

# Descriptions and Expectations of Recommended BMPs for Improving the Bosque River Watershed

February 2008



*Constructed Treatment Wetlands Photo Courtesy: NRCS*

By Lucas Gregory and Megan Meier  
Texas Water Resources Institute

**Sponsored By:**



This material is based upon work supported by the Department of Energy under Award Number DE-FG-02-06ER64255. Funding for this work was championed by Congressman Chet Edwards.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

# Executive Summary

---

The Bosque River and its watershed face complex water quality problems that are not easy to solve. Attempts have been made to improve the quality of the water moving through this watershed, but have had little success due to the broad scope of work that is needed to positively impact water quality in the Bosque River. This document is part of a multi-faceted project that aims to improve the environmental infrastructure in the watershed in a manner that focuses on existing pollution issues. The project's first phase, which included the development of an environmental infrastructure improvement plan, has been completed. This plan outlined a methodology for determining likely areas that would contribute the most significant source of pollution to the watershed and developed a tool for determining the priority in which all sub-watersheds in the basins should be evaluated for needed pollution abatement measures. The Phase I report also established a list of feasible best management practices (BMPs) and ranked them based on the recommendations of a scientific advisory committee. Six steps were identified as an effective process to choose the proper BMPs for each sub-watershed in the basin. If these steps are followed, the best BMPs for each location should be effectively identified.

This document expands on the Phase I report by providing an in-depth physical description of each BMP along with an overview of potential costs and applicable areas, situations, and locations where these practices should be implemented. The BMPs are organized into five groups based on applicable location(s): on-farm BMPs, between field and creek BMPs, in-stream or gully BMPs, universal BMPs, and city BMPs. The majority of these BMPs target the excessive amount of nutrients, especially phosphorus (P), entering surface water supplies. Several BMPs also focus on sediment control, as some of the soils in the watershed are highly erosive and pose the threat of transporting nutrients with them when they erode. Some BMPs also address ecosystem health and habitat issues in the watershed. Collectively, the recommended BMPs aim to improve the overall quality and productivity of the entire watershed.

Many of these BMPs involve simple, inexpensive adjustments of current practices while others require more significant changes that may require technical and financial assistance. The last section of this document highlights potential sources of technical information and methods for disseminating educational materials to landowners and other interested parties. Potential federal and state sources of funding are also listed in this section for the use of parties considering the installation of multiple or more expensive BMPs on their land.

This document serves as a source of general information about BMPs that would benefit landowners and agency personnel assisting landowners in the Bosque River watershed. This information can help guide interested parties to BMPs that are most feasible for their needs as well as provide a general overview of how to implement the selected practice(s) to yield the best results for their location. Successful BMP implementation will reduce the impact of human activities and lead to environmental improvement in the Bosque watershed.

# Table of Contents

---

	Page
Executive Summary .....	ii
Table of Contents .....	iii
List of Figures .....	v
List of Tables .....	vi
Introduction.....	1
On-Farm BMP Descriptions and Expectations.....	2
Applying chemical agents to high P fields to reduce P solubility .....	2
Implementing sub-watershed soil conservation and erosion control plans .....	3
Improving PL566 structures to increase sediment retention.....	4
Improving quality of water held by PL566 structures .....	6
Installing crops that could be removed from the watershed .....	8
Installing grazing management practices.....	9
Contour ripping/pasture renovation to maintain permeability of soils and increase residence time of water in soils.....	10
Terracing to reduce sediment transport.....	11
Developing nutrient management plans.....	13
Applying a waste injection program to inject fertilizer/manure/etc. directly into soils .....	15
Between Field and Creek BMP Descriptions and Expectations.....	17
Installing vegetation buffers – “polishing strips” .....	17
In-Stream or Gully BMP Descriptions and Expectations.....	20
Implementing a watershed riparian restoration program – streambank stabilization .....	20
Developing constructed wetlands .....	22
Universal BMP Descriptions and Expectations.....	26
Install dams or other barriers in gullies, streams or ditches.....	26
Implementing range re-vegetation practices – management for species beneficial to water detention on land .....	28

City BMP Descriptions and Expectations.....	30
Developing construction site runoff management for pre/post construction activities .....	30
Treating storm runoff by temporary storm storage in retention ponds.....	32
Developing plans for recreation areas to include storm water planning for surrounding residential areas.....	34
Education and Funding Opportunities .....	36
Educating landowners.....	36
Financial assistance.....	36
Conclusions and Recommendations .....	38
List of primary deliverables.....	38
References.....	39

# List of Figures

---

	Page
Figure 1. PL566 structure in the Bosque watershed with sediment build-up and brush growing on the dam.....	4
Figure 2. Duck blinds on a PL566 structure reservoir in the Bosque River basin .....	5
Figure 3. Sod harvesting equipment .....	8
Figure 4. Deep ripping a pasture .....	11
Figure 5. NRCS photo of terraces and contour farming.....	12
Figure 6. Vegetated buffer protected from grazing by a fence .....	17
Figure 7. Stream stabilization using boulders and riparian vegetation along the banks .....	20
Figure 8. Stream stabilization using limestone boulders and riparian vegetation along the banks .....	21
Figure 9. NRCS photo of constructed wetlands used to treat swine farm lagoon effluent .....	23
Figure 10. NRCS photo of a constructed wetland.....	24
Figure 11. Check dam photo from the Ft. Hood re-vegetation project .....	26
Figure 12. Re-vegetated rangeland photo from the Ft. Hood re-vegetation project .....	28
Figure 13. NRCS photo of a silt fence around a construction site .....	30
Figure 14. Wet pond photo from the City of Austin website.....	32
Figure 15. Photo of Edelweiss Park detention area in College Station, TX.....	34

## List of Tables

---

	Page
Table 1. Common practices in soil conservation and erosion control plans.....	3
Table 2. Average efficiency ratios for two PL566 reservoirs in the North Bosque River watershed .....	7
Table 3. Effects of NRCS conservation practices recommended for on-farm use .....	16
Table 4. Effects of NRCS conservation practices recommended for use between the field and creeks .....	19
Table 5. Effects of NRCS conservation practices recommended for use in gullies or streams .....	25
Table 6. Effects of NRCS conservation practices recommended for use as a universal BMP .....	29
Table 7. City of Austin wet pond pollutant removal results .....	33
Table 8. Effects of NRCS conservation practices recommended for use as BMPs in the city .....	35

# Introduction

---

The Bosque River watershed encompasses more than 1,000 square miles of the Brazos River Basin in Central Texas. The river flows through the towns of Stephenville, Hico, Meridian, Clifton, and Valley Mills before entering Lake Waco. The North Bosque River and Lake Waco provide water for agricultural production, consumption, recreational fishing, and swimming. However, the North Bosque River was placed on the 303(d) list in 1998 and classified as impaired in 2000 due to elevated phosphorus (P) levels. The primary concern with elevated levels of P is the potential for excessive algae growth, which can affect the taste and odor of drinking water supplies and can lead to fish kills in the river and lake. Potential problems with bacteria and sediment have also surfaced on the Middle and South Bosque sub-watersheds.

One contributor to the water quality problem in the Bosque River watershed is dairy cows. Dairy farming is the primary agricultural practice in the watershed with 80 dairies operating with more than 40,000 head of milking cows. The dairy industry's rapid expansion in the 1980s raised concerns about the potential impact of nonpoint source pollution runoff from these farms on the quality of the Bosque River. Other water quality concerns in the watershed include the contribution of point sources of pollution (i.e., municipal wastewater treatment plants in the region) and nonpoint source contributions from cities, pastures, rangeland, and cropland.

In an effort to improve and protect water quality, the Texas Water Resources Institute (TWRI), an institute of Texas A&M AgriLife; Texas AgriLife Research; and the U.S. Army Corps of Engineers (USACE) developed an environmental infrastructure improvement plan for the Bosque River. They had guidance from other agencies, including the Natural Resource Conservation Service (NRCS), Brazos River Authority, the City of Waco, the Texas Institute of Applied Environmental Research (TIAER), Texas Farm Bureau, the Texas State Soil and Water Conservation Board (TSSWCB), the Texas Water Development Board (TWDB), Baylor University and the University of Texas. This plan envisions implementing BMPs throughout the watershed to achieve overall water quality improvements. Phase I identified which areas in the watershed needed the most improvement and provided a process for choosing suitable BMPs for those areas. This document is part of Phase II, which expands on the BMPs listed in Phase I by providing complete descriptions of each BMP, including estimated costs and applicability.

Funding for work in Phase II of the Bosque River Environmental Infrastructure Improvement Plan comes from the Department of Energy and was championed by Congressman Chet Edwards. We would like to thank both the Congressman and the Department of Energy for supporting this much-needed plan.



# On-Farm BMP Descriptions and Expectations

---

## *Applying chemical agents to high P fields to reduce P solubility*

Waste application fields (WAFs) are common throughout the Bosque River watershed. They serve as a relatively inexpensive means to dispose of manure or lagoon effluent. Over time, WAFs can become saturated with P and pose a potential pollution threat to ground and surface water supplies. Proper management techniques can be applied to prevent such accumulations; however, fields that already have excess P problems must be approached in a remedial manner. One method to reduce the amount of P in WAFs or other high P soils is the application of P-immobilizing amendments, such as aluminum sulfate, aluminum chloride, or ferric chloride. These chemical compounds can be used to remove P from the wastewater stream (Galarneau & Gehr 1997). Dao et al. (2001) have illustrated the use of aluminum- (Al) and iron- (Fe) based compounds to bind P in animal manure. Chemical agents are typically incorporated into the manure or lagoon effluent prior to application, but can also be applied directly to the field.

Aluminum sulfate (alum) is one of the more common chemical amendments that are incorporated into manure to bind P and render it unavailable to plants. The aluminum reacts with P to form an insoluble aluminum phosphate compound that is less susceptible to runoff or leaching than untreated manure. Zvomuya et al. (2006) demonstrated that alum may be an effective amendment for immobilizing P and reducing P leaching in coarse-textured soils with a long history of waste application. When incorporated with poultry litter, alum is typically added at an equivalent rate of 5 percent to 10 percent of the manure weight (Moore 2005). Alum has proven effective in reducing P runoff in dairy, poultry, and swine manure. Dao and Daniel (2002) show that alum applied to dairy manure and incorporated into the soil effectively reduced dissolved reactive P by 63 percent. Other studies have shown that alum treatment is capable of reducing P runoff from small plots and watersheds by 87 percent and 75 percent respectively when applied to poultry litter (Moore 2005). A study of alum's effects on treating swine manure showed that a 1 percent v/v addition of alum to the manure will result in an 84 percent decrease in P in runoff waters (Smith et al. 2001). Basically, 1 lb of alum would treat 100 lb of manure in this scenario.

Alum typically costs about \$250 per ton and can be purchased in dry or liquid form. To determine costs for alum application to WAFs, several tests should be conducted to determine proper application rates. A soil analysis should also be conducted to determine the amount of P present in the soil and a manure test should be conducted to determine loading rates that the field will be receiving. Once these tests have been completed, an appropriate application rate can be determined and the producer can decide if alum application is a cost-effective BMP for that situation.

Other chemicals have the ability to bind P and therefore greatly reduce P runoff from WAFs. Aluminum chloride is one such chemical that has proven effective for reducing P in swine lagoon effluent. Smith (2005) suggests that P can be reduced to background levels through the incorporation of adding one part of aluminum chloride for each part of P in the manure. According to Smith (2005), aluminum chloride costs between \$200 and \$300 per ton but total

cost will depend on the application rate. Proper application rates can only be achieved through preliminary soil and manure tests to determine the amount of P present in soils and manure.

Ferric chloride (iron chloride) is also used as a chemical amendment that can reduce the amount of P runoff from WAFs. Dao and Daniel (2002) show that incorporating 10 g of ferric chloride per kg of dairy manure into the soil reduced P losses by 96 percent over adding raw manure to the soil. At this application rate, one ton of ferric chloride will treat 100 tons of dairy manure. Current costs for this compound range from \$340 to \$360 per ton plus shipping. Again, soil and manure tests should be conducted to determine proper application rates.

Localized evaluation of this method within the Bosque River watershed would be beneficial in establishing a potential long-term solution to P leaching from WAFs within the watershed. Each location will present a specific scenario and should be evaluated prior to the use of any other chemical to control P losses.

***Implementing sub-watershed soil conservation and erosion control plans***

The focus of soil conservation and erosion control plans is to prevent the detachment of sediment and prevent the transport of soil by runoff. A secondary benefit of these plans is the decrease in nutrient losses, mainly P. In addition, these practices maintain the productivity of the land by retaining soil and nutrients on the farmable landscape. For example, using conservation tillage that leaves at least 30 percent crop residues in wheat and corn has shown to reduce soil loss by 62 percent and 97 percent respectively (Gilley and Eghball 2005).

Soil conservation and erosion control plans are developed based on the particular site’s rainfall characteristics, soil factors such as infiltration capacity and erosivity, topography, climate, land use, and the desired conservation goals (Gilley and Eghball 2005). Plans can be developed for any location after a proper site evaluation is conducted. Soil conservation and erosion control plans can encompass many different BMPs (Table 1), such as grassed waterways, contour farming, strip cropping, conservation tillage, planting cover crops, terracing, and incorporating compost or manure, or may simply use one type of BMP. The Bosque River watershed is a good candidate for a majority of these BMPs, but

**Table 1. Common practices in soil conservation and erosion control plans**

<b>Potential NRCS Practices Recommended for Implementation in a Soil Conservation and Erosion Control Plan</b>	
<b>Practice</b>	<b>NRCS #</b>
Conservation Cover	327
Contour Buffer Strips	332
Contour Farming	330
Critical Area Planting	342
Field Border	386
Filter Strip	393A
Grade Stabilization Structures	410
Grassed Waterway	412
Heavy Use Area Protection	561
Mulching	484
Pasture and Hayland Planting	512
Prescribed Burning	338
Prescribed Grazing	528A
Residue Management	329A,B,C
Riparian Forest Buffer	391
Strip Cropping	585 & 586
Terrace	600
Watering Facility	614

each location needs to be evaluated to determine the most feasible BMP (EPA 2003). USDA-NRCS personnel will be useful for evaluating specific properties and recommending practices to implement.

Erosion control and soil conservation plans have proven to be highly effective when implemented and maintained as planned. Operation and maintenance requirements will vary greatly depending on the BMPs employed in the plan. Therefore, after establishment of the soil conservation or erosion control plan, information on individual BMPs should be obtained to learn how to install, operate, manage, and maintain each individual practice. Each BMP must be managed and maintained individually to sustain the effectiveness of the erosion control or soil conservation plan.

The cost of implementing and maintaining these plans are also dependent upon the type of BMPs included in the plan. A plan that consists of contour farming and strip cropping will be much cheaper than one that incorporates the use of conservation tillage, terraces, grassed waterways, and riparian or vegetative buffers. Plans that include more labor, extensive equipment use or the purchase of specialized equipment to implement and/or maintain included BMPs will be more costly than those that simply suggest modified cropping systems or grazing plans (Gilley and Eghball 2005).

### ***Improving PL566 structures to increase sediment retention***

For 50 years, America's small upstream dams have provided flood protection, municipal water supplies, wildlife habitat, water for livestock, and recreational opportunities, but time has taken its toll on these structures and many are deteriorating. These dams were constructed as a result of Public Law 566, the Watershed Protection and Flood Prevention Act passed in 1954. Many of Texas' dams are quickly approaching their expected economic lifespan and may be in need of repairs that will extend their functional life.

In the Bosque River watershed, sediment reduction is one of the primary functions that these dams perform on a regular basis. A large portion of the soils in the upper North Bosque River watershed are considered highly erodible and are prone to producing large sediment loads during rainfall events. Most PL566 structures in the watershed are located in this section of the basin and can effectively capture significant portions of sediment carried in small streams. In a 2006 report to the Texas Commission on Environmental Quality (TCEQ), TIAER reported results from a water quality monitoring study that evaluated the ability



Figure 1. PL566 structure in the Bosque watershed with sediment build-up and brush growing on the dam

of two PL566 structures to remove various water pollutants over a three-year period by comparing water quality of the inflow and outflow of the two reservoirs. Total suspended solids, or sediment, was one of the parameters monitored in this study. One reservoir retained an average of 95 percent of the sediment that entered the reservoir while the other retained 73 percent (TIAER 2006).

Over time, sediment accumulation can reduce both the volume of water captured by these structures and the amount of sediment that they can remove during runoff events. Removing this extra sediment is the primary mechanism for increasing sediment retention potential. Sediment can be removed from these reservoirs in a number of ways. In the Bosque, most of the PL566 structures do not maintain a large pool of water, but instead drain water down to the primary spillway and then lose waters through their permeable bottoms. In this case, sediment can be removed by using earth-moving equipment. For structures with a continual pool of water, a trackhoe may be able to reach and remove enough sediment to improve the reservoirs capacity, but mechanical or hydraulic dredging may be required for larger reservoirs.

Costs to carry out this task vary greatly depending on the chosen method of removal and the amount of sediment that must be removed from the structure. In reservoirs that maintain a consistent pool of water, dredging may be the only feasible option for removing sediment. According to Cooke et al. (2005), lake dredging costs \$6,235 per acre-foot of sediment removed and is limited to 8 meters below the water surface. Naturally, cost will vary depending on the location and size of the reservoir to be dredged. No hourly or volume-based rates for sediment removal using heavy equipment could be found; however, stock tank construction can be considered a similar practice. The USDA National Agricultural Statistics Service (NASS 2004) reported an hourly stock tank construction rate average of \$71.36 in Central Texas and an average price per cubic yards of \$1.08. NRCS reports standard earth-moving costs for Erath County to be \$2 per cu. yd (2007b). At this rate, sediment removal using heavy equipment would



Figure 2. Duck blinds on a PL566 structure reservoir in the Bosque River basin

be much cheaper. One acre-foot is equivalent to 1,613.33 cubic yards; therefore, the cost to remove one acre-foot of sediment using heavy equipment would be about \$1,742 based on the average rate of \$1.08 per cubic yard as reported by USDA-NASS (2004).

Another maintenance activity that could improve PL566 structures and their ability to retain sediment include modifying vegetation. This practice will vary widely depending on the current condition of each reservoir and

dam. Wetlands are one of nature's most efficient filtering systems and have proven highly effective at removing sediment from runoff events. Wetlands also provide the added benefits of increased wildlife, waterfowl, and fish habitats as well as potential recreational and/or economic benefits from hunting opportunities.

Some PL566 structures in the Bosque watershed may support wetland vegetation if they maintain a relatively constant pool of water throughout the year. An ideal situation for wetland vegetation would be a gently sloping flood pool in which a significant amount of the water is less than 6 feet deep. Plants can be transplanted from other wetland areas if access is available or plants can be purchased from an aquatic nursery, which can be quite expensive. Labor will be the largest cost for planting wetland plant seedlings and will vary depending on the size of the job and time required. Maintenance costs will also vary depending on the specific situation at each reservoir. The most cost-effective way to manage the vegetation is through mowing or burning, both of which require low water levels. Therefore, water levels may need to be lowered after storm events to allow for mowing or burning and to prevent drowning of the wetland vegetation. If pollutant removal is a primary concern, the vegetation must be harvested and removed from the reservoir watershed or else pollutants will be released back into the reservoir; one method of harvesting is to cut and bale the vegetation. Pasture shredding costs for Central Texas were reported to average \$15.61 per acre in 2004 while round baling costs averaged between \$15.66 and \$17.20 per bale depending on the size of the bale produced (USDA-NASS 2004). These numbers may vary though since harvesting vegetation in and around a reservoir is not a typical practice.

Performing proper operation and maintenance activities is also an essential function to ensure that the structures maintain their ability to store excess runoff and retain sediment. Typical operation and maintenance tasks listed by the Culpeper Virginia SWCD (2006) are:

- Annual inspections of the dam, spillway, and primary spillway
- Hiring contractors for routine mowing and maintenance
- Critical period inspections and monitoring (i.e., during unusually heavy rainfall)
- Keeping spillways clear of debris
- Preventing trees or bushes from growing on the dams
- Eliminating burrowing animals from dam embankments
- Maintaining a healthy stand of grass on the dam and spillways to prevent erosion
- Inspecting for seepage on the dam face and around all metal and concrete parts
- Ensuring that gates, valves, and all water control mechanisms are always operable
- Inspecting closely for signs of deterioration (Culpeper Virginia SWCD Office Operation and Maintenance Requirements: CSWCD 2006)

### ***Improving quality of water held by PL566 structures***

PL566 structures are essentially detention/retention basins designed primarily to reduce flooding in severe runoff events. Pollutant removal is an ancillary by-product of the structures as

the slow release of water downstream allows time for settling of some pollutants to occur. A recent study conducted by TIAER evaluated the pollutant-removal capacity of two PL566 reservoirs in the North Bosque River watershed. An average of results from both reservoirs show that the reservoirs were capable of removing about 50 percent or more of the water quality constituents measured (Table 2). Given these results, the reservoirs actually remove a fair amount of pollution from the waters that flow into them; however, over time these nutrients and sediment can accumulate and potentially cause water quality issues in the waters held by the PL566 structures. First, water samples need to be taken from each reservoir to identify any water quality concerns. These samples should be taken throughout the year as pollutants may vary depending on what has been done in the watershed since the last significant rainfall event. For example, a runoff event in late spring may transport a significant load of nitrogen (N) and P fertilizers while a runoff event later in the summer may transport more pesticide/herbicide residue. Water quality improvements in waters held by PL566 structures can be achieved through practices at the structure, including establishment of a wetland ecosystem, sediment removal, and alum application, as well as practices upstream of the structure, such as erosion and sediment control.

Establishing significant wetland vegetation in the reservoir's shallow portions is one option that can provide long-term pollutant removal in the reservoir, if properly managed. As mentioned earlier, wetland vegetation can effectively remove many pollutants from the water column and sediment and store them within the plants' tissues. To maintain a high level of pollutant removal by the plants, excess vegetation may need to be harvested and removed from the reservoir. This removal will allow for new plant growth, which will allow for additional pollutant uptake. Simply mowing the vegetation when water levels are low or burning this vegetation will not remove the pollutants from the system but will instead re-release them to the reservoir. Depending on the growth rate and type of vegetation, this removal may need to be done on a semi-annual, annual, or bi-annual basis. Costs and benefits of establishing and maintaining wetland vegetation are discussed earlier in this report.

Removing sediment trapped by the PL566 structure is another action that can impact the quality of water held by the structure. Wind has the ability to cause sediment, along with pollutants held in the sediment, to be re-suspended in the water column. Sediment re-suspension typically occurs in shallower waters under windy, turbulent water conditions. Given the size and shape of most PL566 structures, this may not be a great concern so other practices will likely yield better water quality improvements. More information, including costs and benefits, of sediment removal are discussed earlier in this report.

Application of alum to a reservoir can positively impact water quality by adhering to P particles, causing them to flocculate and settle out to the bottom of the reservoir. P would then be stored in sediment until it is removed from the reservoir. One problem with this approach is that when new sediment is deposited in the reservoir, it covers up the previously bound P and

**Table 2. Average efficiency ratios for two PL566 reservoirs in the North Bosque River watershed (adapted from TIAER 2006)**

Parameter	Average Removal Efficiency
NH <sub>3</sub> -N	0.51
Organic-N (TKN - NH <sub>3</sub> -N)	0.49
NO <sub>2</sub> -N+NO <sub>3</sub> -N	0.69
SRP (Inorganic-P)	0.46
Organic-P (TP-SRP)	0.69
TSS	0.84

prevents additional P from being bound by the alum treatment. Consequently, the effectiveness of this treatment method depends on the length of time until the next significant sediment deposition into the reservoir. The cost of alum application will therefore vary depending on the frequency of sediment deposition and the reservoir size. In a presentation given by Tarrant Regional Water District (TRWD) personnel, they were quoted a price of \$225 per acre to apply alum to their reservoirs (TRWD personal communication, April 2007). Costs for applying alum to a smaller reservoir may be higher than costs reported for large reservoirs due to the smaller volume of alum sold.

Perhaps the most effective way to improve the quality of water held by PL566 structures is to install BMPs upstream from the reservoir that will retain the majority of pollutants in the watershed instead of transporting them downstream to the reservoir. Many practices that can be used to improve water quality in PL566 structures are described in detail in other sections of this report. On-farm practices suggested for the Bosque River watershed include applying chemical agents to fields that will reduce P solubility; implementing soil conservation and erosion control plans; installing crops that can be harvested and removed from the watershed; and installing grazing management practices. Other practices suggested are contour ripping soils to increase infiltration; terracing to reduce sediment transport; developing nutrient management plans; and injecting waste and/or fertilizers directly into the soil instead of surface applying. Practices that can be implemented in gullies, streams, and along riparian corridors to improve water quality include developing recharge structures, establishing vegetated buffer strips in riparian areas, stabilizing streambanks to reduce sediment, installing gully plugs, and installing permeable reactive barriers/check dams in gullies to reduce sediment and nutrients. In urban areas, implementing construction site runoff management plans, treating stormwater in retention/detention ponds, and developing recreational areas to include stormwater management can all improve water quality downstream at PL566 structures. Costs and expected benefits for these management practices will vary greatly. More information about each practice can be found in other sections of this report.

### ***Installing crops that could be removed from the watershed***

Development of BMPs that provide “value-added” opportunities can provide a win-win situation for local landowners by providing innovative and economically beneficial revenues while potentially reducing nutrient concerns within the Bosque River watershed and assisting in meeting objectives and goals set by applicable TMDLs.

Essentially, this BMP is the planting of any crop (hay, silage, turfgrass, etc.) on high P soils in the



Figure 3. Sod harvesting equipment

watershed or on fields that will receive composted or raw waste from a dairy or similar operation that can be harvested and removed from the watershed. When the crop leaves the watershed, it effectively takes P with it out of the watershed. The overall goal of this approach is to reduce the soil test P levels by removing the crops. Perhaps one of the most effective crops that can be planted and harvested to remove P from a watershed is turfgrass. Not only is P taken up and stored in the grass biomass removed during harvest, but also a thin layer of soil, usually ¼ to ½ inch thick, is taken with the sod. This top layer of soil is usually rich in nutrients, such as P, and contains the majority of P present in the soil. Any crop can technically be used to export P from a watershed when it is harvested; however, crops where the majority of the biomass is removed are more effective than crops harvested for their grain only.

Locations where this practice is most effective have high soil P. Soil type and texture also influence the P removal rate from a field. P removal rates will be higher in lighter soils, like sands, as opposed to a heavier clay-type soil. Higher removal rates will also occur in soils with lower cation-exchange capacity, or nutrient-holding capacity, and with lower soil organic matter. Some crops will be better suited for some areas than others will. For example, turfgrass production is most feasible on relatively flat lands with shallow slopes while switchgrass can be grown in more topographically diverse areas. To remediate or significantly lower soil test P levels in the soil, these crops should be planted in areas where additional P will not be added. When used on WAFs, these crops will not necessarily lower soil test P, but instead can help maintain lower accumulation rates and effectively increase the life and/or the amount of nutrients the WAF can receive.

Costs to establish crops that remove nutrients from a field or watershed can vary greatly depending on the current use of the field(s) and the desired crop to be installed and later removed. If a field is currently used to produce grain crops of corn or maize, simply switching to production of a forage crop will increase the nutrient removal from the field. The majority of sites should only experience additional costs in harvesting the crop. Some practices can be more expensive to install, but have the potential to recover the costs by selling the crop produced or by reducing the need for expanding the WAF area. Installing turfgrass for sod production is one such practice that Munster et al. (in press) found to be a profitable alternative to WAFs in the Bosque River watershed. Average costs to sprig Bermuda grass in Central Texas are \$35.50 per acre (USDA-NASS 2004). Typically, 1.5 crops per year can be harvested from a turfgrass field with each harvest capable of removing 58 percent (Vietor et al. 2002a) to 81 percent (Vietor et al. 2002b) of applied manure P. Economics for sod crop production vary depending on numerous factors. An economic analysis conducted by McDonald (2005) indicated that the first crop must be sold at \$0.84-\$0.85 per yd<sup>2</sup> to break even and the second crop will break even at \$0.68-\$0.69 per yd<sup>2</sup>.

The key to having a successful nutrient removal system using crop exports is to remove completely these harvested crops from the farm and watershed. Many producers currently grow crops that remove P from the soil and store it in its biomass, but they usually keep the majority of the harvested crops on site and feed it to their own cattle, thus returning the previously harvested nutrients to the farm and watershed. By selling some of the harvested crops to producers or consumers outside of the watershed, much of the P on site can be exported while supplementing the farmer's income.



## *Installing grazing management practices*

*NRCS Practice # 528A*

Grazing management plans aim to employ the best practical uses of forage resources and are important to improving or maintaining range condition, improving livestock forage harvest efficiency, and attempting to optimize plant and animal performance. Well-designed plans achieve management goals set by operators while ensuring them a financial benefit and meeting the requirements of animals and plants. Plans improve ecosystem function and watershed protection and are flexible and simple to operate. Grazing plans can be adapted for all range and pasture lands depending upon desired stocking rates, the species of grazing animals, grazing rotation schedules, plant species, and the number of herds and pastures (NRCS 2003a).

The main purpose of grazing management is to maintain a healthy and productive pasture that will allow the grazing land to reach its maximum productive potential. Essentially, grazing management allows for the establishment of good ground cover of grasses and forbs that restrict the movement of sediment, nutrients, and chemicals over the landscape. Water infiltration is also enhanced by establishing and maintaining healthy, vigorous ground cover (Toor and Sims 2005). Grazing management plans also focus on enhancing soil organic matter that preserves the quality of the soil as well as increasing infiltration.

This practice can be applied on rangelands and established pastures as long as adequate water supplies are available for grazing livestock. Pasture- or field-stocking rates must be controlled for proper grazing management. An integral part of an effective grazing management plan is planned rest for each field; therefore, it is essential that grazing livestock can be excluded from a particular field or area as needed. Local NRCS and TSSWCB personnel will provide free assistance to landowners wishing to develop grazing management plans for their property. Costs to implement these plans will vary depending on the management practices recommended in the plan. In many cases, both TSSWCB and NRCS can provide cost-share funding to help defray implementation costs.

## *Contour ripping/pasture renovation to maintain permeability of soils and increase residence time of water in soils*



Figure 4. Deep ripping a pasture

Contour ripping and other pasture renovation practices can provide a beneficial approach to maintaining soil sustainability and other natural resources within the Bosque River watershed. Contour ripping (subsurface fracturing of claypan or compacted soils) increases infiltration and reduces runoff from treated landscapes. Increasing infiltration reduces the potential for soil erosion as

overland flow is disrupted and runoff water is distributed downward into the soil profile. The reduction in overland flow can also reduce the potential for nutrient-impacted sediment transport into local streams and rivers, thus reducing the potential for downstream impacts.

NRCS's definition of this practice (2003b) is the modifying of physical soil and/or plant conditions with mechanical tools by treatments such as pitting, contour furrowing, and ripping or sub-soiling. Other practices, such as pasture renovation efforts using aerators or other mechanical methods to increase the soil's infiltration capacity, can also be included in this definition. The purpose of these practices is to increase plant vigor as well as renovate and stimulate the plant community for greater productivity and yield.

Pastureland, rangeland, grazed forestland, and native pastures are feasible areas to use this BMP if the slope is less than 30 percent and renovation is done on the contour. Best results can be achieved from this practice by allowing adequate resting from grazing after treatment is applied and by ensuring that soils are not too wet prior to treatment. Noxious or unwanted weeds may increase because of soil disturbances; as such, this treatment is best used on areas with few undesirable plants present. Surface roughness will likely increase and could hinder some uses. Tile drains and underground piping should be identified prior to treatment and must be avoided to prevent damage to them and the equipment.

Costs to implement this BMP will include mostly fuel, labor, and equipment costs. Pasture renovating equipment starts at about \$1,000 for a small implement and goes up in price from there. If a small amount of land will be covered using this treatment, then using a smaller implement and tractor will suffice; however, if large tracts of land will be renovated then larger, more expensive equipment will be needed. This method will cut down on overall labor and fuel costs and will pay for itself in the long run. An alternative to owning and operating this specialized equipment would be to hire someone who has the equipment to come in and perform the task. Costs to hire someone will vary depending on the location, number of acres covered, and the desired practice. USDA-NASS (2004) reports the average cost of hiring someone in Central Texas to till a pasture using a deep ripper is \$13.89 per acre.

### ***Terracing to reduce sediment transport***

***NRCS Practice # 600***

Terraces are earthen mounds constructed to reduce the length of moderate to steep slopes and transport runoff to a safe outlet. The main benefits of terraces are the reduction of impacts from sheet and rill erosion, prevention of gully development, and a reduction in sediment and nutrients delivered to streams and lakes (Carman 2005). Terraces can be employed anywhere that sheet and rill erosion and gully formation are problematic; however, extremely rocky, sandy, or shallow soils are not good places to employ terracing due to construction and maintenance problems (NRCS 1984).

There are two main types of terraces: storage terraces and gradient terraces. Storage terraces are built to collect and store water until it can infiltrate into the soil or be released through a stable outlet. Gradient terraces, however, are designed as channels to slow runoff water and carry it to a stable outlet. Storage and gradient terraces can be built with three main cross sections. Grassed backslope terraces have a farmable front slope and a steep, unfarmable backslope that is



Figure 5. NRCS photo of terraces and contour farming

seeded with perennial grasses for stabilization. Narrow base terraces are built with a 2:1 slope (2 ft horizontal to 1 ft of vertical drop) on the front slope and backslope; each side of this terrace is unfarmable and is planted with perennial grasses. Broad base terraces have a flatter appearance and can be farmed on the front and backslopes. This type of terrace can only be used on shallower slopes, typically less than 8 percent (Carman 2005).

Proper spacing of terraces is the key to maintaining their effectiveness on varying soil types. Spacing should be adjusted to

accommodate an even number of trips between terraces with equipment. In addition, terraces should be kept as parallel to each other as possible and have long, gentle curves that accommodate farm machinery (NRCS 2002). The NRCS's National Handbook of Conservation Practices (NHCP) provides a formula to determine the appropriate vertical and/or horizontal spacing for terraces depending on conditions at your specific location (2002). Besides proper spacing and alignment, an effective outlet for water carried by the terrace needs to be available for the terrace to function appropriately (Carman 2005).

Terraces can have detrimental effects on water quality due to lack of maintenance, failure, or if they concentrate nutrients and accelerate their delivery to surface or groundwater (NRCS 1984). The NRCS's NHCP recommends the development of an operation and maintenance plan that provides for periodic and post-runoff inspections, accompanied by prompt repair of damaged components; maintenance of ridge height and outlet elevations; removal of sediment and maintenance of the channel grade to assure that the inlets for outlet structures are clean and at the lowest point; maintenance of vegetated areas, which may require replanting; and instruction of workers to avoid damaging the structure with machinery or equipment (2002).

The pollutant removal efficiency of terraces can be increased by using other BMPs in conjunction with terraces. Implementing farming techniques, such as no-till planting or conservation tillage, will reduce the amount of sediment transported to the terraces and in turn reduce maintenance requirements. Alternating crops will also change runoff and nutrient uptake between the terraces and can also reduce sediment and runoff transported to the terraces.

Terraces that are most effective and economical can be farmed using contour and conservation tillage techniques or replanted with herbaceous cover for grazing. A site evaluation should be conducted prior to construction of terraces to determine if terracing is an effective BMP to address pollution issues at your site. Terraces are not cost effective on land with slopes that are too steep because repairs would have to be made too often or on slopes that are too shallow because the terrace is simply not needed. Costs to establish terraces include earthwork costs to build the terrace and the outlet plus the possible cost of vegetation establishment. Some farmable land may be lost through the construction of terraces and outlets, but these losses can be minimized through proper planning. Costs for construction of terraces vary greatly depending on the size and type of terrace and outlet built. Typical terrace construction cost ranges between \$1 and \$6 per linear foot (Carman 2005) but will be dependent on conditions at your location. USDA-NASS (2004) reported average costs for terrace construction in Central Texas to be about \$70.83 per hour while NRCS (2007b) reports new construction and leveling costs for old terraces in McLennan County to be \$220 per ac.

### ***Developing nutrient management plans***

### ***NRCS Practice # 590***

A nutrient management plan provides guidelines for applying manure or soil amendments that minimizes nonpoint source pollution and maintains the overall condition of the soil (NRCS 2006). These plans are developed in accordance with technical requirements of the NRCS Field Office Technical Guide (<http://www.nrcs.usda.gov/technical/efotg/>), policy requirements of the NRCS General Manual, procedures contained in the National Planning Procedures Handbook ([http://www.nrcs.usda.gov/technical/afo/cnmp\\_guide\\_index.html](http://www.nrcs.usda.gov/technical/afo/cnmp_guide_index.html)), and technical guidance contained in the National Agronomy Manual ([http://policy.nrcs.usda.gov/media/pdf/M\\_190\\_NAM.pdf](http://policy.nrcs.usda.gov/media/pdf/M_190_NAM.pdf)). These plans should be site specific and include the following components, as applicable:

- 1) Aerial site photographs or maps, and a soil map  
These maps can be computer-generated or hand-drawn, as long as they depict the boundary and size of the field, location of sensitive areas (described below), and the distribution of the different soil types present (NRCS 2000a).
- 2) Location of designated sensitive areas or resources  
Sensitive areas are those that are highly erodible, contain highly leachable soils, located in an aquifer recharge zone, and/or close to other private or public property (NRCS 2000a).
- 3) Current and/or planned plant production sequence or crop rotation  
This information is needed as when and what crops are present determines how much nutrient is left in the soil, how much nutrient need to be applied, and when the best time is to apply needed nutrients (NRSC 2000a).
- 4) Soil test results and recommended nutrient application rates  
Soil testing is an important element of nutrient management as it determines how much phosphorus is needed to maximize plant growth as well as how much phosphorus the soil

can contribute to runoff (Sharpley et al. 2005). This testing needs to be performed about every five years so that the management plan is based on the most current soil condition. Soil testing needs to be performed at an approved laboratory, such as Texas AgriLife Extension Service's Soil, Water, and Forage Testing Laboratory at Texas A&M University (<http://soiltesting.tamu.edu>). Guidelines on how and where soil samples should be taken for submission to the lab at TAMU can be found on their website (<http://soiltesting.tamu.edu/files/soilwebform.pdf>). Analysis cost per sample is about \$10 but the total cost of this analysis will vary depending on how many samples are needed to fully represent the entire acreage.

- 5) Plant tissue test results, when used for nutrient management  
These data, along with soil and other nutrient source data, are needed to calculate the nutrient budget for a specific location.
- 6) Quantification of all-important nutrient sources  
Nutrient sources can include manure, fertilizers, soil reserves, legume credits, irrigation water, and deposition from the atmosphere (NRCS 2000a). Quantification of the amount of phosphorus in these sources allows for determination of the amount of manure, fertilizer, etc. needed to maximize crop growth while simultaneously reducing polluted runoff and economic costs. The TAMU lab also analyzes biosolids, such as manure; sample collection guidelines are posted on its website (<http://soiltesting.tamu.edu/files/biosolidweb2.pdf>). Analysis cost per sample is \$15 but total cost will depend on the number of manure stock piles or lagoons present.
- 7) Realistic yield goals and a description of how they were determined  
Expected yields depend on the crop variety, soil type, and climatic factors, with higher crop yields generally requiring the application of more nutrients. The expected crop yield will vary by location and should be determined through consultation with the local county Extension agent.
- 8) Complete nutrient budget for N, P, and potassium (K) for the plant production system  
A nutrient budget provides the background on what nutrients are available and can be used to determine whether additional nutrients are needed for a crop to achieve the expected yield. If too many nutrients are available, then the nutrient management plan needs to address methods to reduce the nutrient level to prevent environmental damage.
- 9) Planned rates, methods, and timing (month and year) of nutrient application  
Nutrient application rates should be based on realistic yield goals and the results of soil testing. If liquid manure is being applied, then the application rate should be less than the infiltration rate of the soil so that ponding and runoff does not occur (NRCS 2006). Nutrients should be applied in a method that reduces the chance of polluting runoff; some of these methods include uniform application of materials, avoiding application to saturated soils, avoiding application to an area within 100 ft of surface water and wellheads, coordinating with irrigation practices, and rapid incorporation of the nutrients with the soil. The time of year for nutrient application should be planned based on when

planting occurs (do not apply nutrients in winter if planting will not occur until the spring), weather conditions, and field accessibility (NRCS 2006).

10) Guidance for implementation, operation, maintenance, and recordkeeping.

Nutrient management plans should be dynamic and updated with every new soil test and possibly sooner if these tests are not done on a regular basis. Updates should also occur if there are any major changes in feed management or in the number of animals (NRCS 2006). Detailed records of nutrient application should be kept to provide a point of reference for any future adjustments that may be needed (NRCS 2003c).

If the conservation management unit lies within a hydrologic unit area identified or designated as having impaired water quality associated with N or P, nutrient management plans include an assessment of the potential for N or P transport from the field. When such assessments are made, nutrient management plans will include: 1) a record of the site rating for each field and 2) information about conservation practices and management actions that can reduce the potential for P movement from the field.

***Applying a waste injection program to inject fertilizer/manure/etc. directly into soils***

Waste injection is a potentially effective way of incorporating liquid manure into soils. In this practice, liquid flows through a tube attached to a knife that places the material in a band below the soil surface. Liquid manure injection offers a number of advantages over broadcasting including: 1) fewer odors, 2) ability to place nutrients directly into the seedbed, 3) reduce loss of fertilizer value, and 4) reduce contact with surface runoff. Besides the previous advantages, waste injection is also provides a quicker application method that requires less power than other land application methods (Sheffield 2006). While this method is effective, care must be taken to prevent soil smearing and compaction when the soil is too wet. Caution is also needed in soil conditions susceptible to macropore flow. This method is not appropriate for areas with shallow, highly leachable soils as the nutrients in the manure could easily be transported by runoff.

The cost of waste injection is dependent on equipment availability as a tank or spreader, along with a tractor, will be needed. If a tank and tractor are available, then the cost of outfitting the tank with injectors is about \$6,000 (EPA 2001). Other costs include annual operation and maintenance costs, which are usually 2 percent of initial costs, and the cost of diesel fuel.

**Table 3. Effects of NRCS conservation practices recommended for on-farm use**

<b>NRCS Conservation Practice Effectiveness</b>				
<b>BMP Name and Associated Effect of Implementing the Practice on the Listed Resource Problem</b>				
<b>Resource Problem</b>	<b>Contour Buffer Strip - 332</b>	<b>Nutrient Management - 590</b>	<b>Prescribed Grazing - 528A</b>	<b>Terraces - 600</b>
Sheet & Rill Erosion	Slight to Significant Decrease	Slight to Moderate Decrease	Slight Decrease	Slight to Moderate Decrease
Soil Erosion from Wind	Situational	Slight decrease	N/A	Slight Decrease
Concentrated Flow Erosion	Slight Decrease	Slight Decrease	Slight Decrease	Significant Decrease
Streambank Erosion	N/A	Slight Decrease	N/A	Slight to Moderate Decrease
Soil Condition: Tilth, Infiltration, Organic Matter	Slight Decrease	Slight Increase	Slight to Significant Decrease	Slight to Significant Increase
Water Quantity: Runoff and Flooding	Slight Decrease	Insignificant	Slight Decrease	Moderate Decrease
Water Quantity: Subsurface Water	Slight Increase	Slight Decrease	N/A	Slight Increase
Groundwater Quality Concerns	Slight to Moderate Decrease	Slight Decrease	Slight to Moderate Decrease	Slight to Moderate Decrease
Surface Water Quality Concerns	Moderate to Significant Decrease	Significant Decrease	Moderate Decrease	Slight to Moderate Decrease
Plant & Cropland Productivity	Slight Decrease	Slight to Significant Decrease	N/A	Moderate to Significant Decrease
Pasture and Hay Productivity	N/A	Slight to Significant Decrease	Significant Decrease	Slight to Moderate Decrease
Domestic Animal Habitat: Food, Water, Shelter	N/A	Significant Decrease	Significant Decrease	Slight Decrease
Wildlife Habitat: Food, Water, Shelter	Slight Decrease	Significant Decrease	Slight Decrease	Slight Decrease

# Between Field and Creek BMP Descriptions and Expectations

---

## *Installing vegetation buffers – “polishing strips”*

*NRCS Practice #s 391 & 393A*

Vegetation buffers or “polishing strips” are also known as filter strips, which are simply a strip or area of herbaceous vegetation situated between cropland, grazing land, or disturbed land and environmentally sensitive areas such as streams or reservoirs (NRCS 2003d). The purpose of buffer strips is to reduce sediment, particulate matter, and contaminants transported in runoff or irrigation tailwaters. These strips or areas of vegetation also restore, create, or enhance herbaceous habitat beneficial for wildlife and insects (NRCS 2003d). Vegetation in these areas effectively slows runoff, which minimizes sheet and rill erosion and allows time for sediments to settle out of the runoff. The vegetation also improves the soil’s infiltration capacity and moisture holding ability (Green and Haney 2005). Field borders are a similar practice that is defined as a permanent border established at the edge or perimeter of a field. This practice is typically used around cropland while vegetative buffers or polishing strips are used in many areas. Field borders and polishing strips perform similar functions and are primarily erosion control BMPs (NRCS 2003d).

The use of vegetation buffers (polishing strips) in riparian zones requires a different approach than traditional rangeland/pasture management and focuses primarily on conservation benefits such as filtering runoff, stabilizing stream banks, and enhancing habitat. Buffers can vary in size, vegetation types, species compositions, and spatial arrangements. Even though wider buffers provide more benefits, buffers with widths as narrow as 20 feet can still contribute to water quality improvements (Riley 1998). In addition, grasses, shrubs, and trees have different capabilities to provide site-specific benefits (Dosskey 1998). The challenge regarding an integrated approach to riparian management in private-land states is that riparian systems cross landownership, thus requiring a concentrated effort across property lines in development of benefits throughout the watershed. Nevertheless, individual landowners can benefit from localized development of this BMP to enhance habitat and control erosion on their property.



Figure 6. Vegetated buffer protected from grazing by a fence (NRCS)

Locations that are feasible for vegetated buffers are typically agricultural areas where both point and nonpoint source pollution occur; however, they can also be used in urban settings with potential sediment erosion, leaching, and runoff problems (Green and Haney 2005). In all cases,



the polishing strip should be located down slope of the potential pollution source. The drainage area above filter strips should range in slope from 1 to 10 percent. The ratio of the drainage area to the filter strip area should be from 50:1 and 70:1 depending on the rainfall and runoff erosivity index as described in the Revised Universal Soil Loss Equation. Vegetative cover in filter strips should be well established and permanent and should consist of either a single species or a mixture of grasses, legumes, and/or other forbs that are adapted to the climate, soil, nutrients, chemicals, and agricultural practices in the area. In addition, plant stems should be no farther than 1 inch apart and should be hardy and stiff enough to effectively reduce runoff and trap sediment (NRCS 2003d).

Vegetative buffers should be designed to specifically meet the sediment and nutrient removal needs of the operation. Adjusting the species of vegetation and the size and length of the strips are ways that pollutant removal goals can be met. In some cases, the edge of field filter strips can be a type of harvestable grain that is planted before the main crop and has grown enough to handle the runoff load from the first irrigation. The NRCS recommends that a plan be established for each site where a filter strip will be implemented. These plans should include:

- the location, size, and slope of the filter strip
- construction, management, and maintenance requirements
- seeding/sprigging rates, planting dates, and methodologies for each plant species

Operation and maintenance of polishing strips must be conducted to maintain the ability of the BMP to perform its designated functions. Vegetation within these strips should be selectively harvested to promote dense growth, maintain upright growth, and remove excess nutrients or contaminants held in plant tissues. Limited prescribed burning and grazing management may be used as vegetation management, but should only be used when moisture conditions will promote a cool burn that will not consume all vegetation or when excess compaction from cattle traffic will not be an issue. Polishing strips should be inspected after runoff events to evaluate their integrity and need for repair. Periodic sediment removal or grading may be needed to maintain sheet flow and prohibit channelized flow through the strip.

Costs to implement polishing strips will vary for each location depending on their size, type, and amount of labor and equipment costs. Strips installed around currently farmed fields will cost less due to lowered labor and equipment costs. The primary cost in that situation would be vegetation establishment and seeding or sprigging costs. USDA-NASS (2004) reports these costs to average \$9.16 and \$35.51 per acre, respectively. NRCS (2007) reports typical costs to establish a filter strip to treat runoff in Erath County at \$80 per ac. Grazing protection, or fencing, may be needed to establish and maintain high quality vegetative buffers. Average fencing costs in Central Texas for a 4- to 6-wire barbed wire fence with steel posts averaged \$6,555 per mile in 2004, according to USDA-NASS. Implementation and maintenance costs can be offset when crops, such as hay or small grains, are planted and harvested from the polishing strips. Polishing strips that are implemented along streams or gullies may cost more than field borders due to increased construction and maintenance costs, but this will be site specific (NRCS 2003d). These types of polishing strips may reduce the opportunity to harvest vegetation, but can increase wildlife habitat that could be leased out for hunting purposes.

**Table 4. Effects of NRCS conservation practices recommended for use between the field and creeks**

<b>NRCS Conservation Practice Effectiveness</b>			
<b>BMP Name and Associated Effect of Implementing the Practice on the Listed Resource Problem</b>			
<b>Resource Problem</b>	<b><i>Field Borders - 386</i></b>	<b><i>Filter Strips - 393A</i></b>	<b><i>Riparian Forrest Buffer - 391</i></b>
Sheet & Rill Erosion	Slight to Significant Decrease	Slight to Significant Decrease	N/A
Soil Erosion from Wind	Slight to Moderate Decrease	Slight to Moderate Decrease	Slight to Moderate Decrease
Concentrated Flow Erosion	Significant Decrease	Slight Decrease	N/A
Streambank Erosion	Slight Decrease	Slight to Moderate Decrease	Slight Decrease
Soil Condition: Tilt, Infiltration, Organic Matter	Slight to Significant Decrease	Slight to Significant Decrease	N/A
Water Quantity: Runoff and Flooding	N/A	N/A	Slight Decrease
Groundwater Quality	Insignificant	Slight Increase	Slight Decrease
Surface Water Quality	N/A	Slight Decrease	Significant Decrease
Plant & Cropland Productivity	N/A	Slight Decrease	N/A
Pasture and Hay Productivity	N/A	Slight Decrease	N/A
Domestic Animal Habitat: Food, Water, Shelter	Slight to Moderate Decrease	Moderate to Significant Decrease	N/A
Wildlife Habitat: Food, Water, Shelter	Slight to Moderate Decrease	Moderate to Significant Decrease	Significant Decrease

# In-Stream or Gully BMP Descriptions and Expectations

---

*Implementing a watershed riparian restoration program – streambank stabilization*

*NRCS Practice # 590*

Stream channels, streambanks, and associated riparian areas are dynamic and sensitive ecosystems that respond to changes in land use activity. Streambank and channel disturbance resulting from human and natural disturbance can increase the stream's sediment load or increase the stream's ability to transport sediment. This increase can lead to channel erosion and/or sedimentation, both of which have adverse effects on the biotic system. The primary goals of streambank stabilization measures are to decrease erosion, maintain channel flow capacity, and minimize further degradation of the stream channel, habitat, and water quality. A multitude of BMPs regarding streambank or channel stabilization exist (e.g. preservation of existing vegetation, in-stream rock or log structures, geotextiles, etc.) that are best applied in combination with other BMPs to accomplish the project's overall goal. Streambank stabilization can provide a crucial BMP for addressing both sediment and nutrient issues in the Bosque River watershed.



Figure 7. Stream stabilization using boulders and riparian vegetation along the banks

In its simplest form, streambank stabilization is any measure that can be used to stabilize the streambank or channel. Many BMPs are available for use in stabilizing and/or restoring a degraded stream reach. In some cases, one type of BMP may be the best method for dealing with current and projected future problems; however, many cases will require the use of two or more types of BMPs. For example, the main goal of a restoration or stabilization project may be to re-vegetate the streambank to reduce sediment and improve habitat in

the stream and riparian corridor. Despite re-vegetation being the project's only goal, the nature of the stream and the rate of erosion along the streambank may not allow re-vegetated areas to establish fully before being eroded away. In this case, the best option would be to couple BMPs that reduce runoff or the erosive potential of the stream before attempting to re-vegetate the banks. Even though a BMP integrated across a watershed would provide the most benefits, multiple, smaller scale stabilization practices on individual property can accumulate to provide benefits for the entire watershed.

When considering implementing streambank stabilization as a BMP, any applied treatment should not cause adverse effects to endangered, threatened, or sensitive species. In fact, these treatments should be designed to improve habitat for fish and wildlife communities. Habitat linkages, diversity, daily and seasonal habitat ranges, and native plant communities should all be considered when designing a BMP implementation plan. A diverse mixture of native or compatible species that serve multiple functions should be used instead of nonnative species that could become a nuisance. Additionally, BMPs should be implemented based on the aesthetic objectives of the project. The construction and materials used in these devices should mesh well with adjacent lands and land uses. The BMP should also incorporate any plans for recreational use to insure a safe recreational environment.

An extensive assessment of the degraded streambank should be conducted to determine the cause of erosion and the extent of loss that has occurred. This assessment should be used to determine appropriate BMPs that can alleviate site-specific problems. Stream reaches upstream and downstream of the problem area should also be evaluated to prevent the degradation of current stream conditions during the restoration or stabilization of the designated stream reach. An assessment of impacts that potential BMPs will have on stream health and stability must also be done before the implementation process. Potential changes in the hydrology of the stream and watershed throughout the life of the BMP need to be considered and planned for accordingly. Essentially, all planned actions or management practices must be extensively evaluated to assess their future impacts on the stream, its processes, function, and habitat.

Operational considerations for installed BMPs will be minimal but maintenance must be diligently conducted. Properly maintaining BMPs will help prolong the life of the structures and help keep them functioning properly. All structures should be checked for accelerated weathering and/or displacement and should be repaired immediately. Vegetation maintenance may include reseeding, fertilizing, or weeding to ensure that vigorous growth occurs. Built-up debris should be removed to prevent damage to the installed BMPs. Fences and protective measures need to be properly maintained to keep unwanted livestock or people out of the area. Any other damage caused by people or animals that jeopardizes the integrity of these structures or may cause them to function below their capacity should be addressed immediately.



Figure 8. Stream stabilization using limestone boulders and riparian vegetation along the banks

The cost of implementing streambank stabilization measures varies depending on the material and labor required for construction and implementation of the practice. For minor cases of streambank erosion, simple measures such as protecting current vegetation with fencing or enclosures may produce the desired effects. These methods range in price from about \$0.50 each for individual tree protection (fencing or tubing) to up to \$5 or \$10 per foot for fencing off an area depending on the type of fence used. If the BMP involves re-vegetation, then the price is dependent on which method, i.e. seeding, sprigging, sodding, or clump plantings, are employed.

Purchasing and broadcasting seed is the cheapest method and usually costs about \$1 per 1,000 square feet. Sprigging typically costs about \$75 per 1,000 square feet, sodding costs about \$400 per 1,000 square feet, and clump planting costs about \$5 for each clump (Wilson 2005). Costs for constructing other types of BMPs, such as rock gabions, rock riprap, or root wads with rock, are typically more expensive than vegetative measures. Rock gabions usually cost about \$95 per cubic yard, rock riprap costs about \$40 per cubic yard, and root wads with rock cost about \$15 per linear foot. If possible, debris removed from the channel or streambank should be used, which will help keep the project aesthetically pleasing while potentially reducing the costs of BMP construction and implementation. These costs are all approximations and will vary depending on the location, type of plant material used, and labor costs to conduct these efforts. A more detailed list of erosion control measures and their approximate costs is given by Wilson (2005).

### *Developing constructed wetlands*

### *NRCS Practice #s 656 & 658*

Constructed wetlands are shallow water ecosystems that are designed to simulate natural wetlands and reduce pollution in runoff waters (NRCS 2000b). Constructed wetlands use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating water sources (EPA 2000). In general, these systems should be engineered and constructed in uplands, outside waters of the United States, unless the source water can be used to restore a degraded or former wetland. Constructed wetlands can provide multiple benefits to landowners and the environment including: 1) habitat enhancement, 2) sediment retention, 3) nutrient retention, and 4) aesthetic values. The use of constructed wetlands as a BMP for environmental infrastructure improvement within the Bosque River watershed has considerable potential for addressing multiple issues and can be employed in the agricultural and urban setting.

Numerous laws and regulations must be considered and adhered to when using constructed wetlands as a BMP. One law is that these wetlands must not be designed to discharge into waters of the state unless allowed by permit. Constructed wetlands shall be located outside the limits of a wetland of any classification and, if located within a floodplain, they should be protected from inundation or damage from a 25-year flood event or larger. In addition, the distance to residential and commercial structures should also be considered so problems with odors or aesthetics will not occur (NRCS 2000b).

The design of constructed wetlands is important in the system's functionality. If properly designed, constructed wetlands used to treat lagoon effluent can be designed as a secondary treatment process that makes water safe for reuse in the animal operation. A constructed wetland should be divided into multiple cells that retain water and slowly transmit it to the next cell. These cells should be 10 to 15 times longer than they are wide if used to treat wastewater and should be 4 to 10 times longer than they are wide for runoff treatment. This design allows for increased residence time and maximum exposure to the plants within the cells. The slope of the wetland cells is also crucial in determining the residence time and flow rate of water through the cells. The NRCS (2000b) states that individual wetland cells should be level from side to side and have a slope less than 0.05 ft/ft lengthwise. Inlet structures that keep debris and the majority

of sediment out of the wetland cells should also be installed. Fencing around the perimeter of the constructed wetland is helpful in keeping livestock out of the cells and preventing the destruction of vegetation or inlet/outlet structures.

The amount and type of influent entering a constructed wetland must be considered when designing the wetland as the size and depth of the wetland will depend on the volume and rate of flow entering the structure. Residence time of water in the wetland will be influenced by its size, shape, volume of flow, and flow paths. To obtain maximum water treatment capabilities and limit the amount of sediment accumulation, the depth of constructed wetlands should be kept between 4 and 24 inches. The maintenance of an appropriate depth may result in the construction of a large wetland to accommodate large flow volumes. Raised berms, filter strips, or grassed waterways may be needed on agricultural lands upslope of the structure to reduce sediment loading and a sediment retention basin may be needed in urban areas (NRCS 2000b).

Vegetation is an important component of constructed wetlands because plants influence the movement of water and the pollutant removal capabilities. Plants selected for use in the wetland should be adapted to the climate and tolerant of nutrients, pesticides, and other material in the runoff present at each specific site. Soil types and characteristics also dictate the type of plants that will be feasible to plant as well as the wetlands' ability to hold water and retain pollutants. Native hydrophytic plants should be used if possible while noxious species should not be used at all.



Figure 9. NRCS photo of constructed wetlands used to treat swine farm lagoon effluent

Constructed wetlands can be used in many locations for numerous purposes. Regardless of their designed use and source of water, the wetland should be constructed down stream from the source, but as close to the source as possible. In a situation such as the swine farm to the left, the wetlands can be located relatively close to the source. However, a constructed wetland capturing urban stormwater or runoff from crop or pasture land may be farther from the source.

The effectiveness of constructed treatment wetlands will vary depending on factors such as precipitation, pollutant load, and retention time. A farm-wide waste management plan that includes constructed wetlands will yield the most effective water treatment in most cases. If wetlands are not properly planned, or if too much nutrient load is entering them, their effectiveness will be jeopardized shortly after being established. An analysis of wetlands used to

treat dairy, swine, poultry, and aquaculture waste show average P removal rates of about 42 percent but range from 20 percent to 90 percent depending on the specific site set up (Hawkins 2005).

Operation and maintenance of constructed wetlands is vital to preserving proper treatment functions. Sustaining the desired flow rate and retaining the desired water level in the wetland cells influences the residence time and treatment capability of the system. These components should be monitored as closely as possible to ensure proper wetland functions. Other operations and maintenance tasks should include:

- monitoring wetland performance and effectiveness
- monitoring the inlet and outlet for flow obstructions
- repairing structural damage
- controlling or replacing vegetation
- repairing fencing and pipelines
- controlling unwanted animal (varmints) or insect species (mosquitoes) (NRCS 2000b).

The cost to build a constructed treatment wetland can be an imposing initial capital cost. The bulk of these costs are incurred from labor and machinery and, in some cases, the cost of land that can no longer be used. The need for precise dimensions and slopes of these structures requires added labor and machinery expense. Generally, surface flow wetlands that receive water from an above-ground pipe or waterway cost about \$20,000 per acre. When compared to conventional treatment methods, initial costs are usually higher, but when lifespan and replacement values are considered, they can be up to 30 percent cheaper. In addition, the lack of operational energy requirements has proven to repay the differences in capital investment costs between the wetland system and other conventional methods in a relatively short time (Hawkins 2005). Annual costs to operate and maintain constructed wetlands typically range from \$400 to \$2,000 per year depending on the type of system (Hawkins 2005). Some of these costs can be recuperated through water reuse or leasing the wetland for hunting.



Figure 10. NRCS photo of a constructed wetland in a pasture

**Table. 5: Effects of NRCS conservation practices recommended for use in gullies or streams**

<b>NRCS Conservation Practice Effectiveness</b>		
	<b>BMP Name and Associated Effect of Implementing the Practice on the Listed Resource Problem</b>	
<b>Resource Problem</b>	<b><i>Constructed Wetland - 656</i></b>	<b><i>Streambank &amp; Shoreline Protection - 580</i></b>
Streambank Soil Erosion	N/A	Significant Decrease
Water Quantity: Runoff & Flooding	Slight Decrease	N/A
Water Quantity: Subsurface Water	Slight Decrease	N/A
Groundwater Quality	Slight to Mod. Decrease	N/A
Surface Water Quality	Mod to Significant Decrease	Slight to Significant Decrease
Wildlife Habitat; Food, Cover, Water, Shelter	Moderate Decrease	Slight Decrease



# Universal BMP Descriptions and Expectations

---

## *Installing dams and other barriers in gullies, streams, or ditches*

*NRCS Practice # 410*

The installation of small dams, gully plugs, or other barriers in streams and gullies is a temporary practice that slows the movement of water down slope. The velocity decrease accomplishes three goals: 1) lowers the erosive potential of the channelized flow; 2) allows sediment and substances to settle upstream of the dam, which effectively refills the gully or stream over time; and 3) increases recharge to shallow groundwater tables. This BMP is best for use in watersheds smaller than 10 acres and in ephemeral streams or gullies without constant flow. This practice works well with other BMPs, such as streambank stabilization and seeding.

When implementing this BMP, extra care must be taken to prevent further streambank erosion or to change the overall physics of the stream (Mayben 2006). Bank erosion problems typically occur downstream of dams and gully plugs due to a lack of sediment in the stream (Knight 2002). This erosion problem can be minimized, however, by installing a series of at least three dams or gully plugs to reduce the channel slope and the velocity of the water moving through the gully or channel (Riley 1998). Also, ponds at the lower extent of the watershed could serve as a sediment trap that can hold a majority of sediment and nutrients in the watershed (California Department of Transportation 2003).

Construction of dams or gully plugs can be a simple process that can require a limited amount of materials. Dams would most likely be constructed from soil or concrete while gully plugs use porous materials such as rocks or logs. To install one of these structures properly, a cut



Figure 11. Check dam photo from Ft. Hood re-vegetation project (Courtesy of W. Fox).

must be excavated into both banks and the bed of the stream or gully so that the structure will be firmly anchored (Jones et al. 2007). Materials should never be dumped into the channel as that can increase erosion (EPA 2007a). If rocks are used, the base of the structure must be wide enough to allow the rocks to be stacked without falling off. The center of the structure should be at least 6 inches lower than the edges so that water flows through and not around the structure. Trapezoidal, or flat-topped dams or gully plugs, can be constructed so they are wide enough to allow for automobiles or farm equipment to travel over them, which reduces time

spent traveling around the stream or gully. If logs are used, then several of the logs should be driven into the bed or placed in the stream or gully as a fence post would be planted in the

ground to anchor the structure. Debris such as the limbs from the logs used to build the dam or gully plug could be placed in front of the structure to further break the flow of water moving down the channel and give the sediment deposited some structure to help keep it in place. If a series of dams is used, then proper spacing is essential to prevent further downcutting; the base of the upstream dam should be at the same elevation or lower than the top of the downstream dam (NRCS 1994; Riley 1998).

Permeable reactive barriers (PRB) are another option for reducing sediment and dissolving P in runoff. PRBs are constructed with porous media bags filled with crushed stone allowing water to leach through the material inside the bags. These bags are stacked in channel in pyramid fashion and effectively form a permeable check dam that temporarily traps water moving down stream. Minerals inside the bags have an affinity for attracting nutrients depending upon the bags' contents. Zeolite is used to retain ammonium and a crushed limestone is being tested for its ability to attract P. This technology has been used in groundwater applications and is currently being tested for the treatment of storm flows in the Bosque River watershed; results will be available when testing is finished (Wolfe 2006).

Costs to construct a small dam or gully plug will primarily depend on material, labor, and equipment costs. In most cases, aggregate will have to be purchased and the typical cost for large aggregate 6 to 12 inches in diameter is about \$8 to \$12 per ton, not including trucking costs. Rock cost should not be as expensive in the Bosque River watershed as limestone that could be used for this purpose is readily available. Permeable structures built from logs or straw bales may have lower initial costs but may be more expensive over the long-term due to higher maintenance costs (EPA 2007a). Typical construction costs for these structures in McLennan County as reported by NRCS (2007b) are \$1.2 per cu. yd. for earthmoving and \$160 per cu. yd. for constructing a reinforced concrete structure. Cost to establish PRBs in streams are not known at this point and may be cheaper since soil removal is not necessary; however, more data is needed to determine the cost-effectiveness of this BMP.

Equipment costs will outweigh material costs unless the person wanting to implement the BMP(s) already has that equipment. Use of a backhoe or track hoe is the most feasible piece of equipment that can be used for this task because they can dig the perpendicular trench across the gully and move the necessary materials to construct the dam or gully plug. Backhoe rental rates vary widely depending on the unit's location and size. Average daily rates range between \$200 and \$500 per day and up to \$2,000 per week. Track hoe rental rates are generally higher due to the size of the equipment and freight charges. Typical track hoe rental rates range from \$400 to \$1,250 per day and up to \$5,000 per week depending on implement size (rental rates obtained from online search of rental companies March 2007). These costs do not include fees for an operator, which may make hiring someone to perform the work more feasible. Cost of operation and maintenance, such as removing deposited sediment and replacing materials damaged or removed by runoff from large storm events, should also be considered.

Proper vegetation management has the potential to minimize nonpoint source pollution in many rangeland/pastureland systems. If proper and adequate vegetative cover is maintained, landowners can influence the development of healthy watersheds. Re-vegetation can also be used in degraded or disturbed construction areas to provide a more permanent erosion solution than temporary seeding. Management for healthy bunchgrass-dominated systems can increase infiltration, decrease surface runoff, and reduce soil loss compared to sod grass or bare ground (Knight 2002). This BMP has the additional benefit of providing or improving livestock forage and wildlife habitat (NRCS 2003e). Native vegetation species also require less maintenance as they are better adapted to the climate, soils, and diseases of the region than nonnative species (NRCS 1994).

Native seed may be sowed among the current vegetation or in a cleared area. If the area is cleared, then the ground should be tilled before the seed is broadcasted. Seeding is best performed in early spring but seed can be sowed in the fall if the site already has some vegetative cover (EPA 2007b). Multiple years of seeding may be required before some species can become fully established.

Management, such as grazing, mowing or burning, is necessary to prevent natural succession from a grass-dominated system to one dominated by shrubs and trees (NRCS 1994). If the re-vegetated site is not used for livestock forage, then shrubs and trees can be beneficial in that they: 1) remove nutrients more efficiently than grasses; 2) reduce runoff volume; 3) increase wildlife habitat diversity; and 4) enhance riparian habitat through reducing water temperature and stabilizing banks (NRCS 2003e; NRCS 1994). Other management practices, such as using irrigation, fertilizer, herbicide, and/or pesticide, may also be needed to improve vegetation establishment.



Figure 12. Re-vegetated rangeland photo from the Ft. Hood re-vegetation project (Courtesy of W. Fox).

The cost of implementing range re-vegetation can vary greatly depending on the availability of commercial native seed, the acreage to be re-vegetated, and whether additional management is required to establish the vegetation. NRCS (2007b) reported typical range planting costs for Comanche County to be about \$90 per ac. Commercial seed can cost about \$1.00 per 1,000 ft<sup>2</sup> while clump planting costs \$5.00 per planting (Green and Haney 2005). Re-vegetation efforts in Florida have costs up \$1,000/acre because commercial native seed was not available and had to be acquired by harvesting seed by hand and mechanically from natural stands (Williams and

Grabowski 2006). Regardless of cost, this BMP can provide multiple benefits to landowners within the Bosque River watershed and provide a beneficial tool in the implementation of environmental infrastructure improvement.

**Table 6. Effects of NRCS conservation practices recommended for use as a universal BMP**

<b>NRCS Conservation Practice Effectiveness</b>		
<b>BMP Name and Associated Effect of Implementing the Practice on the Listed Resource Problem</b>		
<b>Resource Problem</b>	<b><i>Early Successional Habitat Development/Management - 647</i></b>	<b><i>Grade Stabilization Structures - 410</i></b>
Sheet & Rill Erosion	Slight Decrease	N/A
Soil Erosion from Wind	Slight to Moderate Decrease	N/A
Concentrated Flow Erosion	Insignificant	Insignificant
Streambank Erosion	N/A	Significant Decrease
Soil Condition: Tilt, Infiltration, Organic Matter	Slight Decrease	N/A
Groundwater Quality	Slight Decrease	Insignificant
Surface Water Quality	Slight Decrease	Insignificant
Plant & Cropland Productivity	N/A	Insignificant
Pasture and Hay Productivity	N/A	Insignificant
Domestic Animal Habitat: Food, Water, Shelter	N/A	Moderate Decrease
Wildlife Habitat: Food, Water, Shelter	Moderate Decrease	Moderate Decrease

# City BMP Descriptions and Expectations

---

## *Developing construction site runoff management for pre/post construction activities*

TCEQ currently regulates construction activities on sites that disturb more than 1 acre of soil. The contractor must complete a stormwater pollution prevention plan, obtain a Texas Pollutant Discharge Elimination System Permit, and file a notice of intent and notice of termination before



Figure 13. NRCS photo of a silt fence around a construction site

beginning the project and after the project is completed. Several waivers are available for low erosion areas, but implementing erosion control practices is still a smart idea. Construction sites should employ stabilization and structural control measures to get the best results. These measures include temporary and permanent seeding, mulching, earthen dikes, silt fences, sediment traps, and sediment basins (Persyn et al. 2005). These practices can be and should be used on all construction sites throughout the basin.

Temporary seeding is the “planting of rapidly growing annual grasses, small grains, or legumes on disturbed areas” (NRCS 1994). These plants provide temporary stability (up to one year) by reducing runoff and erosion while permanent vegetation and other stabilization practices become established. Other benefits to seeding include creation of wildlife habitat, aesthetic improvements, and stormwater pollutant removal (average removal of suspended solids is 90 percent; EPA 1993). Seeded areas should be protected by other temporary erosion and sediment control measures to allow the vegetation time to establish. However, once established, vegetation can extend the life span of other BMPs, such as earthen dikes and sediment traps/basins. This practice should be installed on areas where a final grade has been achieved and the slope is less than 5 percent. Plowing may be necessary to prepare a suitable seedbed in soils compacted by construction activities. Once installed, the vegetation should be inspected to determine if fertilization, irrigation, or reseeded is required. Seeding on these sites typically has an initial cost of about \$400/acre, with maintenance costs averaging about 20 percent of initial costs (EPA 1993).

One construction site BMP that can be used along with seeding, or by itself, is mulching. Mulching is the application of materials, including grass, hay, wood chips, wood fibers, straw, post consumer paper content, yard trimming composts, or gravel (EPA 2007c), to stabilize exposed surfaces or protect recently seeded surfaces (EPA 2007c). This BMP also provides the extra benefits of reducing runoff velocity and increasing infiltration. Mulches can reduce soil loss from erosion by up to 99.8 percent and they can reduce runoff velocity by 78 percent (EPA 2007c). Most mulch can be applied by hand, but special equipment will be needed if a tackifier or method to bind the mulch together is used. Mulch should be evenly applied over the exposed

surface; however, a mulch layer that is too thick can lower soil temperature and delay seed germination. Some organic mulch can absorb soil nutrients and effectively prevent the plant from accessing them. Lighter mulches, like straw and paper, may require anchoring with biodegradable netting or a tacking agent, especially when applied on steep slopes. To maintain effectiveness, mulches may need to be re-applied after a major storm event. Straw mulching, without an anchor, costs about \$1.25/yd<sup>2</sup> (EPA 1990), while a combination of seeding and mulching costs between \$800 to \$3,500/acre (EPA 1993).

Another temporary BMP for sediment control is a silt fence, which consists of a woven synthetic fabric attached to anchoring posts constructed around the perimeter of a disturbed area. These fences minimize runoff velocity and keep sediment from leaving the construction site. Silt fences are most appropriate for use in small drainage areas (less than ¼ acre per 100 ft of silt fence length) where slope length behind the fence is less than 100 ft, gradient is less than 50 percent, and the runoff velocity is no more than 0.5 cfs (NRCS 1994; EPA 2007d). The filter fabric should be 36 in wide, with a minimum unit weight of at least 4.5 oz/yd, have a minimum burst strength of 190 lb/in<sup>2</sup>, ultraviolet stability greater than 70 percent and an apparent opening size of at least U. S. sieve No. 30 (TNRCC 2000). Galvanized woven-wire backing and hot-rolled steel fence posts should be used to support the fabric (TNRCC 2000). The posts should be a minimum of 4 ft long and embedded into the ground at least 1 ft, with a painted or galvanized surface, nominal weight of at least 1.25 lb/ft<sup>2</sup>, and a Brindell hardness above 140 (TNRCC 2000). The fence should be erected down slope of the construction site and entrenched at least 6 inches into the ground to prevent runoff from flowing under the fence. Silt fences should be inspected often to fix any gaps or tears in the fabric and to remove sediment once it accumulates to half the height of the fence. Silt fence installation can cost about \$6.00/linear ft (USEPA 1992) while unit costs are estimated to be between \$2.30 and \$4.50/linear ft (SWRPC 1991).

An earthen dike is a temporary ridge or berm of compacted soil that is constructed around the perimeter of a construction site. Earthen dikes are used to minimize erosion by directing runoff to a sediment trap/basin (discussed below) or a stable outlet. Earthen dikes can be used as a BMP for drainage areas as large as 10 acres, but the dike must be fully stabilized before construction begins. The size of an earthen dike will vary depending on the size of the drainage area, but the minimum size dimensions are a 6 ft wide base, 2 ft wide top, 18 in height, and side slopes no steeper than 2:1. The large size of earthen dikes can be a disadvantage as it results in disturbing more area and can be a barrier to construction equipment. Frequent inspection is needed to detect and repair any deterioration from rainfall or constant vehicle crossing. Seeding can help reduce the frequency of repairs and extend the life span of earthen dikes but will increase the total costs. The cost of constructing an earthen dike varies based on size, whether stabilization methods are required, material availability, site location, and access. Costs for earthwork and stabilization range from \$15 to \$55 per foot while smaller dikes typically cost between \$2.50 and \$6.50 per linear foot (CASQA 2003).

A sediment trap or basin can be a temporary or permanent BMP formed by constructing an earthen embankment or excavating a basin to catch and store sediment-laden runoff as well as reduce the volume of stormwater runoff from the construction site. Sediment traps are better suited for construction areas smaller than 5 acres while sediment basins are more efficient at removing sediment from runoff from areas as large as 100 acres (EPA 1990). Sediment traps and basins have an average total suspended solids removal rate of 60 percent and 70 percent,

respectively. Sediment basins are typically able to remove more sediment, especially finer particles, due their larger surface area to volume ratio (EPA 1993,). The volume of both sediment traps and sediment basins should be a minimum of 1,800 ft<sup>3</sup> per acre of total drainage area. The exact volume and design of a sediment basin should be determined by a professional engineer and will be site specific. Sediment traps and basins should not be used in areas where failure of the earthen embankment would result in damage to nearby property. Sediment traps are better suited for short-term (less than 2 years) sediment control while sediment basins can be built to minimize sediment transport from the development even after construction is completed. To maintain sediment removal efficiency, sediment traps and basins should be inspected periodically to check for damage from erosion and to remove accumulated sediment. The average cost of installing a sediment trap or sediment basin with an area less than 50,000 ft<sup>3</sup> is about \$0.60 per cubic foot of storage (EPA 1993). Sediment basins larger than 50,000 ft<sup>3</sup> have an average cost of approximately \$0.30 per cubic foot of storage (EPA 1993). Maintenance costs will vary depending on the frequency and volume of required sediment removal.

Construction sequencing, which is coordinating the installation of the structural controls described above with the time land disturbance occurs, is a nonstructural practice that can provide a cost effective way of minimizing sediment loss and erosion (NRCS 1994). Only part of a construction site is disturbed and then stabilized before another section is disturbed. Before construction begins, a list should be generated of what BMPs need to be employed to prevent or minimize problems for each phase of construction. For example, silt fences and sediment traps should be installed at the beginning of a construction project to reduce sediment loss from the exposed site, while mulching and seeding would occur after construction is complete to stabilize the site. The NRCS and EPA websites both provide detailed outlines of what BMPs are appropriate for different phases of construction (NRCS 1994; EPA 2007e).

***Treating storm runoff by temporary storm storage  
in retention ponds***

***NRCS Practice #s 350 & 638***

Retention ponds are designed to capture the bulk of rapid storm runoff. Water is held in these ponds until the structure reaches capacity and water begins to leave through the emergency spillway, evaporates, or infiltrates into the ground (Persyn et al. 2005). Retention ponds, also known as wet ponds, typically maintain a significant permanent pool of water between runoff events (EPA 1999). These ponds allow almost all of the sediment and many of the nutrients carried in the water to settle into the basin. Aquatic plants and microorganisms can further increase nutrient and pollutant removal by consuming those constituents and by reducing the amount of sediment that is re-suspended by inflows. The permanent pool of water enables the



Figure 14. Wet pond photo from the City of Austin website

ponds to support lake or wetland-like ecosystems that act as natural filters. Retention ponds can be used effectively in many areas and, if properly managed and cared for, can be aesthetically valuable and provide good habitat for plants and animals (EPA 1999).

In some cases, retention ponds have been incorporated into new developments to add a semi-natural ecosystem to the area, which increases the property’s economic and aesthetic value. For example, the City of Austin has constructed a series of three connected ponds on 10 acres of a 39-acre development that includes an apartment complex and the Central Market. The pond itself can retain approximately 300,000 ft<sup>3</sup> of stormwater, most of which drains from a 164-acre watershed; however, the flood detention basin also on this site will contain and slowly release a much larger volume of water. The ponds, along with the hiking trails and picnic areas on the site, have been well received by the public. Besides being a public amenity, the Austin wet pond also provides a cost effective means for the city to treat stormwater before it enters into Town Lake; total costs incurred by the city for design and construction were \$584,000 in 1998 (City of Austin 2001). These costs have been supported by the efficiency of the wet ponds to remove nutrients and other pollutants entering the system (Table 5).

**Table 7. City of Austin wet pond pollutant removal results**

<b>Typical Pollutants</b>	<b>Average percent Pollutant Removal</b>
Total Suspended Solids	79 %
Total Petroleum Hydrocarbons	57 %
Total Phosphorus	44 %
Lead	97 %
Zinc	65 %
Copper	70 %

Several installation and maintenance issues must be carried out for retention ponds to be effective. First, the development must have an area large enough to accommodate the pond. The permanent pool size requires calculation of the volume of stormwater inflows and outflows by a trained hydrologist. When determining size, consideration also needs to be given to how much valuable wildlife habitat might be inundated by the pond. Liability can also be an issue if a deep permanent pool is located near an area where children play. The shape of the pond is another important consideration; long, narrow ponds or wedge-shaped ponds can promote efficient movement of stormwater flows (NRCS 1994). Shallow areas (less than 6 feet deep) can support a healthy wetland-type ecosystem where a majority of pollutants can be stored in sediment or plant biomass. Plants in these areas may need to be mowed or harvested to maintain the pond’s ability to hold stormwater and remove pollutants. Removal of plants and debris can also improve the location’s aesthetics by preventing the development of nuisance odors. Other maintenance includes removing deposited sediment as well as inspecting and repairing the inlets, outlets, and the pond bottom. Annual maintenance costs vary but are estimated at 3-5 percent of the construction costs (NRCS 1994). For the city of Austin, these costs would be between \$17,000 and \$30,000 but a smaller 1-ac pond constructed for \$13,662 would have maintenance cost of about \$500 (Stormwater Center 2005).



### *Developing plans for recreation areas to include storm water planning for surrounding residential areas*

Stormwater ponds, such as retention and detention ponds, provide a measure to manage stormwater quantity and quality to a level similar to pre-development levels. Retention ponds typically have a permanent pool of water best suited as a focal point in a park where a pond or wetland type ecosystem is desirable (as the Central Market wet ponds described above). Detention ponds basically slow water movement downstream and have the ability to capture a large volume of water and then regulate its release (Persyn et al. 2005). Retention ponds typically remove pollutants more efficiently than detention ponds, which are better for minimizing runoff peak flows and protecting downstream channels. However, pollutant removal efficiency can be increased for detention ponds if they can be designed to hold stormwater for more than 24 hours; these types of detention ponds are referred to as dry extended detention ponds (Schueler et al. 1992). Dry extended detention ponds have been found to remove 45 percent of sediment and 35 percent of phosphorus (IDEQ 2005).

Detention ponds could be incorporated into athletic parks that cover a large surface area. Playing fields (baseball, football, and soccer) or playgrounds could be constructed at a low point in the complex and serve as the detention pond with an outlet that regulates flow. Since these ponds are only temporarily wet, these ponds would be a great dual purpose BMP that could also provide an economic benefit by increasing nearby property values. This BMP is best for sites larger than 10 acres with a reasonably flat slope (EPA 2007f). The detention pond design should be created by a professional engineer to include not only recreational needs of the community but also to address the issues of pretreatment, treatment, conveyance, maintenance reduction, and landscaping (EPA 2007f). Once constructed, detention ponds should be inspected regularly to check for embankment erosion, damaged ground cover, or sediment accumulation. These problems can be addressed along with other regular maintenance issues, such as mowing side slopes, removing litter and debris, and cleaning inlets and outlets (EPA 2007f). Proper maintenance of detention ponds is essential to prevent structural failures that could result in damage to surrounding property as well as threaten the lives of residents (IDEQ 2005). The cost to construct a dry detention pond, without including the cost of recreational facilities, can range from approximately \$40,000 for a 1 acre-foot pond to nearly \$1.5 million for a 100 acre-foot pond with annual maintenance costs about 3-5 percent of the total construction cost (EPA 2007f). In general, the costs will be determined by the amount of soil that must be moved to construct the structure. NRCS (2007b) reports earthmoving costs to range between \$1.2 and \$2 per cu. yd. in the Bosque River watershed.



Figure 15. Photo of Edelweiss Park detention area in College Station, TX

Proper maintenance of detention ponds is essential to prevent structural failures that could result in damage to surrounding property as well as threaten the lives of residents (IDEQ 2005). The cost to construct a dry detention pond, without including the cost of recreational facilities, can range from approximately \$40,000 for a 1 acre-foot pond to nearly \$1.5 million for a 100 acre-foot pond with annual maintenance costs about 3-5 percent of the total construction cost (EPA 2007f). In general, the costs will be determined by the amount of soil that must be moved to construct the structure. NRCS (2007b) reports earthmoving costs to range between \$1.2 and \$2 per cu. yd. in the Bosque River watershed.

**Table 8. Effects of NRCS conservation practices recommended for use as BMPs in the city**  
**NRCS Conservation Practice Effectiveness**

<b>BMP Name and Associated Effect of Implementing the Practice on the Listed Resource Problem</b>		
<b>Resource Problem</b>	<b><i>Sediment Basins - 350</i></b>	<b><i>Water &amp; Sediment Control Basins - 638</i></b>
Sheet & Rill Erosion	Insignificant	Insignificant
Soil Erosion from Wind	Insignificant	Insignificant
Concentrated Flow Erosion	Slight to Significant Decrease	Significant Decrease
Streambank Erosion	Slight to Significant Decrease	Insignificant
Soil Condition: Tilt, Infiltration, Organic Matter	Moderate Increase	Slight to Significant Decrease
Water Quantity: Runoff & Flooding	Moderate Decrease	Moderate Decrease
Water Quantity: Subsurface Water	Slight Increase	Slight Increase
Groundwater Quality	Slight Increase	Slight to Moderate Increase
Surface Water Quality	Slight Decrease	Slight to Significant Decrease
Plant & Cropland Productivity	Slight Decrease	Insignificant
Pasture and Hay Productivity	Slight Decrease	Insignificant
Domestic Animal Habitat: Food, Water, Shelter	Slight to Moderate Decrease	Slight to Moderate Decrease
Wildlife Habitat: Food, Water, Shelter	Slight to Moderate Decrease	Slight to Moderate Decrease

# Education and Funding Opportunities

---

## *Educating landowners*

Education is the key to successfully employing any BMP. Until landowners completely understand the benefits of installing a BMP, they will be less likely to implement and properly maintain these structures or practices. Education can be accomplished through outreach efforts, such as simply distributing copies of this document; generating fact sheets summarizing priority BMPs and funding opportunities; conducting informational meetings or workshops; and/or implementing BMP demonstration projects in the watershed. For additional technical assistance, landowners can contact their local County Extension office (<http://texasextension.tamu.edu/>), the TSSWCB (<http://www.tsswcb.state.tx.us/contact>), or a local NRCS office (<http://offices.sc.egov.usda.gov/locator/app>).

Conducting BMPs workshops or field days will be an important step in the education process before the implementation process begins. These workshops or field days can effectively educate producers about various BMPs that may be feasible on their land. Field days will be held on the site of one or more implemented BMPs so interested producers can see the practice in place and develop a better idea of how to incorporate them into their property. An expert on the installation, operation, and maintenance of the specific BMPs will speak about the practice and answer any questions that field day participants may have. Workshops are a secondary means of educating landowners about BMPs and are typically less effective because the BMP can only be seen in pictures.

## *Financial assistance*

Several federal and state sources have funding, depending on which BMP is implemented. Most funding will be available through the U.S. Department of Agriculture Natural Resource Conservation Service (NRCS) Environmental Quality Incentive Program (EQIP). This program provides incentive payments and cost-sharing for specific conservation practices for up to ten years (NRCS 2007a). Existing dairy operations in the Bosque River watershed are currently a high funding priority with a 50-90 percent cost-share on several practices as well as incentives for nutrient management and manure transfer (NRCS 2007a). Eligibility information and forms to apply for the EQIP program are available on the Texas NRCS website ([www.tx.nrcs.usda.gov/programs/EQIP/apply.html](http://www.tx.nrcs.usda.gov/programs/EQIP/apply.html)).

Another NRCS funding opportunity for landowners restoring, enhancing, or protecting wetlands is the Wetlands Reserve Program (WRP). Landowners can enroll eligible property as a permanent easement, 30-year easement, or a restoration cost-share agreement (EPA 2005). With a permanent easement, USDA pays for the easement, up to 100 percent of the restoration cost, and the cost of recording the easement at the local land records office (NRCS 2007a). The 30-year easement is similar except USDA only pays for 75 percent of the permanent easement for the land and up to 75 percent of the restoration cost (NRCS 2007a). The restoration cost-share

agreement does not place an easement on the property, but the USDA will pay up to 75 percent of restoration cost for a minimum of 10 years. Land in a WRP easement can still be leased for hunting and fishing as long as no restrictions are violated. Additional land uses, such as cutting hay and grazing livestock, may also be allowed if it is approved as a compatible use for the wetland (NRCS 2007a).

Landowners who implement BMPs that develop and maintain fish and wildlife habitat can also be eligible for the NRCS Wildlife Habitat Incentives Program (WHIP). This program provides a 50 percent cost-share for at least 3 years for practices such as range planting and riparian zone improvements (Texas NRCS 2007). Those interested in applying for this program should contact the local NRCS office for more information.

The U. S. Environmental Protection Agency has two funding programs available for managing nonpoint source pollution. The Clean Water Act Section 319 grant provides funding to states who then distribute the money among organizations and individuals (EPA 2005). The Texas Commission on Environmental Quality (TCEQ; [www.tceq.state.tx.us](http://www.tceq.state.tx.us)) and the Texas State Soil and Water Conservation Board (TSSWCB; [www.tsswcb.state.tx.us](http://www.tsswcb.state.tx.us)) administer the 319 program's grant funds in Texas to nonagricultural and agricultural entities, respectively. The second EPA funding source is the Clean Water State Revolving Fund (CWSRF). This program funds low interest loans for nonpoint source pollution control and watershed management through the Texas Water Development Board (TWDB; [www.twdb.state.tx.us](http://www.twdb.state.tx.us)). These loans can be more beneficial than a grant as there are fewer federal requirements and do not require a nonfederal match (EPA 2005); however, these loans must be paid back.

## Conclusions and Recommendations

---

Phase II of this project adds another chapter to the environmental infrastructure improvement plan for the Bosque River watershed. This document expands on the BMPs recommended in Phase I by providing the physical description, suitable locations, applicability, and general cost of each BMP. This information was compiled from various publications on BMPs by multiple agencies to provide a basic implementation guide to landowners and agency personnel assisting landowners in the Bosque River watershed. The financial and technical assistance section of this document provides additional resources for landowners that will help them successfully implement one or more BMPs on their property. Successful implementation of BMPs will reduce the impact of human activities and lead to overall environmental improvements of the Bosque River watershed.

Because of this work, it is recommended that further economic modeling assessment of each BMP be conducted. This economic analysis is an integral component of the management approach that will allow the public to make informed decisions about the costs and expected benefits of implementing each BMP. This research, coupled with findings from previous research, will enable the development of mitigation and management strategies aimed at preventing water quality contamination from nonpoint sources of pollution, thereby improving water quality within the watershed.

The fundamental approach to this economic analysis is to evaluate extensively each BMP and suites of recommended BMPs. The analysis will be focused on determining which practices or sets of practices will yield the best pollution control results at the best cost to the people or agency implementing the practice. The suites of BMPs evaluated will be based on outputs from the SWAT model's BMP evaluation. Only sets of BMPs that yield the highest nonpoint source pollutant removal will be evaluated for their economic feasibility.

Once all suites of applicable BMPs have been economically analyzed, a final chapter to the environmental infrastructure improvement plan will be added. This chapter will highlight which BMPs/sets of BMPs can have the greatest impact on nutrient removal and remain economically feasible for the landowner. Additionally, specific locations for implementing recommended BMPs will be identified. This will serve as a final step in the planning process before implementing BMPs can begin.

### *List of primary deliverables*

- A complete economic analysis of each suite of BMPs recommended in the SWAT model's BMP implementation recommendation
- A final chapter in the environmental infrastructure improvement plan for the North, Middle, and South Bosque Watersheds that highlights the economic feasibility of each suite of BMPs recommended for implementation and specific locations where these BMPs should be implemented

## References

---

- Beck, P., N. Harris, and R. Sweeny. 2001. Design, installation, and performance assessment of zero-valent iron permeable reactive barrier in Monkstown, Northern Ireland. Contaminated Land: Applications in Real Environments, Demonstration Project.
- City of Austin. 2001. Central Park Wet Ponds. Watershed Protection Development Review Website. Accessed May 21, 2007. Available online at: <http://www.ci.austin.tx.us/watershed/centralpark.htm#economic>.
- California Department of Transportation. 2003. Construction Site Best Management Practices Manual. Accessed July 5, 2006. Available online at: [www.dot.ca.gov/hq/construc/stormwater/SC-04.pdf](http://www.dot.ca.gov/hq/construc/stormwater/SC-04.pdf).
- Carman, D. 2005. Terraces. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- CASQA. 2003. Earth Dikes and Drainage Swales fact sheet. California construction BMP handbook. Available from <http://www.cabmphandbooks.org/Construction.asp>.
- Cooke, G.D., E.B. Welch, S. Peterson, and S.A. Nichols. 2005. *Restoration and Management of Lakes and Reservoirs, 3<sup>rd</sup> Ed.* CRC Press. Boca Raton, FL. 2005.
- CSWCD. 2006. 2005-2006 Annual Report: Culpeper Soil and Water Conservation District. Available and accessed online at: <http://culpeper.vaswcd.org/annual05-06.pdf>.
- Dao, T.H., L.J. Sikora, A. Hamasaki, and R.L. Chaney. 2001. Manure phosphorus extractability as affected by aluminum- and iron byproducts and aerobic composting. *Journal of Environmental Quality*. 30:1693-1698.
- Dao, T.H. and T.C. Daniel. 2002. Particulate and Dissolved Phosphorus Chemical Separation and Phosphorus Release from Treated Dairy Manure. *Journal of Environmental Quality*31:1388-1398.
- EPA. 1990. Sediment and erosion control: an inventory of current practices. EPA Contract No. 68-C8-0052, Work Assignment 1-19, Task 2. Available online at: <http://www.epa.gov/npdes/pubs/owm0192.pdf>.
- EPA. 1992. Stormwater management for construction activities: developing pollution prevention plans and best management practices. EPA 832-R-92-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- EPA. 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. EPA 840-B-92-002. U. S. Environmental Protection Agency, Office of Water, Washington, DC.

- EPA. 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012. August 1999.
- EPA. 2000. Guiding principles for constructed wetlands: Providing for water quality and wildlife habitat. WPA 843-B-00-003.
- EPA. 2001. Cost Methodology Report for Swine and Poultry Sectors. EPA-821-R-01-018. January 2001.
- EPA. 2003. National Management Measures to Control Nonpoint Source Pollution from Agriculture. Accessed July 5, 2006. [www.epa.gov/nps/agmm/index.html](http://www.epa.gov/nps/agmm/index.html).
- EPA. 2005. Financial assistance summaries for AFOs. U.S. Environmental Protection Agency, Office of Water, Washington, DC. Available online at: [http://www.epa.gov/ndpes/pubs/financial\\_assistance\\_summaries.pdf](http://www.epa.gov/ndpes/pubs/financial_assistance_summaries.pdf).
- EPA. 2007a. Check dams. National Pollutant Discharge Elimination System. Available online at: [http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet\\_results&view=specific&bmp=36](http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=36).
- EPA. 2007b. Seeding. National Pollutant Discharge Elimination System. Available online at: [http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet\\_results&view=specific&bmp=42](http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=42).
- EPA. 2007c. Mulching. National Pollutant Discharge Elimination System. Available online at: [http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet\\_results&view=specific&bmp=41](http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=41).
- EPA. 2007d. Silt fence. National Pollutant Discharge Elimination System. Available online at: [http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet\\_results&view=specific&bmp=56](http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=56).
- EPA. 2007e. Construction sequencing. National Pollutant Discharge Elimination System. Available online at: [http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet\\_results&view=specific&bmp=51](http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=51).
- EPA. 2007f. Dry detention ponds. National Pollutant Discharge Elimination System. Available online at: [http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet\\_results&view=specific&bmp=67](http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=67).
- Galarneau, E. and Gehr, R. 1997. Phosphorus removal from waste waters: Experimental and theoretical support for alternative mechanisms. *Water Resources Research* 31:328–338.

- Gilley, J.E. and Eghball, B. 2005. Erosion Control Systems. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- Green, C.H. and Haney, R. 2005. Filter Strips. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- Hawkins, J. 2005. Constructed Treatment Wetlands. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- IDEQ. 2005. Dry extended detention pond. IDEQ Storm Water Best Management Practices Catalog. Available online at: [http://www.deq.idaho.gov/water/data\\_reports/storm\\_water/catalog/sec\\_4/bmps/14/pdf](http://www.deq.idaho.gov/water/data_reports/storm_water/catalog/sec_4/bmps/14/pdf).
- ITRC. 2005. Permeable reactive barriers: lessons learned/new directions. Available online at: <http://www.itrcweb.org/Documents/PRB-4.pdf>.
- Jones, C.A., W.E. Fox, and D.W. Hoffman. 2007. Combating soil erosion on military lands: Best management practices development and verification. USDA-Natural Resources Conservation Service, Draft Report.
- Knight, R. W. 2002. Management applications of water quality information on rangelands. In: Drawe, D. L. (Ed), Rangeland Hydrology and Water Quality in the Texas Coastal Bend. NOAA NA07OZ0134.
- Mayben, K. 2006. NRCS Engineer. Weatherford, TX. Personal communication.
- McDonald, B. 2005. The fate of manure phosphorus during production and harvest of turfgrass sod. M.S. Thesis, Texas A&M University. Available online at: <http://handle.tamu.edu/1969.1/2285>.
- Moore. P.A. 2005. Treating Poultry Litter with Aluminum Sulfate (Alum). Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- Munster, C.L., J.E. Hanzlik, D.M. Vietor, R.H. White, and A. McFarland. In press. Assessment of manure phosphorus export through turfgrass sod production in Erath County, Texas. *Journal of Environmental Management*.
- NRCS. 1994. Planning and design manual for the control of erosion, sediment, and stormwater. Available online at: <http://www.abe.msstate.edu/csd/p-dm/>.
- NRCS. 2000a. Comprehensive Nutrient Management Plans fact sheet. Available online at: [www.nrcs.usda.gov/Technical/afo/pdf/CNMPFactSheet.pdf](http://www.nrcs.usda.gov/Technical/afo/pdf/CNMPFactSheet.pdf).
- NRCS. 2002. Terrace. National Handbook of Conservation Practices. Available online at: <ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/600.pdf>.
- NRCS. 2003a. Prescribed Grazing. National Handbook of Conservation Practices. Available online at: <ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/528.pdf>.



- NRCS. 2003b. Grazing Land Mechanical Treatment. National Handbook of Conservation Practices. Available online at: <ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/548.pdf>.
- NRCS. 2003c. Comprehensive Nutrient Management Planning Technical Guidance. Available online at: <http://policy.nrcs.usda.gov/viewRollUp.aspx?id=3073>.
- NRCS. 2003d. Filter Strip. National Handbook of Conservation Practices. Available online at: <ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/393.pdf>.
- NRCS. 2006. Nutrient Management. National Handbook of Conservation Practices. Available online at: <ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/590.pdf>.
- NRCS. 2007a. Farm Bill 2002: Wetlands Reserve Program fact sheet. Natural Resources Conservation Service. Available online at: <http://www.nrcs.usda.gov/PROGRAMS/wrp/2007WRPFactSheet.pdf>.
- NRCS. 2007b. NRCS Program Costs Information. Available online at: <http://ssiapps.sc.egov.usda.gov/nationalcosts/>
- Persyn, R. A., M. Griffin, and A. T. Williams. 2005. Stormwater Management. Technical Report B-6158. Texas Cooperative Extension – Texas A&M University System.
- Riley, A. L. 1998. Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens. Island Press. Washington, D.C.
- Schueler, T. R., P. A. Kumble, and M. A. Heraty. 1992. A current assessment of urban best management practices – techniques for reducing non-point source pollution in the coastal zone. Metropolitan Washington Council of Governments, Department of Environmental Programs, Anacostia Restoration Team, Washington, DC.
- Sharpley, A., J. Weld, and P. Kleinman. 2005. Soil Testing. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- Sheffield, R. 2006. Selecting the Appropriate Land Application Method. Livestock and Poultry Environmental Stewardship Curriculum. Available online at: [http://www.lpes.org/Lessons/Lesson36/36\\_Application\\_Equipment.html](http://www.lpes.org/Lessons/Lesson36/36_Application_Equipment.html).
- Smith, D.R., P.A. Moore, Jr., C.L. Griffis, T.C. Daniel, D.R. Edwards, and D.L. Boothe. 2001. Effects of Alum and Aluminum Chloride on Phosphorus Runoff from Swine Manure. *Journal of Environmental Quality*. 30:992-998.
- Smith, D. 2005. Treating swine manure with aluminum chloride. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).

- Stormwater Center. 2005. Retention pond. University of New Hampshire. Available online at: [http://ciceet.unh.edu/news/releases/stormwater\\_report\\_05/images/treatments/retention\\_pond/retention\\_pond.pdf](http://ciceet.unh.edu/news/releases/stormwater_report_05/images/treatments/retention_pond/retention_pond.pdf).
- SWRPC. 1991. Costs of urban nonpoint source water pollution control measures. Technical report 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.
- Texas NRCS. 2007. Wildlife habitat incentives program. Texas Natural Resources Conservation Service. Available online at: <http://www.tx.nrcs.usda.gov/programs/whip/index.html>
- TIAER. 2006. Sampling history report. Final project report for monitoring to support North Bosque River model refinement. Technical Report 0613.
- TNRCC. 2000. Description of BMPs – Erosion Control BMPs. Texas Natural Resource Conservation Commission. Available online at: [www.tceq.state.tx.us/assets/public/assistance/compost/401best.pdf](http://www.tceq.state.tx.us/assets/public/assistance/compost/401best.pdf).
- Toor, G. S. and J. T. Sims. 2005. Grazing Management. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- USDA-NASS. 2004. Texas Custom Rates Statistics. Available online at: <http://smith-tx.tamu.edu/publications/custom04.pdf>.
- Viotor, D.M., E.N. Griffith, R.H. White, T.L. Provin, J.P. Muir, and J.C. Read. 2002a. Export of manure P and N through turfgrass sod. *Journal of Environmental Quality* 31:1731-1738.
- Viotor, D.M, R.H. White, C.L. Munster, and T.L. Provin. 2002b. Reduced nonpoint source pollution through manure use and export in turfgrass sod. In: Saleh, A. (Ed.), Proceedings of total Maximum Daily Load (TMDL) Environmental Regulations Conference, Ft Worth, TX, 11-13 March, pp. 396-402.
- Williams, M. J., and J. Grabowski. 2006. Brooksville plant materials center: developing sources of native grass seed for revegetation in Florida. Natural Resources Conservation Service. Available online at: <http://www.plant-materials.nrcs.usda.gov/pubs/flpmssy6920.pdf>.
- Wilson, B. 2005. Streambank and Shoreline Protection. Available online at: [www.sera17.ext.vt.edu/](http://www.sera17.ext.vt.edu/).
- Wolfe, J. 2006. Assistant Research Scientist. Blackland Research and Extension Center, Temple, TX. Personal Communication.
- Zvomuya, F., C.J. Rosen and S.C. Gupta. 2006. Phosphorus sequestration by chemical amendments to reduce leaching from wastewater application. *Journal of Environmental Quality*. 35:207-215.