures, lateral stability structures are carefully designed and constructed to mimic natural features. Providing adequate reach-wide lateral stability until the mature stream bank and floodplain vegetation can establish is essential to the success of natural channel design projects. The protection afforded by lateral stability structures prevents accelerated stream bank erosion and associated loss of land and riparian habitat, protecting both the project reach and downstream reaches from water quality degradation.

Root Wads

Root wads are in-stream structures that provide increased lateral stability by armoring the stream banks and work particularly well in small streams. Root wads are the root masses

or root balls of live trees dug out of the ground with the trunk of the tree still intact. Root wads function by deflecting energy away from the stream banks, thus preventing erosive forces from acting on the stream banks themselves. Root wads can also provide improved in-stream habitat by promoting scour near the outside of a meander bend, in close proximity to the cover and structure supplied by the root wads.



Root Wad Examples

Log Vanes

Log vanes can be constructed completely out of log materials, or in combination of both log and boulder materials. Log vanes are typically utilized along outer meander bends, areas where flow direction changes abruptly, and areas where pool habitat for fish species is desirable. Location, vane length, angle, and slope are all considered and designed for the specific site conditions. Log vanes function by intercepting stream flow and redirecting that flow away from the stream bank and towards the center of the channel, reducing the erosive force of water on the banks. Log vanes also improve in-stream habitat by creating scour pools and providing oxygen and cover.



Log Vane (Under Construction)



Log Vane and Root Wad Structure

J-Hook and Rock Vanes

J-hook and rock vanes may be constructed out of logs or rock boulders. The structure arm turns water away from the banks and re-directs the flow energies toward the center of the channel. Both structures provide stability to stream banks; however, j-hook vanes also promote pool scour and provide structure within the pool habitat. J-hooks are rock vane structures that have two to three boulders placed in a hook shape at the upstream end of the vane. The boulders are placed with gaps between them to promote flow convergence through the rocks and increased scour of the downstream pool. Due to the increased scour depths and additional structure that is added to the pool, J-hooks are primarily used to enhance pool habitat for fish species. The boulders that cause flow convergence also create current breaks and holding areas along feeding lanes. The boulders tend to trap leaf packs and small woody debris that are used as a food source for macroinvertebrate species.



J-Hook and Rock Vane Examples

Toe Wood Structures

Toe wood structures may be constructed using a combination of native materials such as logs, branches, brush, live cuttings, sod mats, transplants, and soil. The structure helps ensure long-term stability against eroding banks and provides a more natural appearance than hard armoring. Toe wood can be a cost-effective solution for bank protection while restoring channel dimensions and floodplain connection. In addition to providing stream bank stability, toe wood structures enhance aquatic and terrestrial habitat within the pool area by establishing a source of detritus and large woody debris.



Toe Wood (Under Construction)



Toe Wood (After Growing Season)

Bed Form Diversity Structures

Bed form diversity is defined as the variation in depth and character of the streambed. Bed forms include riffles, runs, pools, and glides. Riffles are defined as straight sections of the channels with shallow depths. Runs are transitional features between the upstream riffle and the downstream pool. Pools are deep areas created by scour that have slopes that are much less than the average slope. Glides are transitional features between the upstream pool and the downstream riffle and are the only bed feature that slopes uphill in a down valley direction.

Bed form diversity is primarily achieved by re-establishing patterns in alluvial streams. Riffles form in the straight sections and pools form in the meander bends. For straight channels and colluvial streams, bed form diversity is achieved through a step pool channel morphology. In both cases, in-stream structures can be used to further diversify the bed by creating more depth variability and complexity. The added complexity is primarily achieved by adding more wood or structure to the channel. Double wing deflectors, single wing

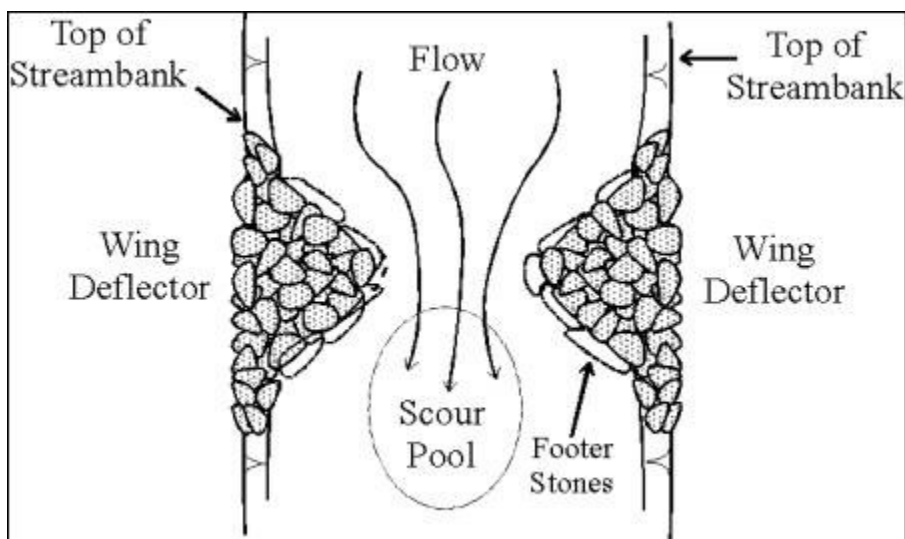
deflectors, and large woody debris cover logs are structures that are commonly used to provide additional bed for diversity.

Double Wing Deflectors

Double wing deflectors are used to provide enhanced bedform diversity. Double wing deflectors are constructed by installing matching “wing-shaped” boulder sills, one on each side of the stream, centered about the thalweg. Each sill extends out from the stream bank, runs parallel to the stream bank in the downstream direction, and then returns to tie in to the stream bank. The narrow area between the boulder sills creates and maintains a well-defined, narrowed low flow channel. The flow convergence created by the structure also creates controlled areas of bed scour immediately downstream of the deflector.



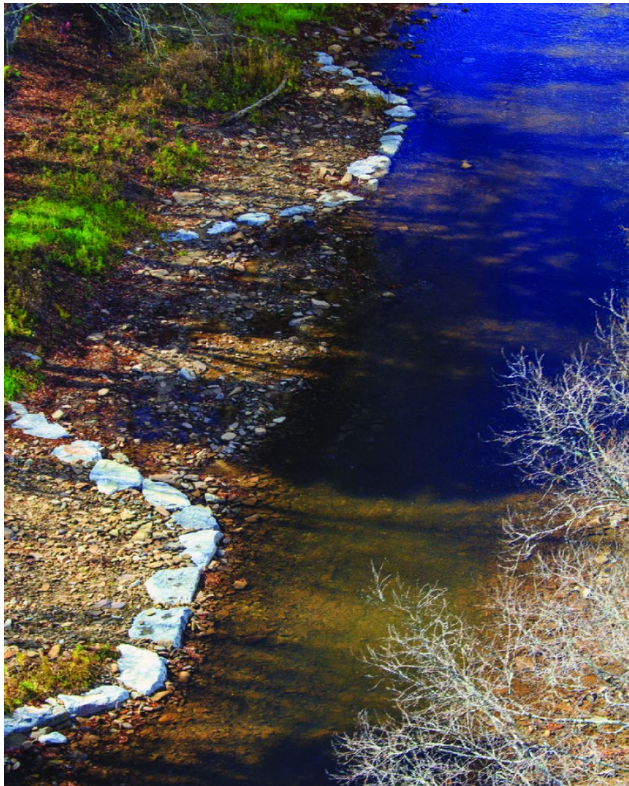
Double Wing Deflectors Examples



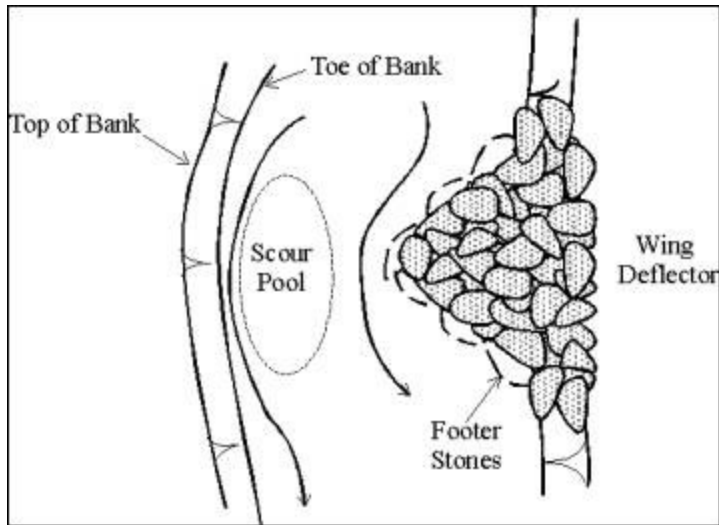
Double Wing Deflector Schematic

Single Wing Deflectors

Like double wing deflectors, single wing deflectors are used to provide enhanced bedform diversity. Single wing deflectors are constructed in the same manner as double wing deflectors but only include one boulder sill on one side of the stream channel. The alignment and construction of the sill is the same as described for the double wing deflector. The narrowed area between the boulder sill and the opposite stream bank helps maintain a better defined, narrowed low flow channel.



Single Wing Deflector



Single Wing Deflector Schematic

Large Woody Debris Cover Logs

A cover log is placed in the channel to provide cover and enhanced habitat in the pool area. The log is buried into the outside bank of the meander bend; the opposite end extends through the deepest part of the pool and may be buried in the inside of the meander bend, in the bottom of the point bar. The placement of the cover log near the bottom of the bank slope on the outside bend encourages scour in the pool, provides cover and ambush locations for fish species, and provides additional shade. Cover logs are often used in conjunction with other structures, such as vanes and root wads, to provide additional structure in the pool.



Large Woody Debris Cover Log in a Pool

Bioengineering

Bioengineering methods are used to provide lateral stability. Bioengineering can be implemented as a stand-alone practice, or in combination with in-stream structures. Within the context of natural channel design, bioengineering is simply defined as the specialized use of plant materials to stabilize stream bank soils. Bioengineering provides stabilization through the accelerated establishment of vegetation along the stream banks. The vegetation growing out of the stream banks acts like flexible armoring against erosive stream flow, and the associated root mass growing into the stream banks adds “structural reinforcement” by holding the stream bank soils together. Examples of common bioengineering techniques include brush mattresses, brush layers, live stakes, geolifts, fascines, transplants, and erosion control matting.

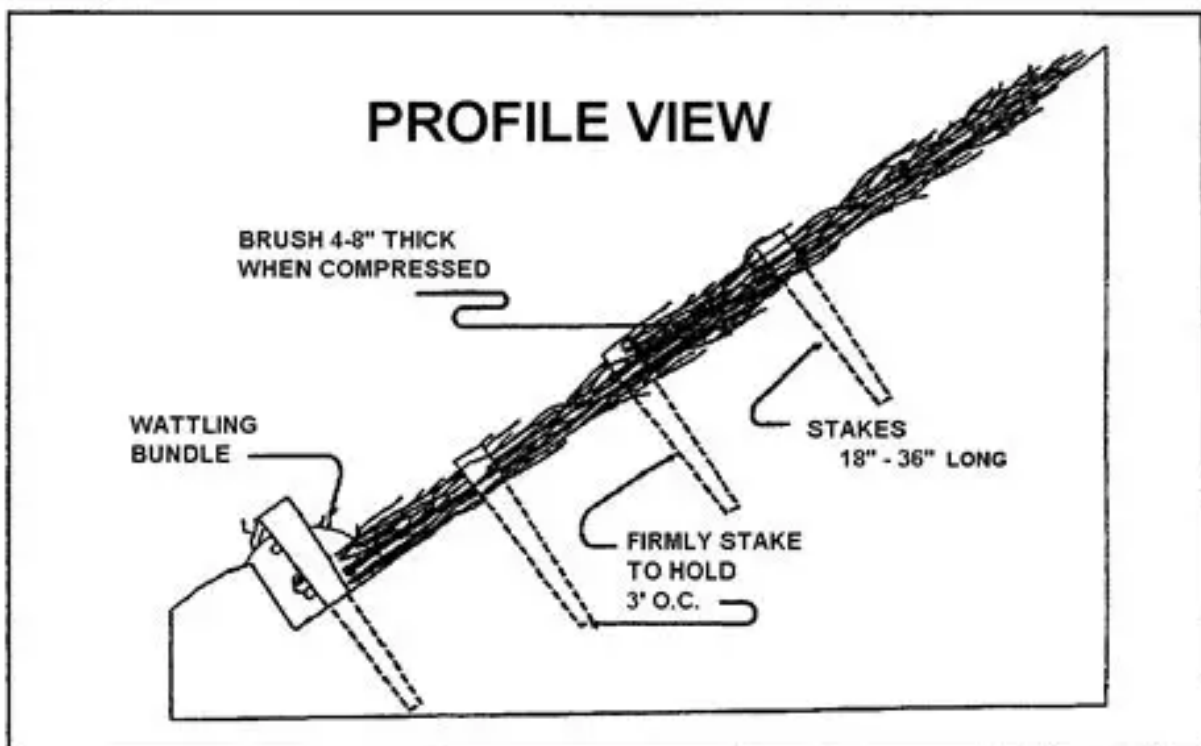
Beyond stabilizing the stream banks, the use of bioengineering provides many other benefits. These benefits include adding biomass to the stream system, stream shading, quicker vegetation establishment, lower costs for establishing vegetation by utilizing native and/or local materials, improved aesthetics, improved riparian and in-stream habitat, increased infiltration, and increased sediment deposition.

Brush Mattress and Brush Layers

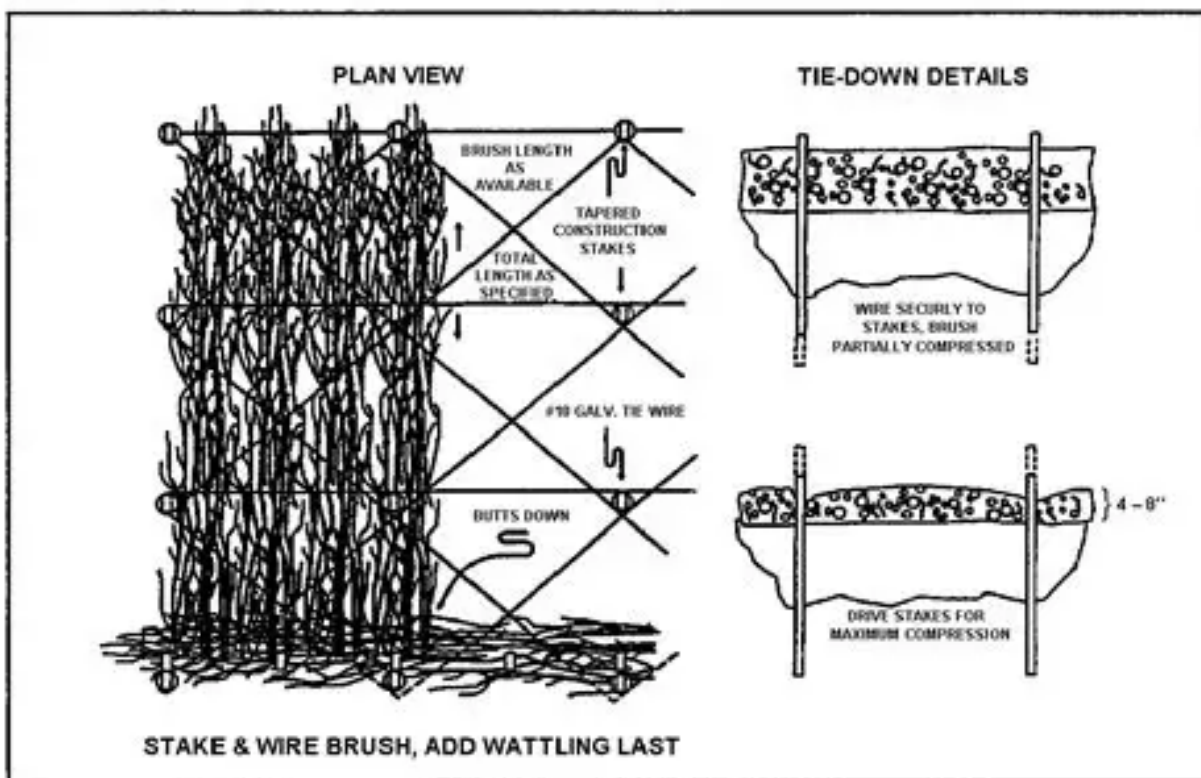
Brush mattresses are placed on bank slopes for stream bank protection. Layers of live, woody cuttings are wired or tied together and staked into the bank. The woody cuttings are then covered with a fine layer of soil. The plant materials quickly sprout during the growing season and form a dense root mat across the treated area, securing the soil and reducing the potential for erosion. Within one or two years, a dense stand of vegetation can be established that, in addition to improving bank stability, provides shade and a source of organic debris to the stream system. Deep root systems often develop along the waterline of the channel, offering another source of organic matter and a food source to certain macroinvertebrate species, as well as cover and ambush areas for fish species. Brush mattresses are typically placed along the outer meander bends, areas where bank sloping is constrained, and areas susceptible to high velocity flows.

Brush layers are very similar to brush mattresses, except that they are placed on the top of the bank instead of on the bank slopes for stream bank protection. Brush layers are therefore used in conjunction with other bank protection structures or measures such as vanes or root wads, as brush layers do not provide immediate protection of the toe of bank.





a. Profile view



Live Stakes

Live stakes are live cuttings, typically collected during the dormant season, from native woody plant species that are directly planted into the stream banks. Some species are better suited than others for use as live stakes, with willow and dogwood species typically performing best. Live stakes can often be harvested on site, particularly with proper planning during both the design and construction phases. They should be harvested from live, healthy, vigorous, well-rooted plants. Proper handling and storage of live stake material is also vital. Live stakes are normally installed in areas of higher stress, such as along the outside of meander bends, but can also be installed anywhere along the stream channel where accelerated vegetation growth is desired. They are usually installed through the erosion control matting, directly into the restored stream bank. Each live stake is installed approximately two feet into the ground, with not more than one foot exposed above ground. The intent is to install them as deep as possible and as close to the water table as possible. Live stakes are thus installed within the limits of the bankfull channel and are installed by pushing or hammering them into the stream banks. Live stakes provide all of the advantages associated with establishing riparian vegetation at relatively low cost and are most commonly used in conjunction with other in-stream structures, and not used as a stand-alone measure.



Live stakes Examples

Geolifts

Geolifts are a bioengineering measure used to stabilize stream banks. Geolifts are most commonly used along the outside of stream meander bends. They are basically a series of large overlapping soil “burritos”, or lifts, constructed using coir fiber erosion control matting and native soils. Often, live cutting materials from specific woody native species

plants are planted in the layers between the lifts. A stone toe base is typically installed to provide protection at the toe of the stream bank and to provide a foundation for the geolifts. The geolifts are installed on top of the stone base to comprise the entire restored stream bank up to the bankfull channel elevation. Geolifts can be used to effectively stabilize restored stream banks for all sizes of streams simply by varying the number of lifts required to form the stream bank.



Geolift Example

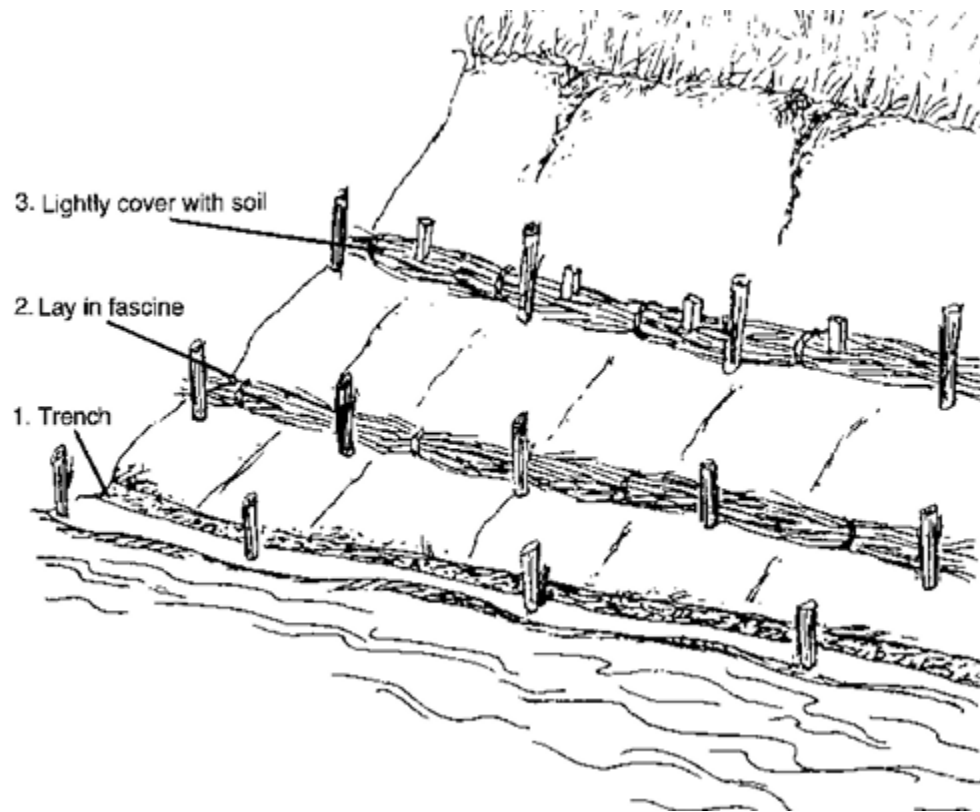
Fascines

Fascines are bundles of long live cuttings, typically collected during the dormant season, from native woody plant species that are planted to help stabilize the stream banks. Some species are better suited than others for use as fascines, with willows and some dogwood species typically performing best. Fascines can often be harvested on site, particularly with proper planning during both the design and construction phases. They should be harvested from live, healthy, vigorous, well-rooted plants. Proper handling and storage of fascine materials is also vital. Fascines are normally installed in areas of higher stress, such as along the outside of meander bends, but can also be installed anywhere along the stream channel where accelerated vegetation growth is desired. They are usually installed laterally along the toe of the stream bank or at elevations within the bankfull channel and securely staked in trenches, with their tops being exposed just above the ground. Fascines provide all of the advantages associated with establishing riparian vegetation at relatively

low cost and are most commonly used in conjunction with other in-stream structures, and not as a stand-alone measure.



Installing Live Fascines



Live Fascine Schematic

Transplants

Transplants are used to increase lateral stability by providing instant living root mass within the stream bank. They are living native plants that are excavated and replanted on site and are typically harvested from areas of the project site that are to be rescued, abandoned, cleared, or otherwise be impacted during the construction process. These areas include the existing stream banks, existing flood plain, haul roads, staging and stockpile areas, etc. Native plants that are suited to stream bank areas and can be successfully harvested and replanted along the restored stream banks may be good candidates for transplanting, understanding that some species transplant better than others. Because transplants are harvested from areas where the existing vegetation would be impacted or removed as a result of construction, transplanting tends to be a relatively inexpensive way to help prevent lateral instability, while also salvaging and recycling on-site materials.

Transplants are harvested with the root ball and the surrounding soil intact and are quickly re-planted along the stream banks and the flood plain to avoid drying out of the roots. They

can be planted as a stand-alone measure to provide stream bank protection or installed in conjunction with other in-stream structures, such as log vanes and root wads, where they are typically planted at the interface where the in-stream structure ties into the stream bank. Transplants have mature root systems that re-establish in their new location, much quicker than the smaller commercially grown harvested planting stock typically used for stream bank planting. This accelerated rate of vegetation establishment allows the root system from the transplants to help hold the stream bank together and help prevent stream bank erosion. Transplants also significantly contribute to in-stream habitat as they provide a permanent source of shading and contribute organic material to the stream system.



Tree Transplanting

Erosion Control Matting

Coir (coconut) fiber matting is the type of erosion control matting most commonly used to stabilize restored stream banks. This type of erosion control matting is available in many different styles and weights. The most common used for stream bank restoration is the 700-gram matting. This erosion control matting is fabricated from 100% coir twine woven into a high strength blanket. Erosion control matting is installed on all of the newly

constructed stream banks, from the toe or edge of water, up to the top of the stream bank or bankfull elevation. After the proposed stream channel construction is complete, temporary and permanent seed, fertilizer, and other soil amendments, and mulch are applied. The erosion control matting is then immediately installed on top to hold everything in place. The matting is secured in place using specified wood or metal stakes. Both the temporary and permanent vegetation germinate faster and grow more vigorously when installed with mulch under the erosion control matting. Erosion control matting is installed along all of the restored stream banks as described. A possible exception is that sometimes the point bars on the inside of the meander bends are not matted, as these are depositional features and therefore not typically subject to erosion.



Erosion Control Matting



PART IV: Wetland Management

WETLAND RESTORATION TECHNIQUES

Wetlands come in a wide variety of types and sizes, and support a great diversity of wildlife. We have come to realize that collectively wetlands are of great benefit to society by providing wildlife habitat, improving water quality, reducing flood damage, and offering recreational opportunities and aesthetic value. In the past, we had less understanding of the functions of wetlands and often placed little value on them. As a result, many were drained, filled, or otherwise degraded for other land uses.

Historically, Michigan had an estimated 11 million acres of wetlands, or about one-third of the state's land mass. Since European settlement, over 35 percent of these wetlands have been lost. In southern Michigan the loss is even greater -- more than 75 percent in some counties. In some cases, the loss is permanent. In others, we are able to reverse these impacts, such as drainage, and restore the wetland.

Wetland restoration techniques provide private landowners with an opportunity to benefit wildlife, themselves, and their community. If at one time a wetland existed on your land, you might be able to restore it. This chapter explains how.

Wetland Ingredients

There are three characteristics that every wetland possesses.

- 1) Hydrology: A supply of water that is at or near the ground surface at least a portion of the growing season.
- 2) Hydric soils: Soils that develop under saturated conditions. Hydric soils have the capacity to hold water on or near the ground surface for at least a portion of the year.
- 3) Wetland vegetation: Plants that are adapted to grow in wet soils.

Wetland restoration involves returning one or more of these three characteristics to a site. Hydric soils form over a long period of time and the soil characteristics are very difficult to create. For this reason, restorations take place where the hydric soils remain but the hydrology or vegetation has been altered.



Wetland Creation Versus Restoration

Wetland creation involves impounding water with berms and dikes or by excavating depressions in areas that did not previously contain wetland soils or vegetation. Essentially, all three key characteristics are missing. Adding these characteristics where they do not exist is difficult, costly, and often unsuccessful. Financial assistance to land owners is not generally available. For these reasons, landowners are often discouraged from undertaking creation projects. However, it is possible to create a small shallow pond for wildlife on upland areas. Refer to the chapter on **Building and Managing Ponds** in this section for more information.

Wetland restoration involves returning one of the wetland ingredients, generally water retention, to a degraded or drained wetland site. Sites that have been ditched, tiled or leveed, or degraded from excessive logging, uncontrolled cattle grazing, or unrestricted off-road vehicle use are all candidates for restoration. Projects can span the spectrum from curtailing these or other damaging practices to restoring the water source and/or other wetland properties. Because the degree of current damage will vary, the effort needed to restore sites will also vary. For instance, a partially drained wetland may be fairly simple to restore to its natural

water level. The remainder of this chapter will focus on restoring wetlands that have been fully or partially drained.

Locating Restoration Sites

Identifying a drained wetland is the first step in restoring it. Some degraded or partially drained wetlands are readily apparent, while others may be apparent only through review of soil maps, photographs, or other records. Drained wetland sites will have hydric soils. You can obtain a copy of the County Soil Survey from your local Conservation District (CD) office and ask a staff person to help indicate any hydric soils on your property. You can also ask the CD staff if aerial photographs are available for review. On photos, degraded wetlands or wet spots appear as dark areas and field tiles appear as dark, linear marks. Reviewing photos taken from several different years, and those taken 20 years ago or more may help identify areas that were wet at one time. In addition, records from, or conversations with, previous landowners or neighbors may help to identify past drainage.

A field inspection can also help to identify restorable wetlands. Hydric soils often display similar field characteristics (see **Introduction to Wetland Management**). Also, drainage ditches or evidence of drain tiles may be apparent. Spots in fields that hold water briefly after a heavy rainfall may be tilled and drained wetland basins. Also, look for clumps of wetland vegetation in existing fields, low areas where crops are stressed or do not grow, or wet areas where farm machinery

royal fern



marsh-marigold



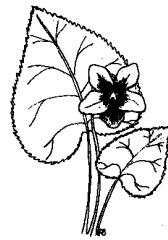
cardinal flower

Wetland plants that occur in wetlands 99 percent of the time.

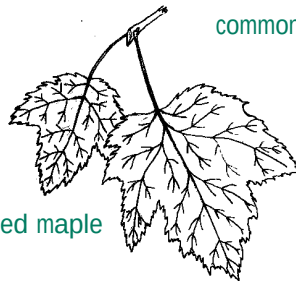
trout lily



common blue violet



red maple

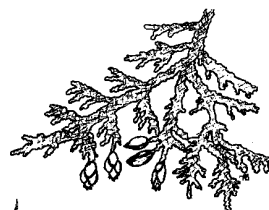


Wetland plants that occur in wetlands 67-99 percent of the time.

balsam fir



northern white cedar



showy lady's slipper



Wetland plants that occur in wetlands 34-66 percent of the time

has been stuck. On fields no longer farmed, look for changes in vegetation including the presence of wetland vegetation, and depressional areas that are wet or hold water at least a portion of the year.

Before Beginning

Wetland restoration is typically NOT a do-it-yourself project. A wildlife biologist or wetland specialist can help assess the project area, look for potential impacts to others, and determine if hydric soils and a water source are present. Voluntary programs offering technical and financial help may be available to help restore your wetland - check with your local CD staff for initial assistance before proceeding any further. You can probably save yourself time and money by working with the CD staff.

Projects begin with planning to determine feasibility and design. Without proper planning, projects may lead to problems for you or your neighbors. Develop a reasonable management goal and stick to it. Safety is a primary concern both during and after construction. Also, the good neighbor policy applies -you don't want to flood a neighbor's crop field or basement, or interrupt their drainage. By talking with your neighbors you can address their concerns, and may find they want to join in on the project. In addition, watershed size is important - too much water or too little water may mean the project is not workable. If a project looks like a "go," survey equipment will be used to determine water levels for the completed project and to help design structures, such as ditch plugs,

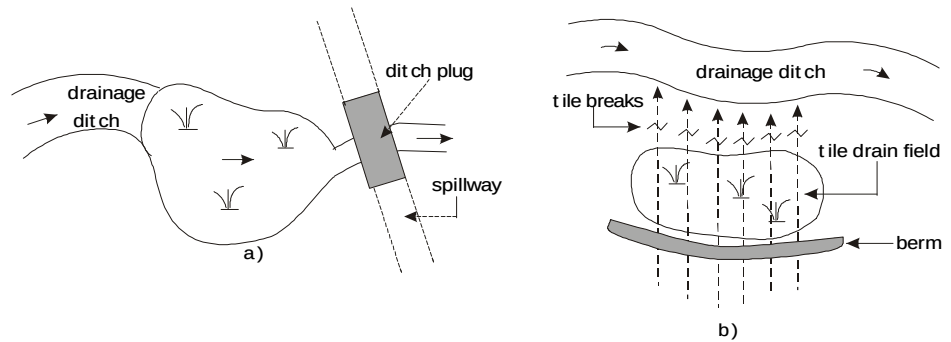
WETLAND RESTORATION TECHNIQUES

dikes, or spillways. Finally, local, state, or federal permits may be needed. In Michigan, permits are required from the Michigan Department of Environmental Quality (DEQ) for any work in a stream, flood plain, and most existing wetland areas.

Restoration Techniques

Typical projects restore water to a fully or partially drained wetland basin by removing underground drain tiles, plugging open ditches, or building small dikes. Projects are often one to three acres in size, and have an average water depth of about 18 inches. Many small-basin wetlands of this type that were drained for agriculture, provide opportunities for restoration today. Generally marshes or swamps, with seasonal or permanent water, are most often restored.

The simplest restoration, a "tile break," involves removing a section of underground agricultural tile that is draining a wetland basin. Drain tile, or field tile as it is often called, is usually made of clay or perforated plastic and buried at a depth of two to six feet. Generally, a contractor with a backhoe is used to remove or crush a 25 to 50 ft section of tile downstream of the basin. The downstream end or outlet pipe is then plugged with a bag of redi-mix concrete or clean



Examples of restoring drained wetlands a) drainage ditch stopped with ditch plug, and spillway b) tile drain field broken, and berm constructed to prevent flooding in areas that are to remain dry.

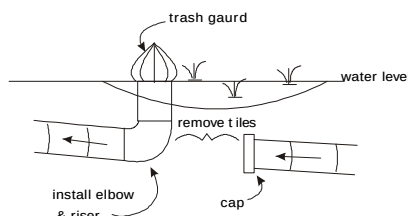
clay fill, and the trench is filled. Sometimes, a portion of unperforated tile, called a "riser", is connected to the downstream end of the tile line and brought to the surface in order to control the water level. Water will fill the wetland basin until it reaches the mouth of this riser where it will then flow back through the tile line into the ditch. This may work well when you wish to maintain downstream drainage.

A "ditch plug" restoration builds an earthen wall to impound water. This type of restoration uses equipment to fill a portion of a drainage ditch to natural ground level. Again, a riser may be used to let water flow through a tube once it reaches a certain level. A small dike or berm may also be used, which will impound the water that will begin to collect once the drain has been plugged. A dike prevents the drainage of water downstream and requires a spill way or other water-control structure to regulate the water level and prevent the dike from being washed away during periods of heavy runoff.

Typically, a berm or dike is constructed with a top width of eight to 10 feet and a maximum side slope of 3:1 (three feet of horizontal width to each foot of rise). A three foot high dike would have a

bottom width of 24 to 30 feet. When constructing a low-level dike, soil is often pushed up or excavated from within the former wetland site. This helps to form a deeper pool within the basin. Sod and topsoil are stripped from the construction site and stockpiled. The dike or berm is then constructed with subsoil, often with a good clay component. Topsoil from the basin, which is a good seed source for wetland plants, is then spread back into the basin and on the dike or berm. Disturbed upland areas, including areas of the ditch plug, dike, or berm, are seeded with grasses to minimize erosion and provide cover. Generally, nothing is planted in the wetland basin as wetland vegetation usually re-establishes itself quickly from seeds that have remained dormant in the soil.

Managing water, especially excess water, is important on restoration projects. A water-control structure can be used to manage water levels within a project. Examples include plastic or metal risers, and corrugated metal or plastic stop-log structures. These help to manage the normal flow of water. An emergency spillway, which is a wide trough-like opening in the side of the dike, should be designed into wetland restoration projects if excess water is expected



Removing tiles from a drain field to restore a wetland

WETLAND RESTORATION TECHNIQUES

during flood events. Emergency spillways are sized according to the watershed but typically are at least eight feet wide and one to two feet below the top of the ditch plug, dike, or berm. These spillways allow water to pass through without damaging the retention structures in high-water events. Since water management is critical, consult a professional for design specifications suitable for your wetland.

Most restoration projects involve open-area wetlands, but forest and shrub wetlands are also important and can be restored too. Restoration of wooded sites should be done cautiously, however, to avoid killing the trees and shrubs that normally grow in wetlands. Woody wetland plants can often withstand brief flooding during the growing season, but be aware that prolonged inundation may stress trees and kill them.

Maintenance of the Restored Site

Simple basin restorations should be relatively maintenance-free. However, some restored wetlands, particularly those with water-control or earthen structures, require some maintenance. Water-control structures should be checked periodically. Fallen leaves, twigs, or other debris may build up around the mouth of the structure. An accumulation of debris may partially obstruct the flow causing the water level to rise. Inspection of the site, particularly during and after a big storm, will allow you to

remove materials before problems develop.

Ditch plugs, dikes, and berms also require some care. Established seedings of grasses should be periodically mowed or burned to prevent woody vegetation from invading. Root growth from woody vegetation will allow water to penetrate the earthen structure, which will cause it to leak and may contribute to a future washout. Annual maintenance also means keeping muskrats, beaver, and woodchucks in check by filling their excavations, and removing some through trapping if necessary.

As you enjoy your restored wetland, you can also keep an eye open for potential problems and address them quickly. It is much easier to solve a problem while it is small than to wait until it is out of hand. Also, remember that a restored wetland is most often only four feet deep at its deepest spot and averages only two feet deep throughout the basin. This is not a fish pond. If you want to create a fish pond, see the chapter on **Building and Managing Ponds** in this section.

State and federal agencies and conservation groups often have programs that may be able to assist you in identifying potential restoration sites and in wetland restorations. These programs may provide technical assistance and cost-share expenses. Start with your local CD office staff as they will be

able to direct you to available assistance programs.

In summary, restoring wetlands may require more time, effort, and money to complete than many other wildlife projects. Fortunately, technical and financial help is available, and the rewards are well worth the effort. Most landowners are quite pleased to see how quickly the wetland is re-established when water is restored. They also often report rapid use by wildlife. You will also have the satisfaction of returning to health a part of Michigan's natural history.

FOR ADDITIONAL CHAPTERS CONTACT:

Michigan United
Conservation Clubs
PO Box 30235
Lansing, MI 48909
517/371-1041



Private Land Partnerships: This partnership was formed between both private and public organizations in order to address private lands wildlife issues. Individuals share resources, information, and expertise. This landowner's guide has been a combined effort between these groups working towards one goal: Natural Resources Education. We hope this manual provides you with the knowledge and the motivation to make positive changes for our environment.

FOR ADDITIONAL ASSISTANCE: CONTACT YOUR LOCAL CONSERVATION DISTRICT