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North Central Texas Water Quality
Final Report

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Final Report

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List of Acronyms

BMPs: best management practices
DO: dissolved oxygen
SSL: Spatial Sciences Laboratory
SWAT: Soil and Water Assessment Tool
TCEQ: Texas Commission on Environmental Quality
TRWD: Tarrant Regional Water District
TWRI: Texas Water Resources Institute
USDA–NRCS: United States Department of Agriculture – Natural Resources Conservation Service

Background and Introduction

Tarrant Regional Water District (TRWD) is one of the largest raw water suppliers in Texas, serving about 1.6 million people in ten counties including Fort Worth and the surrounding area. With growing urbanization, the District is expected to serve a projected population of 2.66 million in 2050. TRWD has contracts with 65 cities and is responsible for management of water resources in five major reservoirs in the Trinity basin with a combined storage of 2,384,314 acre feet (ac-ft). These resevoirs are: Bridgeport, Eagle Mountain, Benbrook, Cedar Creek and Richland-Chambers. They have conservation capabilities of 386,420, 190,460, 88,200, 679,200, and 1,135,000 ac-ft respectively.

Average annual precipitation ranges from 28 inches in the northwestern part of the basin to 39 inches in the southeastern portion of the basin. Agricultural land uses dominate the reservoir's watersheds. Soils range from course-textured loamy sands in Cross Timbers area to fine-textured montmorillonitic clays in the Blackland Prairie

TRWD has been concerned about the recent water quality issues caused by point and nonpoint source pollution sources in the watershed. The District has already initiated efforts to address the water quality issues, developing a water quality monitoring program to collect data for these reservoirs and their associated watersheds. The District has collected water quality data for nearly 40 parameters since 1989.

Effluent discharges from the wastewater treatment plans and nonpoint source pollution from urban and agricultural runoff are reported as the major causes for water quality impairment in the district. Excess nutrient loading to the reservoirs has led to eutrophication, depletion of dissolved oxygen (DO), excess algal growth, and fish tissue contamination. More than 10 river segments in the watershed, including some in reservoirs, are classified under 2000 CWA 303 (d) list for water quality impairment by point and nonpoint sources by the Texas Commission on Environmental Quality (TCEQ). Examples are: detection of atrazine contamination of water in Richland-Chambers reservoir; depleted DO in and around Bridgeport reservoir, Chambers Creek, and Clear Fork; bacterial counts exceeding standards in Cedar Bayou and Lake Livingston; and chlordane in fish tissue in several river segments. Hence, the District's top priority has been focused on protecting water quality.

The District had made efforts to understand the mechanisms that allow pollutant loads to reach the reservoirs and what hydro-dynamics are taking place within the reservoirs. The District is working with Texas AgriLife Research, through the Spatial Sciences Laboratory (SSL) and Texas Water Resources Institute (TWRI), to develop and use simulation models to identify potential contaminant sources, estimate the potential costs and benefits of best management practices (BMPs) to reduce contaminant loading, and develop plans to improve water quality.

Work conducted through this project was built upon previously conducted work by the project partners in the watersheds of TRWD reservoirs. Exhaustive modeling has been completed in the Cedar Creek watershed and is now under way in the Eagle Mountain and Richland-Chambers watersheds. Previous modeling has resulted in a model that accurately represents conditions in the watershed and is highly capable of predicting the impacts of implementing designed BMPs in the watershed. Coupled with outputs from the modeling effort, an economic analysis has been conducted to evaluate the costs and benefits of implementing various BMPs throughout the Cedar Creek watershed. Educational activities have also focused on engaging local stakeholders and providing materials that are based on modeled outputs about pollutant concerns, impacts of these pollutants, and types of BMPs that address these pollutants in reservoir watersheds. The development of a watershed protection plan for the Cedar Creek watershed has been under development and is a culmination of the modeling, economic analysis, and stakeholder education components of the project. This plan has resulted in a detailed management plan that is tailored specifically to the Cedar Creek watershed and focuses on addressing issues of concern through a voluntary, stakeholder-driven approach.

This project, overall, had four principle components:

- Simulation of the impacts of BMPs on nutrient loading for the watersheds of five major reservoirs in the study area,
- Economic analysis of the cost of implementing the simulated BMPs,
- Educational programs for stakeholders in the watershed, and
- Development of watershed protection plans for the five reservoirs.

First, simulation of current practices and the impacts of BMPs have been conducted by a team lead by Dr. R. Srinivasan, Director of the Texas A&M SSL within the Department of Ecosystems Sciences and Management at Texas A&M University. The team has used SWAT, a physically-based watershed/landscape simulation model developed by the USDA-ARS. Major components of the model include hydrology, weather, erosion, soil temperature, crop growth, nutrients, pesticides, and agricultural management. Additionally, it has the ability to predict changes in sediment, nutrients such as organic and inorganic nitrogen and organic and soluble phosphorus, pesticides, dissolved oxygen, bacteria and algae loadings from different management conditions in large, un-gauged basins. SWAT operates on a daily time step and can be used for long-term simulations. At present, the model output is available in daily, monthly, and annual time scale, although efforts are being made to account for sub-daily time steps. SWAT coding sand subroutines are modular, allowing for addition of new subroutines when necessary.

Model parameters related to (sub) watershed/landscape processes will be adjusted to match the measured and simulated flow, sediment and nutrients key locations in each watershed. All model parameters have been adjusted within literature recommended ranges. After doing so, the model was then validated without adjusting any parameters and a calibration period was chosen. Time series plots and statistical measures such as mean, standard deviation, phosphorus, dissolved coefficient of determination, and Nash-Suttcliffe simulation efficiency were used to evaluate the performance of the models used during calibration and validation.

Another component of this project, led by Dr. Jason Johnson, Associate Professor and Extension Economist for the Texas AgriLife Extension Service, was to conduct a financial and budget analysis to estimate costs and returns by enterprise for alternative best management practices simulated with SWAT. These included a financial analyses, on-site wastewater treatment systems, and urban and agricultural land conservation structures and practices, such as filter strips, gully plugging, terracing, conservation tillage, and fertilizer management. Economic and nutrient loading data have been analyzed to provide TRWD and stakeholder groups with options to reduce nutrient loadings in the study area watersheds .

A team of Texas AgriLife Extension Service educators, led by Justin Mechell, conducted public meetings and targeted educational programs in each of the major reservoirs' watersheds in the project area. They have worked with stakeholders and media to provide appropriate information to the public concerning the past, current, and possible future status of water quality in the watersheds of the major reservoirs used by TRWD. The team closely coordinated its activities with TRWD, the modeling and economics teams, and County Extension Agents throughout the region. County Extension Agents have provided contact with stakeholders, opinion leaders, and the general public for counties in the five major reservoirs' watersheds.

TWRI has been responsible for overall administration of the program, including annual proposal development, report preparation, and administrative and fiscal coordination with Texas AgriLife Research and Extension and USDA-NRCS.

A team led by Mr. Clint Wolfe of the Texas AgriLife Research and Extension Urban Solutions Center has assisted the economic and Extension education teams, as well as worked with stakeholders to develop watershed protection plans for TRWD reservoirs.

Goals and Objectives

The overall goal of the Tarrant Regional Water District is to accommodate varied needs, such as growing population and urbanization, without sacrificing water quality. Watershed management is the first and often most cost-effective step to ensure a safe and reliable public supply. Watershed management is a holistic approach defined by hydrologic boundaries and integrates water quality impacts from both point sources and nonpoint sources. Key objectives of watershed protection plans include identifying potential contaminant sources, evaluating the costs and benefits of implementing management and/or constructing facilities to reduce loadings, producing useful watershed planning tools, and developing plans that can be implemented by TRWD and its cooperators. Lands within the District are owned and managed by many private and public land entities; therefore, an integral component of the watershed approach is involving stakeholder in the watershed.

Key objectives of this project included: assisting the District by assembling information on water quality and pollution loads for its reservoirs and their watersheds, analyzing the biophysical and economic feasibility of alternative management practices and structures, identifying key stakeholders in those watersheds and among the clients of the District, holding public meetings to educate stakeholders and clients in the watershed about their water quality and its protection, and providing public educational programs to help achieve the Districts water quality goals.

Task 1 – SWAT Modeling

Through this task, a team of water quality modelers at the Texas A&M SSL has worked with TRWD and the economics team to develop and assess site-specific conservation practices and locations within the Eagle Mountain and Cedar Creek watersheds. The SWAT model has been utilized to characterize and evaluate the loading potential of sediment and nutrients from small acreage lands by modeling NRCS land management practices and other BMPs that control erosion and prevent nonpoint sources of pollution in the Eagle Mountain Watershed. Appendix A provides a detailed listing of activities conducted in this task. The SWAT modeling report is attached in Appendix B.

Task 2 – Economic Analysis

The economics team utilized the economic model previously developed to finalize cost estimates to implement watershed BMPs in the Eagle Mountain watershed. They have cooperated with the modeling and educational team to develop watershed costs associated with reaching water quality goals through the economic analysis. They also looked at the cost of BMP implementation on small scale lands compared to large tracts of agricultural lands. Task details can be found in Appendix C and the Economic Analysis Report is located in Appendix D.

Task 3 – Education

Working with the Texas AgriLife Research and Extension Urban Solutions Center in Dallas, the education/outreach team continued to conduct stakeholder meetings in the Cedar Creek and Eagle Mountain watersheds. The purpose of these meetings was to gather stakeholder input for implementation of watershed plans.

Additionally, the Texas AgriLife Extension Service has worked with local county officials to continue conducting educational activities in the watersheds managed by TRWD. The goal of these programs was to increase the water literacy of local residents and challenge attitudes and behaviors in order to protect and improve water quality. A major focus was conducting demonstrations for small acreage landowners. Educational materials were developed and delivered relating to management of small acreage lands in Cedar Creek and Eagle Mountain watersheds. A specific list of activities can be found in Appendix E and the fact sheets are located in Appendix F.

Task 4 – Administration

TWRI provided administrative support for tasks 1–3 which included coordination among organizations and tasks, submission of quarterly reports and annual reports. TWRI also maintained a project website which houses all reports, educational materials and general information with regards to the project and water quality. The web address is http://nctx-water.tamu.edu/. Details regarding this task are located in Appendix G.

Conclusion

Overall, Watershed Assistance to Improve Water Quality in North Central Texas project was a success. TWRI, AgriLife Research, AgriLife Extension, and TRWD worked closely together in completing the tasks of the project. As a result, stakeholders within the watersheds have an outlined path forward to reduce the amount of pollutants that flow into the reservoirs.

The development of the "Evaluating the Economics of Best Management Practices for Tarrant Regional Water District's Eagle Mountain Lake Watershed" and the "Eagle Mountain Watershed: Calibration, Validation, and Best Management Practices" reports are technical reports that TRWD will be able to utilize when trying to mitigate development impacts to water quality.

Working with local county offices to conduct educational activities, project personnel and TRWD have utilized material developed within this project and will continue to use that material as stakeholders assist in water quality mitigation efforts.

Projects such as this are why accomplishments are being made toward restoring water quality. The need for such projects statewide in the future is crucial for continued success.

Appendix A

Task 1 SWAT Modeling

- SSL and Texas AgriLife Research and Extension Center at Temple have begun collection of water quality and flow data for the Richland Chambers Watershed.
- Baylor University conducted a sediment survey of Eagle Mountain Reservoir to verify storage capacity, flows and sediment size for the model. A survey of Richland Chambers Reservoir is scheduled to begin in August 2009. The survey has been postponed due to recent rainfall.
- Modeling activities have been completed for Richland Chambers Reservoir Watershed. Data has been gathered and analyzed for computer modeling purposes. The model has been calibrated for flow and the research team is working to finalize model calibration for nutrients. This deliverable is 100 percent complete.
- SWAT model calibration for the Eagle Mountain watershed has been completed.
- Sensitivity analysis for BMPs in Eagle Mountain using SWAT model have been accomplished for the BMPs that were used for CEDAR CREEK as well as 3 additional BMPs to be analyzed
- The SWAT Modeling has been completed for Cedar Creek and calibrated and validated for Eagle Mountain.
- All BMPs have been simulated at 100% adoption rates which also includes the 3 new BMPs
- The Modeling Final Reports are being drafted that will include the calibration, validation and simulations that have been run.
- Cost-effective scenarios for Eagle Mountain will be simulated upon the completion of the economic analysis and is anticipated to be completed by early May.
- The calibrated and validated SWAT model was presented to stakeholders at a June 24 stakeholder meeting. In addition, SWAT runs were presented showing how they fit into WASP so that stakeholders have a clear understanding of how loading reductions are determined.
- Cost-effective scenarios for Eagle Mountain will be simulated during the next quarter as the economic analysis is now completed.

Appendix B

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Eagle Mountain Watershed: Calibration, Validation, and Best Management

By
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Eagle Mountain Watershed: Calibration, Validation, and Best Management Practices

September 12, 2011

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INTRODUCTION

The watershed modeling objective of this project was to use the Soil and Water Assessment Tool (SWAT) to assess the effects of urbanization and other landuse changes on sediment and nutrient delivery to Eagle Mountain Lake. The watershed is located on the West Fork of the Trinity River primarily in Wise County but also partially in Jack, Clay, Montague Parker and Tarrant counties. Eagle Mountain Lake was constructed in 1932 as a water supply reservoir for Tarrant County (Figure 1); the reservoir has a total drainage area of 2,230 km (551,045 acres). All model data in this report, both observed and simulated, includes inflow to Eagle Mountain watershed from Bridgeport Reservoir, also constructed in 1932 (Figure 1). Daily inputs, such as flow, sediment, and nutrients, from Bridgeport Reservoir were represented as a point source in the Eagle Mountain watershed model.

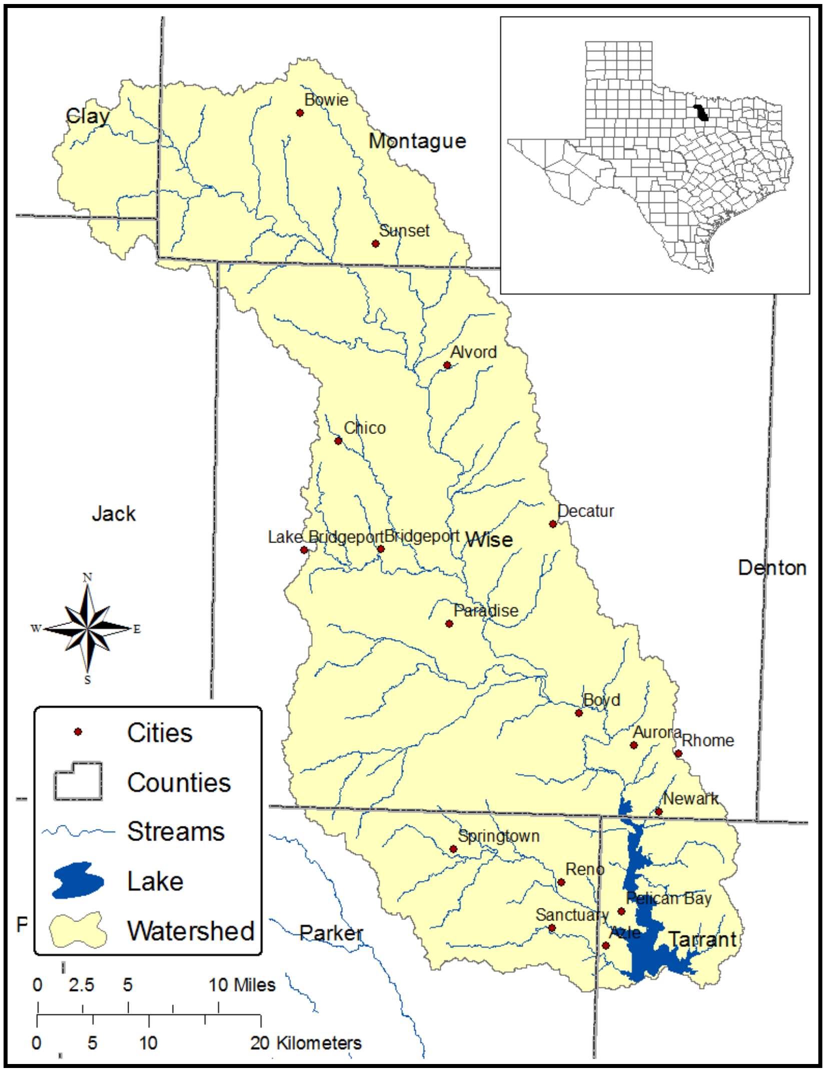


Figure 1. Eagle Mountain watershed and Reservoir

MODEL AND DATA SOURCES

1. SWAT Model

SWAT is a basin-scale distributed hydrologic model. Distributed hydrologic models allow a basin to be subdivided into many smaller subbasins to incorporate spatial detail. Water yield and pollutant loads are calculated for each subbasin and then routed through a stream network to the basin outlet.

SWAT goes a step further with the concept of Hydrologic Response Units (HRUs). In SWAT, a single subbasin can be further divided into areas with unique combinations of soil and landuse, referred to as HRUs. All hydrologic processes are calculated independently for each HRU. The total nutrient or water yield for a subbasin is the sum of the corresponding constituents from all the HRUs it contains. HRUs allow more landuse and soil classifications to be represented in a computationally efficient manner, in turn providing greater spatial detail.

SWAT is a combination of applications, ROTO (Routing Outputs to Outlets (Arnold et al., 1995b) and the SWRRB (Simulator for Water Resources in Rural Basins or SWRRB (Williams et al., 1985). Furthermore, several systems contributed to the development of SWRRB including CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al., 1987) and EPIC (Erosion-Productivity and Impact Calculator) (Williams, 1990). SWAT was created to overcome the maximum area limitations of SWRRB, which can only be used on watersheds a few hundred square kilometers in area and has a limitation of ten subbasins. SWAT, in contrast, can be used for much larger areas. The HUMUS (Hydrologic Unit Model for the United States, also known as the HUMUS project (Srinivasan et al., 1998), used SWAT to model 350 USGS six-digit watersheds in 18 major river basins throughout the United States.

SWAT is a continuous simulation model that operates on a daily time step. Long-term simulations can be performed using simulated or observed weather data. The SWAT model is continually updated every few years to include new features and functionality. The current version, SWAT 2005, is widely used both in the United States and internationally. SWAT 2005 is distributed with the full Formula Translator (FORTRAN) source code, allowing anyone to make modifications to the model.

2. DEM

DEM (Digital Elevation Model) is elevation information created in a digital format. The data was obtained from NRCS (Natural Resources Conservation Service) Data Gateway at 30 meter resolution. The range of elevation in Eagle Mountain watershed is from 186 m to 387 m (610 to 1,270 feet) with average slope of 3.7%.

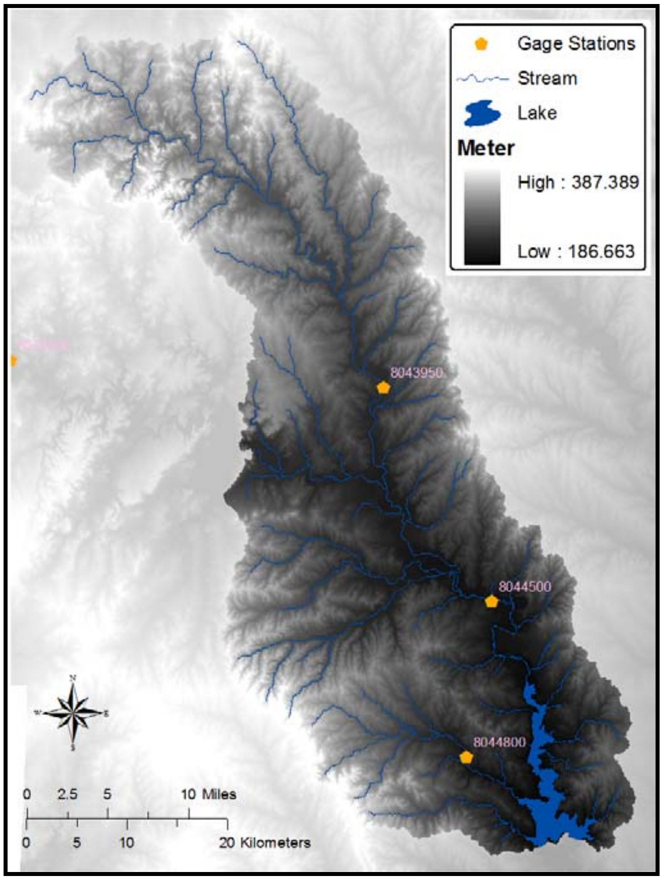


Figure 2. Digital Elevation Model (30m) for Eagle Mountain watershed

3. Landuse

The National Land Cover Dataset (NLCD) created in 1992 was used as SWAT landuse data input. Due to rapid urban development in the watershed, the Texas A&M Spatial Sciences Lab (SSL) enhanced this data for urban expansion using an aerial photograph from 2003 (Figure 3).

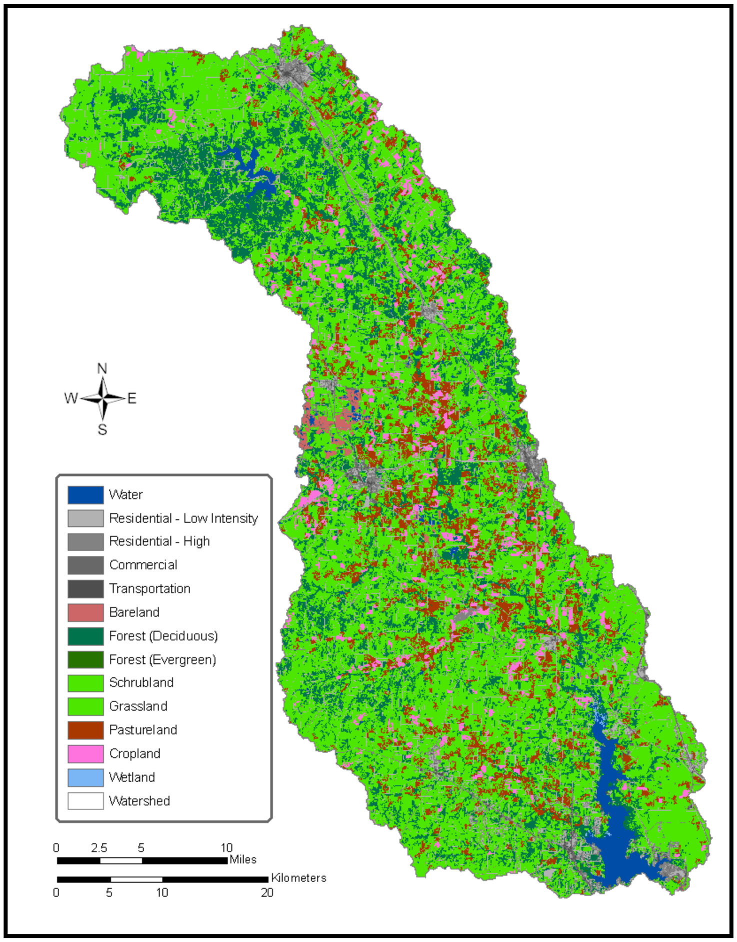


Figure 3. Landuse distribution in Eagle Mountain watershed

4. Soil

The soils dataset SSURGO (Soil Survey Geographic), which is the most detailed soils dataset available, was obtained from the NRCS Data Gateway and used as input for the SWAT model. SSURGO dataset includes soil information in each layer, soil type, texture, conductivity, albedo, and so on.

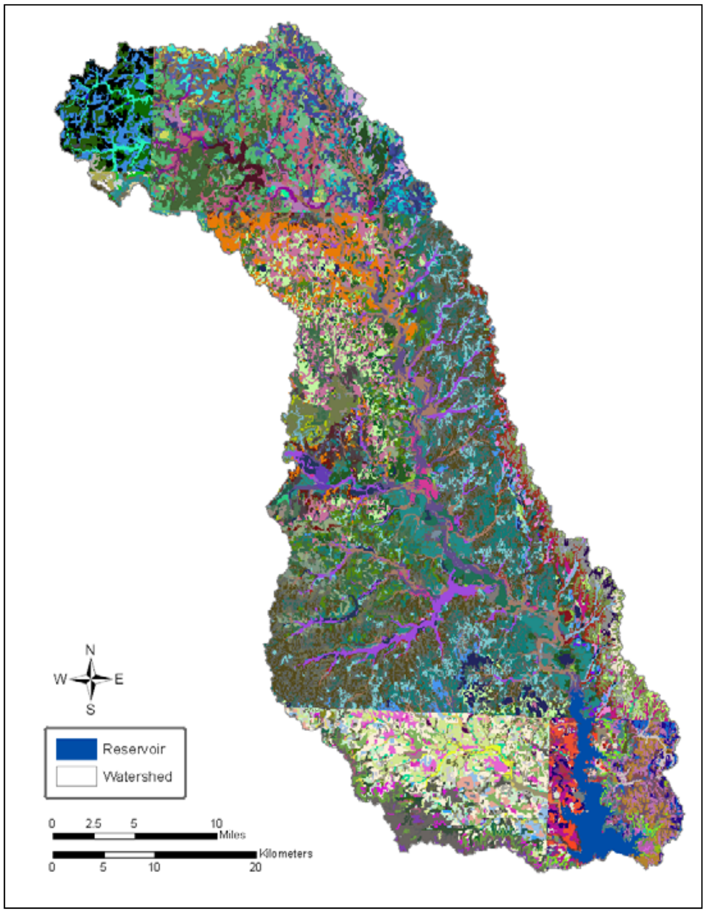


Figure 4. Soil map (SSURGO) of Eagle Mountain watershed

5. Weather

When National Weather Service stations (shown in Figure 5) lacked precipitation data during the period of record (1950–2004), nearby stations provided substitute data, and SWAT generated missing temperature data.

For rainfall data from 1999–2004, NEXRAD data was used to enhance missing rainfall or to create spatially distributed rainfall with finer resolution. It was done by averaging NEXRAD grid data for all subbasins near an individual climate station.

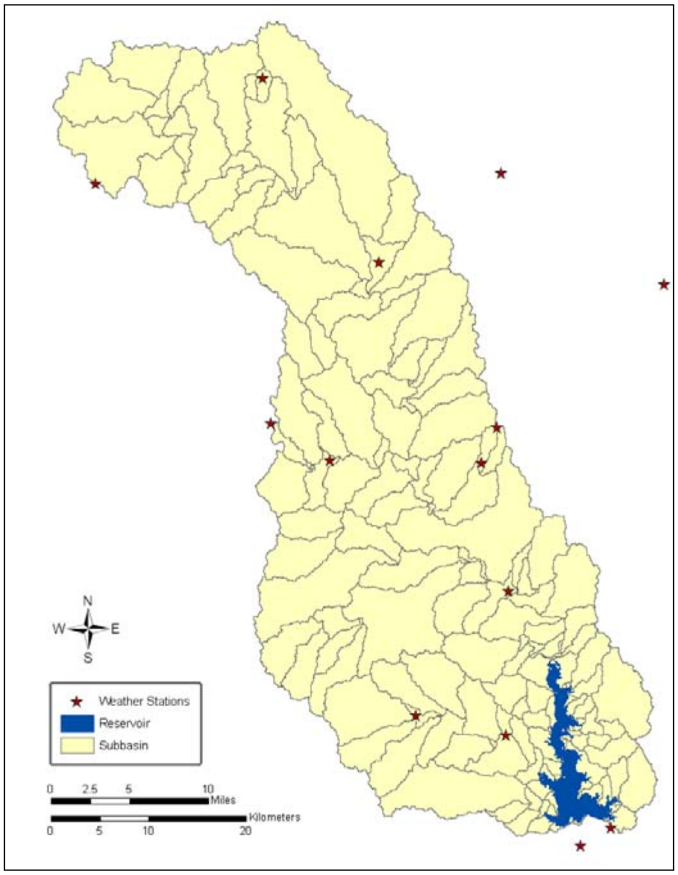


Figure 5. Distribution of weather stations

6. Point Sources

The Eagle Mountain watershed contained a total of 14 waste water treatment plants (WWTP) distributed across the watershed. Two of these WWTPs discharge directly into the lake (Figure 6). WWTPs voluntarily collected weekly nutrient and flow data for one year, which provided point-source loading inputs. Weekly data have been combined into monthly loadings for each WWTP and then routed through the creeks. Table 1 through Table 11 shows the amount of loading (flow, Total N, and Total P) from each WWTP.

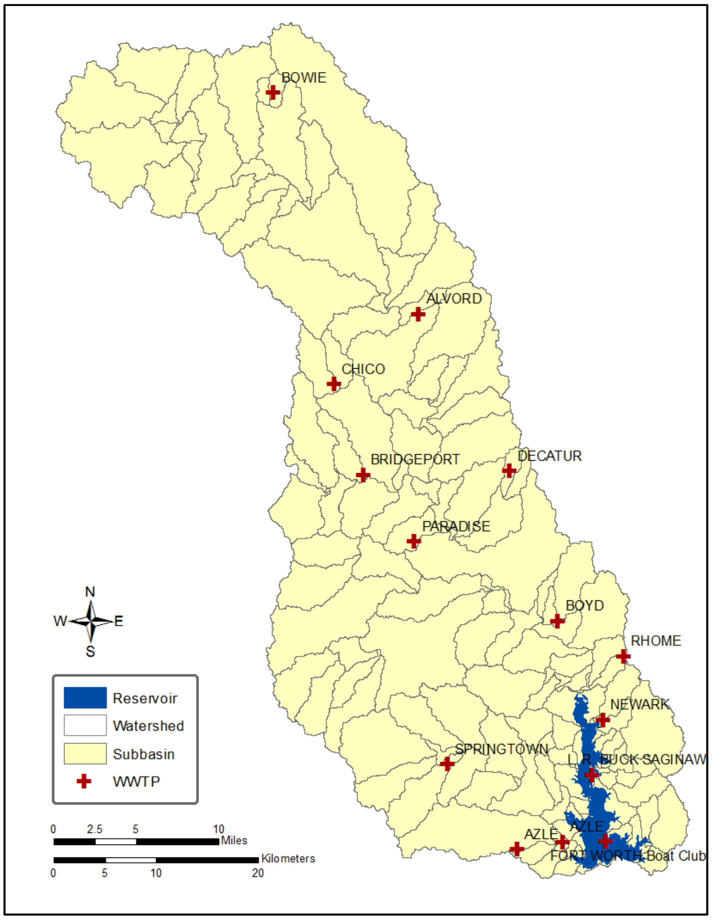


Figure 6. Waste Water Treatment Plants (WWTPs)

Table 1. Daily discharge from WWTP of Alvord

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	230.90	1.83	0.53
Feb-02	204.40	1.90	0.44
Mar-02	234.68	3.17	0.30
Apr-02	200.61	1.06	0.37
May-02	162.76	0.57	0.45
Jun-02	143.84	0.41	0.44
Jul-02	166.55	1.37	0.68
Aug-02	158.98	2.90	0.60
Sep-02	181.69	1.43	0.26
Oct-02	143.84	1.46	0.22
Nov-01	162.76	1.65	0.10
Dec-01	162.76	1.88	0.23

Table 2. Daily discharge from WWTP of Azle

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	2882.03	15.10	2.01
Feb-02	2654.35	6.19	1.24
Mar-02	2916.47	10.63	1.00
Apr-02	3536.10	8.08	3.13
May-02	3443.56	3.97	0.86
Jun-02	2428.19	13.26	0.61
Jul-02	1631.41	17.87	0.81
Aug-02	2250.28	3.34	0.41
Sep-02	2102.28	5.98	0.53
Oct-02	3611.05	12.94	1.77
Nov-01	3195.63	7.76	3.15
Dec-01	3272.66	18.84	2.38

Table 3. Daily discharge from WWTP of Bowie

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	1362.66	26.00	3.92
Feb-02	2258.80	46.76	6.66
Mar-02	2334.50	46.78	7.10
Apr-02	3919.92	77.73	20.05
May-02	2146.19	52.20	7.87
Jun-02	1735.50	42.84	6.03
Jul-02	1552.87	39.68	5.16
Aug-02	1791.90	37.57	5.95
Sep-02	1999.52	47.99	6.40
Oct-02	2119.69	42.44	5.22
Nov-01	1143.12	26.50	3.53
Dec-01	1997.31	41.61	6.34

Table 4. Daily discharge from WWTP of Boyd

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	262.22	2.60	0.40
Feb-02	314.26	4.97	0.77
Mar-02	335.74	5.36	1.00
Apr-02	341.79	1.27	1.22
May-02	327.19	1.15	0.29
Jun-02	270.73	0.45	0.24
Jul-02	279.61	1.06	0.19
Aug-02	274.05	0.43	0.12
Sep-02	363.19	0.77	0.23
Oct-02	355.90	3.45	0.14
Nov-01	325.43	2.12	0.43
Dec-01	351.77	2.99	1.05

Table 5. Daily discharge from WWTP of Bridgeport

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	1646.55	25.29	2.44
Feb-02	2117.80	13.23	4.52
Mar-02	2923.10	11.67	2.61
Apr-02	2057.62	15.15	1.58
May-02	2143.35	12.97	1.44
Jun-02	2347.75	24.82	6.31
Jul-02	2283.40	40.05	11.17
Aug-02	2211.48	39.17	6.63
Sep-02	2061.02	41.98	4.91
Oct-02	2167.39	29.69	4.36
Nov-02	2164.17	7.46	2.77
Dec-02	2259.75	25.46	4.85

Table 6. Daily discharge from WWTP of Chico

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	215.75	5.11	0.99
Feb-02	215.75	5.38	0.90
Mar-02	215.75	5.38	0.94
Apr-02	215.75	4.02	0.86
May-02	215.75	6.21	1.21
Jun-02	215.75	5.34	1.24
Jul-02	215.75	5.22	1.14
Aug-02	215.75	3.91	1.25
Sep-02	215.75	5.47	1.22
Oct-02	215.75	4.46	1.07
Nov-02	215.75	7.29	1.02
Dec-01	215.75	4.24	0.89

Table 7. Daily discharge from WWTP of Decatur

	Daily Loads		
	Flow (m3)	TN (kg)	TP (kg)
Jan-02	1962.99	13.23	3.36
Feb-02	2596.63	31.19	10.32
Mar-02	3003.53	21.81	6.21
Apr-02	3663.10	34.50	5.91
May-02	2748.98	23.65	5.99
Jun-02	3092.48	35.88	14.34
Jul-02	3206.98	89.34	6.82
Aug-02	2654.16	20.01	5.53
Sep-02	2681.79	5.76	0.73
Oct-01	1339.95	15.72	3.94
Nov-01	1402.03	16.50	4.06
Dec-01	1559.49	6.02	1.02

Table 8. Daily discharge from WWTP of Newark

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	64.35	1.04	0.38
Feb-02	215.28	2.03	0.67
Mar-02	164.09	0.58	0.28
Apr-02	154.34	0.35	0.39
May-02	188.73	0.44	0.38
Jun-02	156.99	2.51	0.74
Jul-02	160.19	3.83	0.88
Aug-02	171.37	3.29	0.82
Sep-02	127.18	2.47	0.50
Oct-02	118.76	2.09	0.31
Nov-02	123.87	0.85	0.53
Dec-01	147.81	1.77	0.59

Table 9. Daily discharge from WWTP of Paradise

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	56.78	0.63	0.12
Feb-02	60.56	0.53	0.13
Mar-02	90.84	0.79	0.20
Apr-02	79.49	0.70	0.17
May-02	64.35	0.56	0.14
Jun-02	22.71	0.20	0.05
Jul-02	34.07	0.30	0.07
Aug-02	45.42	0.40	0.10
Sep-02	64.35	0.56	0.14
Oct-01	71.92	1.00	0.22
Nov-01	79.49	0.34	0.13
Dec-01	56.78	0.47	0.12

Table 10. Daily discharge from WWTP of Rhome

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	110.53	0.88	0.29
Feb-02	196.83	0.78	0.09
Mar-02	140.62	1.05	0.24
Apr-02	105.98	0.58	0.14
May-02	213.18	2.08	0.35
Jun-02	134.37	0.93	0.39
Jul-02	200.61	1.94	0.44
Aug-02	215.75	2.09	0.47
Sep-02	219.54	2.12	0.48
Oct-02	215.75	2.09	0.47
Nov-01	120.12	2.49	0.48
Dec-01	121.50	1.73	0.19

Table 11. Daily discharge from WWTP of Springtown

	Daily Loads		
	Flow (m^3)	TN (kg)	TP (kg)
Jan-02	667.45	5.37	1.57
Feb-02	796.69	7.41	1.73
Mar-02	808.13	11.38	1.05
Apr-02	991.71	5.13	1.86
May-02	764.60	2.52	1.92
Jun-02	804.98	2.27	2.49
Jul-02	807.19	6.64	3.33
Aug-02	829.90	15.10	3.14
Sep-02	755.14	5.87	1.06
Oct-02	842.20	8.95	1.30
Nov-01	728.64	7.52	0.48
Dec-01	732.43	8.19	1.06

7. Sampling and Monitoring Stations

In the Eagle Mountain study, two data monitoring/collecting studies were used for a data source. One was an intensive, short-term, low flow study and the other a continuous, long-term water quality analysis on samples taken from various monitoring sites. For the low flow study, Tarrant Regional Water District (TRWD) collected a total of 14 samples at different locations along the stream network on August 18, 2004. The samples were analyzed for dissolved oxygen, biological oxygen demand, ammonia, phosphorus, Chlorophyll-a, organic nitrogen and nitrate-nitrite concentrations. The SSL then used observed data from 10 of the 14 locations to calibrate nutrients under low flow conditions. The TRWD also set up an independent QUAL-2E model based on the measured channel geometry and hydraulics developed during a dye study. The calibrated QUAL-2E kinetic terms and coefficients were then used as initial estimates of instream water quality parameters in SWAT.

The TRWD has six monitoring sites on main tributaries of Eagle Mountain Lake where they periodically collected grab samples from 1991 to 2004 to test for water quality (Figure 7). For SWAT calibration, data from five monitoring sites were used to modify SWAT's instream model parameters.

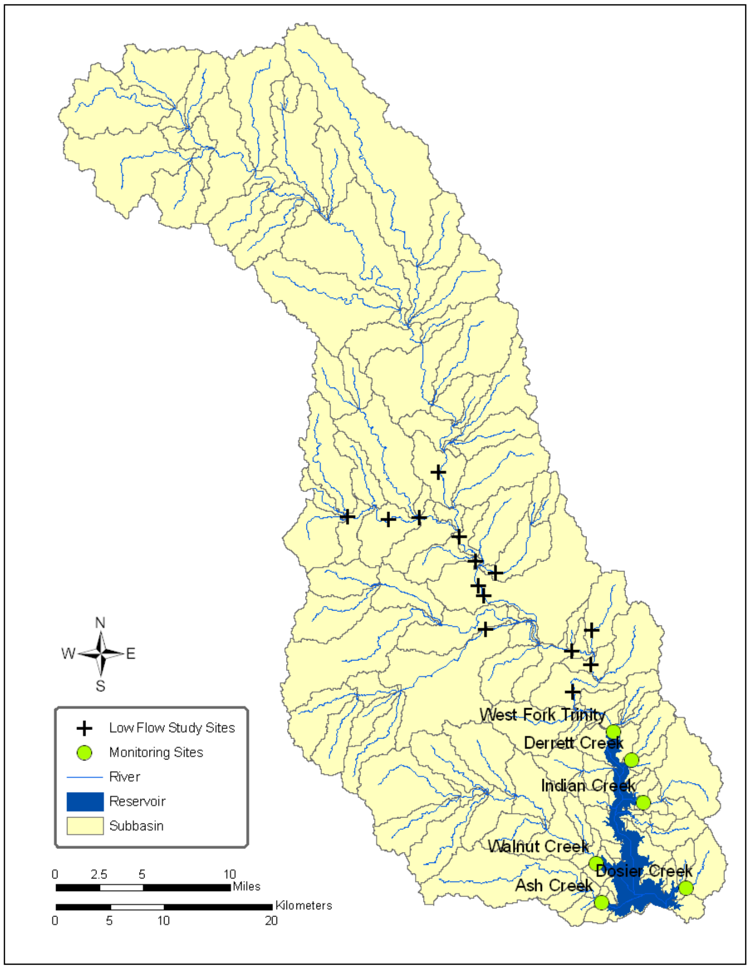


Figure 7. Low flow sampling sites and nutrients monitoring stations

8. Ponds

The Eagle Mountain Basin contains a total of 56 inventory-sized dams, as defined by the Texas Commission on Environmental Quality (TCEQ). These include NRCS flood prevention dams, farm ponds, and other privately owned dams. Physical data such as surface area, storage, drainage area, and discharge rates for these dams where input into SWAT to allow routing of runoff through the impoundments. Four structures were large enough to be simulated as reservoirs while the rest were simulated as small ponds (Figure 8).

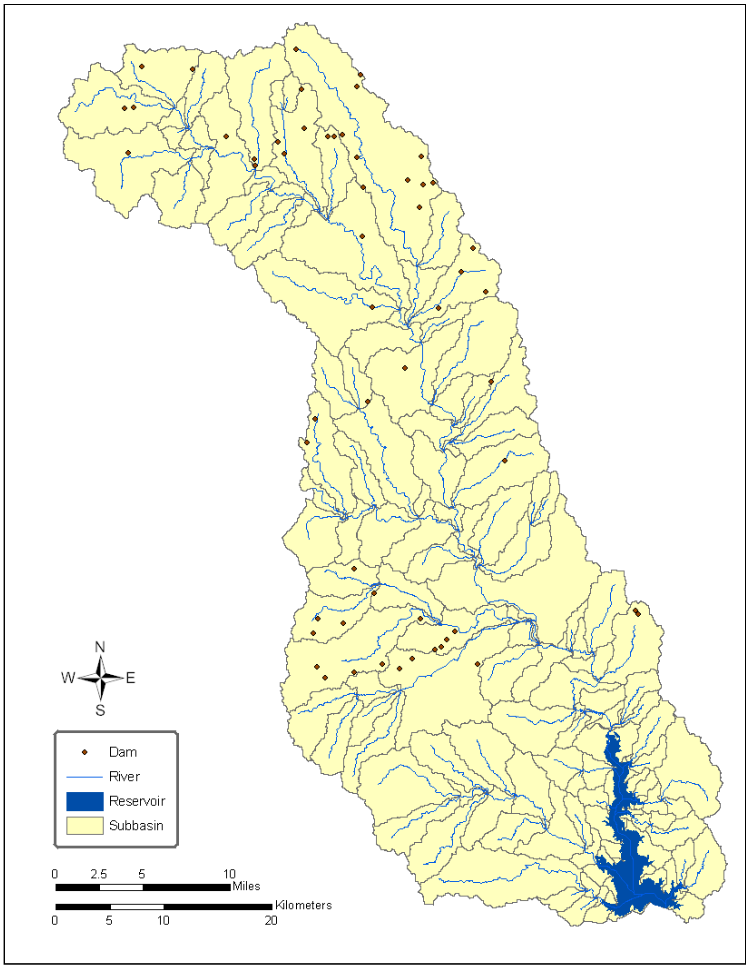


Figure 8. Distribution of NRCS inventory size and other size dams

9. Lake

Eagle Mountain Lake was built in 1932 and current specification of the lake is summarized in Table 12. The surface area at its principle spillway is 8,694 acres (3,518 ha) and it has the capacity of 190,000 acre-ft of its principle spillway (649.1 feet mean sea level). The surface area at the emergency spillway is 21,853 acres (8,843 ha) and has a capacity of 680,000 acre-ft.

Table 12. Characteristics of Eagle Mountain Lake

Specification	Size	
Surface Area at Principle Spillway	8,694	acres
Volume at Principle Spillway	19	10^4 acre-feet
Surface Area at Emergency Spillway	21,853	acres
Volume at Emergency Spillway	68	10^4 acre-feet

MODEL SET UP AND CALIBRATION

1. Model Set Up

SWAT 2005 automatically delineated subbasins within the watershed using DEM and a contributing area definition threshold of 500 ha. SWAT used landuse and soil information for spatial variation in the watershed. The total number of subbasins created by the model was 150 and they are shown in Figure 5. There are some subbasins partially submerged by the reservoir. The area under water in each subbasin was calculated and accounted for the effects of submergence in main channel inputs (channel erodibility and channel cover were set to "0.0"). SWAT simulated the land cover for these submerged areas as water.

SWAT's input interface divided each subbasin into HRUs with unique soil and landuse combinations. The number of HRU's within each subbasin was determined by: 1) creating an HRU for each landuse that equaled or exceeded 2% of each subbasin's area, and 2) creating an HRU for each soil type that equaled or exceeded 10% of any of the landuses selected in 1). Using these thresholds, the interface created 1,516 HRUs within the watershed.

Eagle Mountain watershed contained a total of 14 WWTPs from each major city and they are distributed in the basin as shown in Figure 6. Two of these WWTPs discharge directly into the reservoir. WWTPs voluntarily collected weekly nutrient and flow data for one year, which provided point-source loading inputs. This weekly data was converted to monthly loadings for each WWTP and included in the model. The Eagle Mountain watershed contains a total of 56 inventory-sized dams, as defined by the TCEQ. These include NRCS flood prevention dams, farm ponds and other privately owned dams. The physical properties of each pond such as surface area, storage, drainage area, and discharge rates for these dams were input into SWAT to allow routing of runoff through the impoundments. Four ponds were large enough to be simulated as reservoirs while the rest were simulated as small ponds.

2. Flow Calibration and Validation

The calibration period was based on the available period of record for stream gauge flow. Measured stream flow was obtained from two USGS stream gages (08043950 and 08044500) as shown in Figure 2 for 1991 through 2004. A base flow filter (Arnold et al., 1995a) was used to determine the fraction of base flow and surface runoff at selected gauging stations.

Appropriate plant growth parameters for brush, native grasses, and other land covers were input for each model simulation. Initial inputs were based on known or estimated watershed characteristics. SWAT was calibrated for flow by adjusting appropriate inputs that affect surface runoff and base flow. Adjustments were made to runoff curve number, soil evaporation compensation factor, shallow aquifer storage, shallow aquifer re-evaporation, and channel transmission loss until the simulated total flow and fraction of base flow were approximately equal to the measured total flow and base flow, respectively.

Validation was performed by applying the same model parameters to a different period (1971–1990). Validation was done in an earlier period than calibration because the landuse dataset used in this model represented land cover in 2001. Therefore, it would be more appropriate to calibrate the model for the period that includes the year of the land cover dataset to represent more accurately.

Figure 9 shows the result of flow calibration and validation at USGS gage station 08044500. For calibration period, r^2, NSE (Nash-Sutcliffe Model Efficiency) (Nash and Sutcliffe, 1970), observed mean, and modeled mean were 0.947, 0.913, 7.15 m^3/s, and 7.04 m^3/s respectively. For validation period, they were 0.964, 0.921, 8.59 m^3/s, and 8.50 m^3/s respectively.

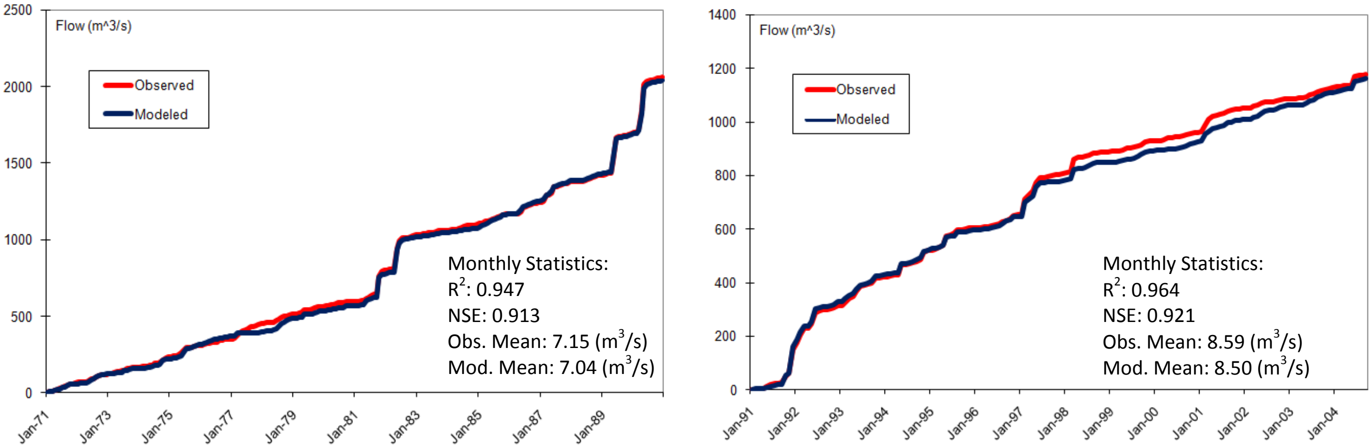


Figure 9. The result of flow calibration and validation by accumulated flow at USGS gage station 08044500.

3. Sediment Calibration and Validation

Two sediment survey studies were conducted on Eagle Mountain Lake. The first study was conducted before modeling began and the second study was done during the modeling study. Sediment calibration was done based on the second study conducted by Texas Water Development Board (TWDB) as the data was considered more accurate and reasonable.

1) The Baylor Study

A lake sediment survey was undertaken by Baylor University in early 2006 by collecting sediment cores to estimate average density and thickness of sediment at the lake bottom (Allen et al. 2006). In addition, a watershed survey was conducted by Allen et al. 2006 to identify stream segments with channel erosion problems and to quantify channel erosion using NRCS field assessment techniques such as RAP-M. Allen et al. (2006) calculated sedimentation in the reservoir based on the original design volume and compared that to what was found in the 2005 survey and found a sedimentation rate of 427.3 ac-ft/year, which is equivalent to 376,000 ton/year in metric unit. The delta sediment density was 98 lbs/ft^3, pro delta sediment density was 26 lbs/ft^3, and average density was 40.4 lbs/ft^3. Based on the lake sediment survey and the watershed survey, the erosion rate of the Eagle Mountain watershed was estimated at about 340,883 metric tons/yr. Of this, channel erosion contributed about 110,144 metric tons/yr (32.3%) and the rest of the sediment (230,739 metric tons/yr) was attributed to overland erosion (67.7%) (Allen et al. 2006). Simulated sediment from SWAT for the 1971 to 2004 period (34 years) was compared to the measured sediment, and appropriate input parameters were adjusted until the predicted annual sediment load from overland and channel erosion was approximately equal to that measured. Final values for SWAT input coefficients used for in flow and sediment calibration are given in Table 15.

2) The TWDB Study:

The second study was conducted by TWDB in 2008 using duel frequency sonar. With this technique, the thickness of the post impoundment sediment in the reservoir was estimated, although shallow areas could not be measured due to limited boat accessibility. Shallow areas full of sediment near the mouth of major tributaries were also not measured with this technique for the same reason.

With these conditions considered, the TWDB sedimentation study was used for calibrating sediment loadings in the SWAT model as it was the most state of the art technology and had finer resolution. However, the ratio between sediment from channel erosion and sediment from overland erosion was adopted from the study by Allen et al (2006).

According to TWDB measurements, the sedimentation rate at the reservoir was 295,822 metric tons/year, which was 45,061 metric tons/year less than the study by Allen et al. Channel contribution was estimated at 98,569 tons/year (33.3%) and 197,313 tons/year (66.7%) from overland erosion.

Simulated sediment from SWAT for the 1971 to 2004 period (34 years) was compared to the measured sediment, and appropriate input parameters were adjusted until the predicted annual sediment load from overland and channel erosion was approximately equal to the measured.

Table 13 and Table 14 summarize sediment calibration for overland erosion and for the entire watershed respectively. The calibration was a series of runs to match yearly average sediment yield and it was considered acceptable when the difference was about 10%. Final values for SWAT input coefficients used in flow and sediment calibration are given in Table 15.

Table 13. Calibration and validation for sediment loading from overland flow

	Observed (ton)	Modeled (ton)	Difference (%)
Total (y^{-1})	197,313	196,909	-0.2
Calibration (1994 – 2004)		206,294	+4.6
Validation (1970 – 1990)		191,748	-2.8

Table 14. Calibration and validation for sediment loading at Reservoir

	Observed (ton)	Modeled (ton)	Difference (%)
Total (y^{-1})	295,822	290,400	+0.2
Calibration (1994 – 2004)		263,827	-10.8
Validation (1970 – 1990)		324,880	+9.8

Table 15. SWAT input coefficients adjusted for calibration of flow and sediment

Variable	Description	Input Value	Units	File
Coefficients related to flow				
CN2	SCS Runoff curve number (adjustment range)	+5 to -5	-	*.mgt
ESCO	Soil evaporation factor	0.85	-	*.hru
GW_REVAP	groundwater re-evaporation coefficient	0.02	-	*.gw
REVAPMN	Groundwater storage required for re-evaporation	1	mm	*.gw
ALPHA_BF	Baseflow alpha factor	0.0431 to 0.0670	$Days^{-1}$	*.gw
CH_N2	Mannings "n" roughness for channel flow	0.125	-	*.rte
CH_K2	Hydraulic conductivity of channel alluvium	0.5 to 5.0	mm/hr	*.rte
Coefficients related to sediment				
USLE_C	Minimum "C" value for pastureland in fair condition	0.007	-	crop.dat

SPCON	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing	0.003	-	basins.bsn
SPEXP	Exponent parameter for calculating sediment reentrained in channel sediment routing	0.67	-	basins.bsn
TRNSRCH	Reach transmission loss partitioning to deep aquifer	0.2		basins.bsn
CH_COV	Channel cover factor	0.001 to 0.9	-	*.rte
CH_EROD	Channel erodibility factor	0.001 to 0.9	-	*.rte

3) Nutrient Calibration and Validation

Nutrient calibration consisted of two parts: first, the model was calibrated based on a low flow study conducted August 18, 2004, and second, using long term tributary monitoring data.

For the first step in the nutrient calibration of SWAT, parameters were adjusted to agree with measurements at 10 sampling sites where sediment, nutrients, and bio-chemical data were collected under low flow conditions (Table 16). Because it was base flow condition, nutrients discharged from WWTP and channel process were greater portions in the calibration. One of the data problems, however, was that there was a 17 mm rainfall in the northeast part of watershed on Aug 16, 2004, and it may have impacted the data.

In the second step of the calibration, the parameters were adjusted for the remainder of the subbasins using monitoring station data. The simulation period was 1971 through 2004. WWTP loads were generated from one year’s worth of monthly data collected by TRWD in 2001 and 2002 and it was assumed that WWTP loadings were constant for each facility.

The output from this simulation was compared to water quality data collected by TRWD from 1991 through 2004 in each major tributary (Ash, Derrett, Dosier, Walnut, and the West Fork of the Trinity River at County Road 4688 as shown in Figure 10). In order to account for daily variability of SWAT, simulated output was averaged for the three days surrounding the day of the measured grab samples. The medians, 25th percentile, and 75th percentile of the 3-day averages from SWAT were compared to the medians, 25th and 75th percentiles of the measured monitoring data samples (Figure 10). The coefficients for all subbasins were adjusted for each watershed to match the observed data. There were some discrepancies with observations at some sites but the West Fork 4688 site, located near the lake, showed relatively good correlation between observed and modeled data. Table 17 summarizes estimated sediment and nutrient loading into the lake as a baseline condition. The baseline condition will be used for BMP analyses in the later chapter of this report.

Table 16. General water quality input coefficients (.wwq) for low flow study and monitoring site calibration

Variable Name	Definition	SWAT-SSL Cal. Coef.	SWAT Default	SWAT Range
LAO	Light averaging option	2	2	2
IGROPT	Algal specific growth rate option	2	2	3 options
AI0	Ratio of chlorophyll-a to algal biomass [µg-chla/mg algae]	10	50	10 - 100
AI1	Fraction of algal biomass that is nitrogen [mg N/mg alg]	0.090	0.080	0.07 - 0.09
AI2	Fraction of algal biomass that is phosphorus [mg P/mg alg]	0.020	0.015	0.01 - 0.02
AI3	The rate of oxygen production per unit of algal photosynthesis [mg O2/mg alg)]	1.500	1.600	1.4 - 1.8
AI4	The rate of oxygen uptake per unit of algal respiration [mg O2/mg alg)]	2.300	2.000	1.6 - 2.3
AI5	The rate of oxygen uptake per unit of NH3-N oxidation [mg O2/mg NH3-N]	3.500	3.500	3.0 - 4.0
AI6	The rate of oxygen uptake per unit of NO2-N oxidation [mg O2/mg NO2-N]	1.000	1.070	1.0 - 1.14
MUMAX	Maximum specific algal growth rate at 20º C [day-1]	2.000	2.000	1.0 - 3.0
RHOQ	Algal respiration rate at 20º C [day-1]	0.300	0.300	0.05 - 0.50
TFACT	Fraction of solar radiation computed in the temperature heat balance that is photosynthetically active	0.440	0.300	0.01 - 1.0
K_L	Half-saturation coefficient for light [kJ/(m2·min)]	0.418	0.750	0.2227-1.135
K_N	Michaelis-Menton half-saturation constant for nitrogen [mg N/lL]	0.400	0.020	0.01 - 0.30
K_P	Michaelis-Menton half-saturation constant for phosphorus [mg P/l]	0.040	0.025	0.001 - 0.05
LAMBDA0	Non-algal portion of the light extinction coefficient [m-1]	1.500	1.000	-
LAMBDA1	Linear algal self-shading coefficient [m-1·(µg chla/l)-1)]	0.002	0.030	0.0065-0.065
LAMBDA2	Nonlinear algal self-shading coefficient [m-1·(µg chla/l)-2]	0.054	0.054	0.054
P_N	Algal preference factor for ammonia	0.100	0.500	0.01 - 1.0

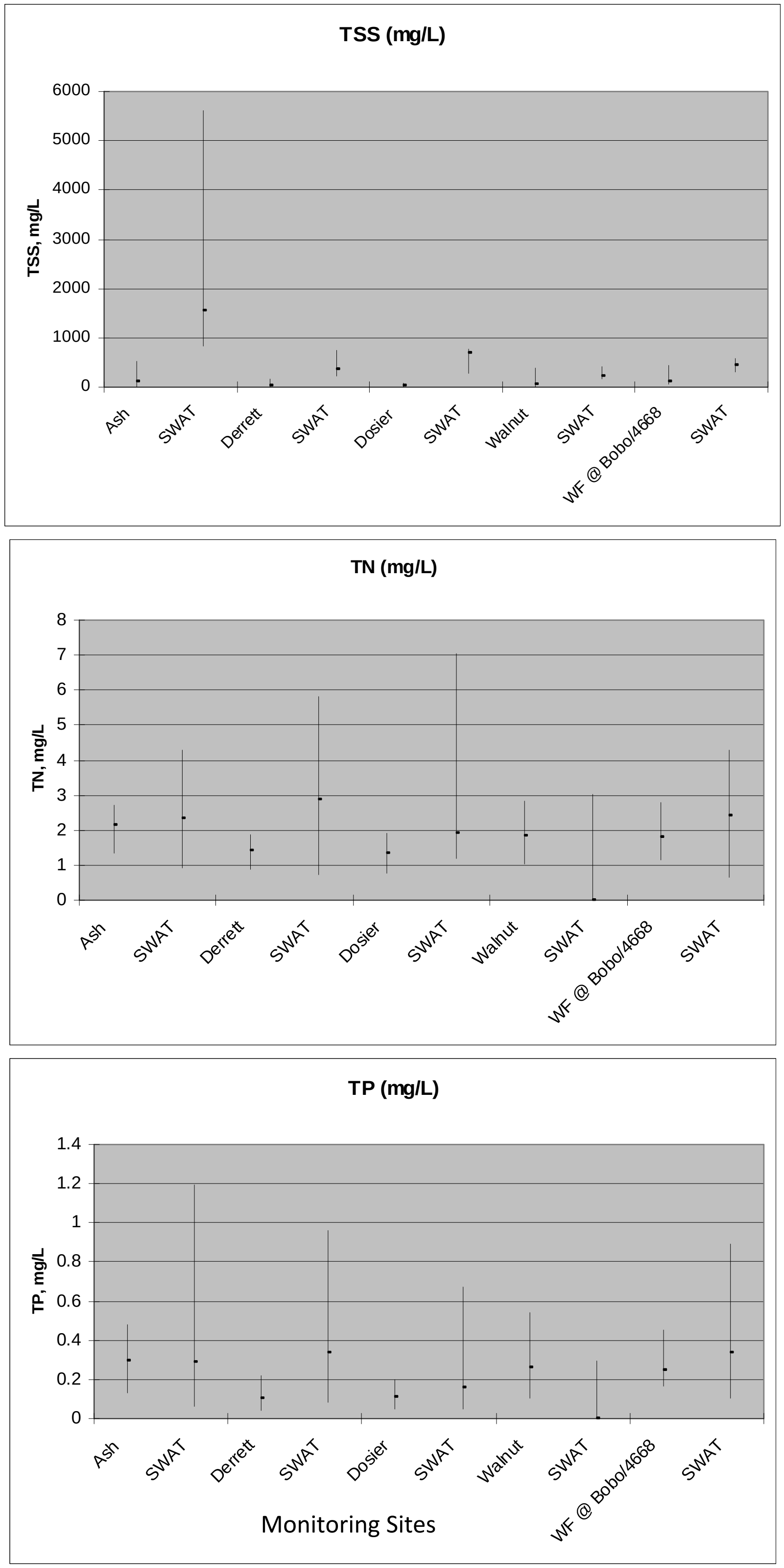


Figure 10. Model calibration for monitoring sites

Table 17. Estimated annual sediment and nutrient loading to Eagle Mountain Lake (Baseline condition) from 1971 to 2004

	Sediment (t/y)*	Total N (kg/y)	Total P (kg/y)
Calibrated model estimation (baseline)	296,400	1,055,220	173,020

* Units are metric units

ANALYSES

1. Average annual load by landuse

Eagle Mountain watershed is composed by 6 landuse categories (Table 18) based on landuse datasets. The largest portion of landuse is occupied by rangeland at almost 60% followed by forest at 17.78%, urban 9.77%, pasture 9.30%, cropland 3.39%, and wetland with 0.04%.

Table 18. Landuse category in Eagle Mountain watershed

Category	Area
Urban	9.77%
Forest	17.78%
Cropland	3.39%
Pasture	9.30%
Rangeland	59.72%
Wetland	0.04%
Total	100.00%

Figure 11 illustrates sediment and nutrient loading by each landuse category. Channel, which is not in the landuse category, is a major contributor of sediment 46.64%, TN 15.45% and TP 25.05%. Cropland, which accounts for only 3.39% of entire watershed, is another major driver for water quality degradation in the lake contributing 31.16% of sediment, 14.90% of TN and 32.16% of TP. On the other hand, rangeland, which encompasses almost 60% of the watershed, generates relatively less sediment 10.86%, TN 44.10% and TP 14.46%.

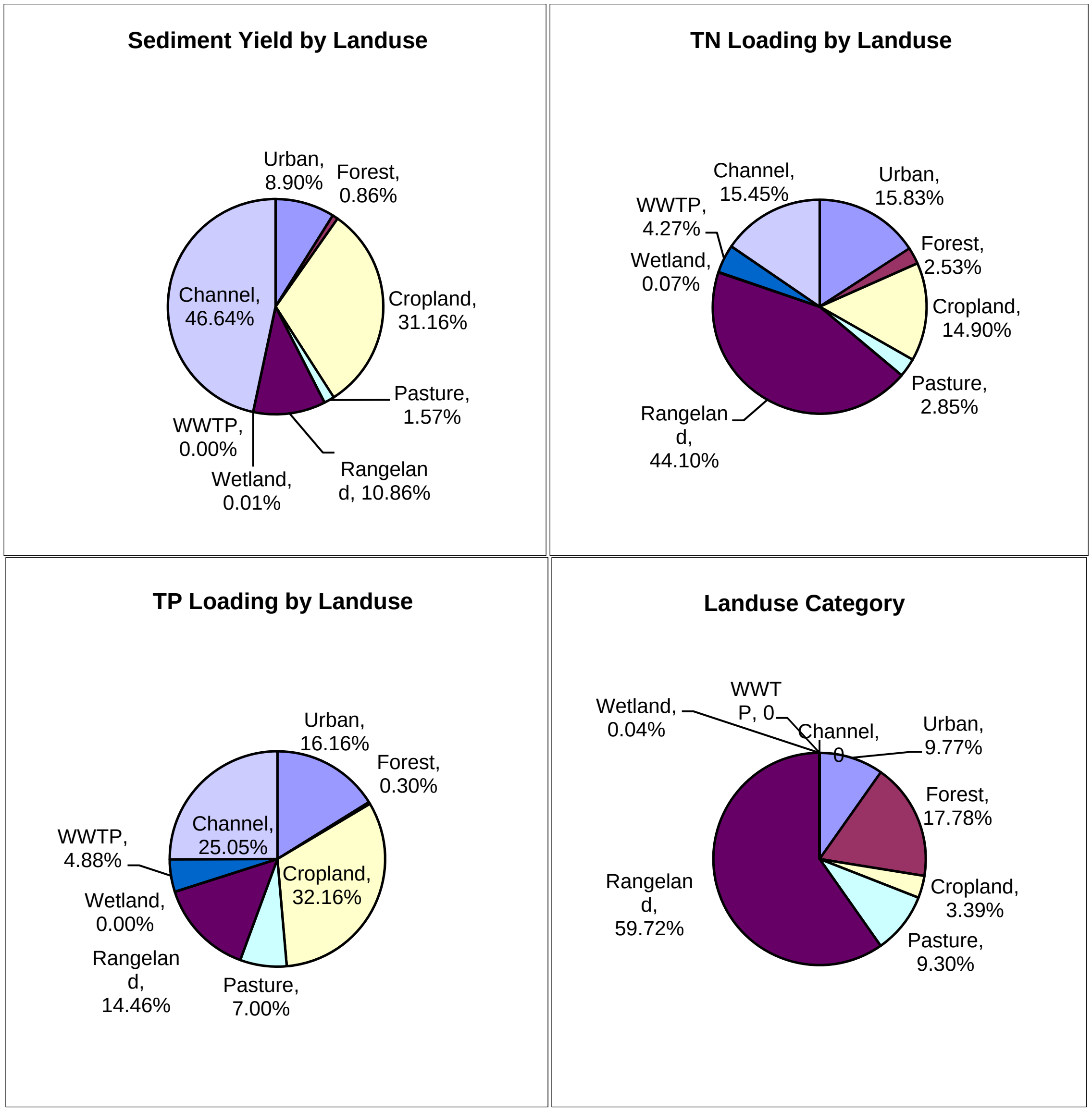


Figure 11. Sediment and nutrients loadings by landuse

2. Average annual load by subbasin

Sediment and nutrient loading by each subbasin are important to identifying 'hot spots' in the watershed and provides an overview of problems. Figure 12 through Figure 14 show sediment and nutrients loadings by subbasins. There is no significant 'hot spot' to intensively manage for pollutant area, but there is general trend that the eastern and southern parts of the watershed generate relatively more sediment and nutrients (red in maps). Those relatively high yield subbasins are the priorities to be managed by best management practices (BMPs). The next chapter describes how BMPs were simulated and what BMPs were necessary to reduce sediment and nutrient loadings to the lake.

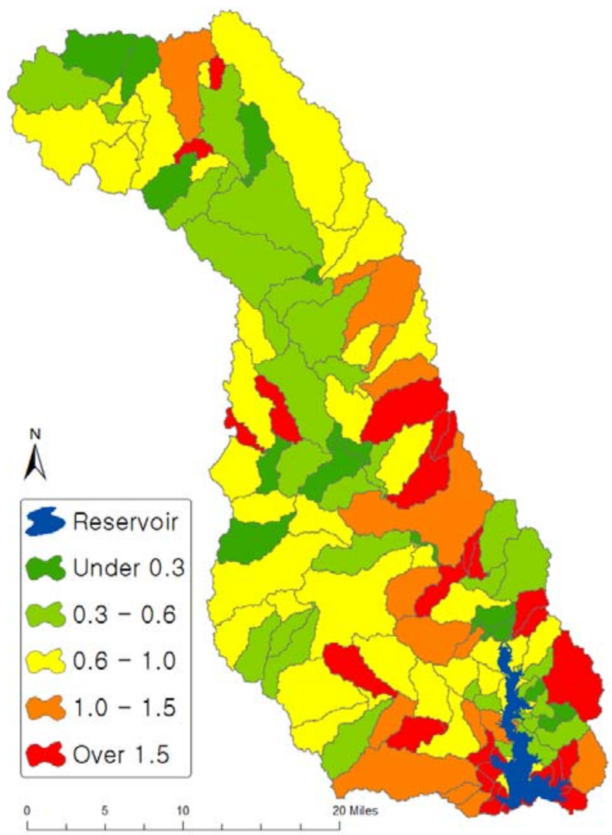


Figure 12. Sediment yield (t/ha) by overland flow predicted by SWAT

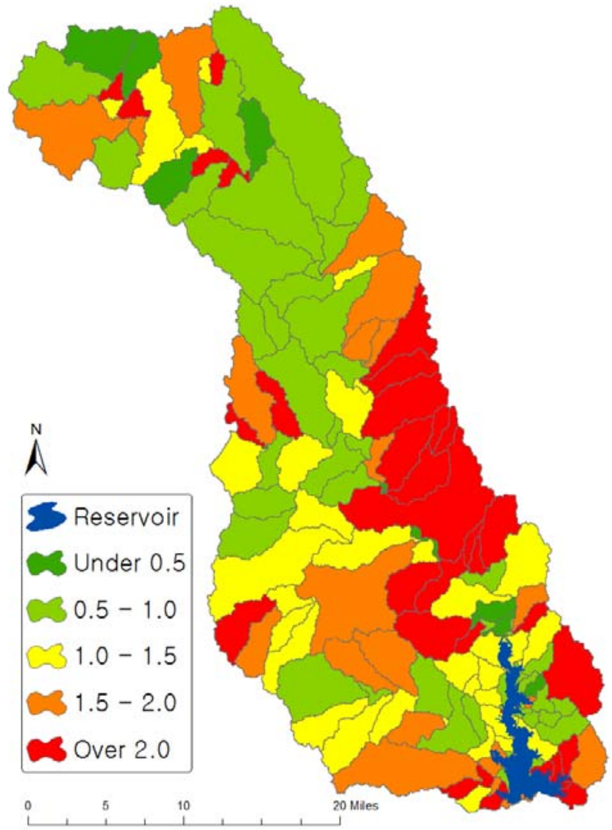


Figure 13. Total Nitrogen loading (kg/ha) by overland flow predicted by SWAT

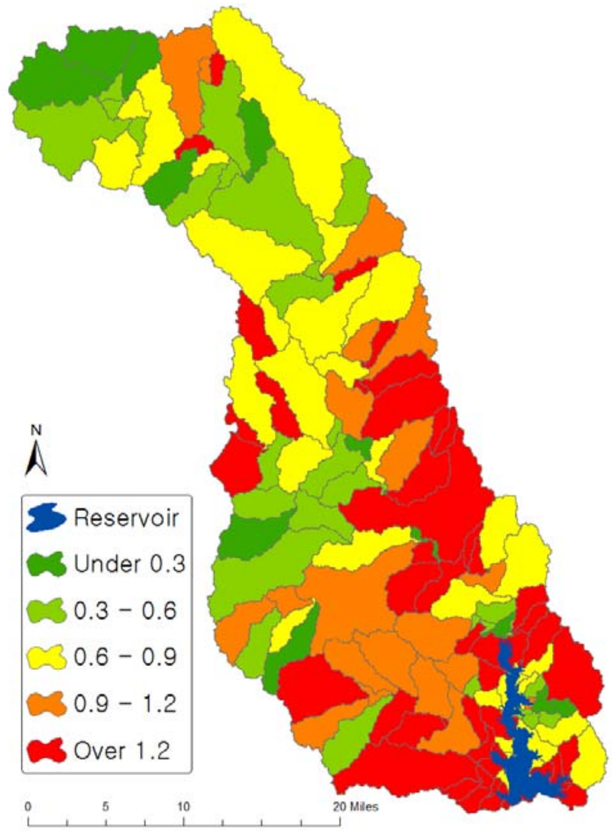


Figure 14. Total Phosphorous loading (kg/ha) by overland flow predicted by SWAT

3. Channel erosion

Sediment yield from each subbasin was calibrated in SWAT based on the Baylor Sediment Study (Allen et al., 2006) as mentioned earlier. Figure 15 and Figure 16 show the estimation of sediment loading by Baylor's study and SWAT. Each channel in the subbasins was categorized by low, medium, and high depending on the amount of channel erosion. The channel erosion from each subbasin was estimated in the model by difference between sediments coming in from above subbasin and from overland and sediments going out of the subbasin. The highly erosive channel segments were not matched very well as illustrated in both maps, mainly due to the higher erosion was estimated at the main channel by SWAT model at the first place, and it was very difficult to make two maps matched. By estimation of SWAT model, most of the channel erosion occurs in the main channel and West Fork sites (shown in red in the map).

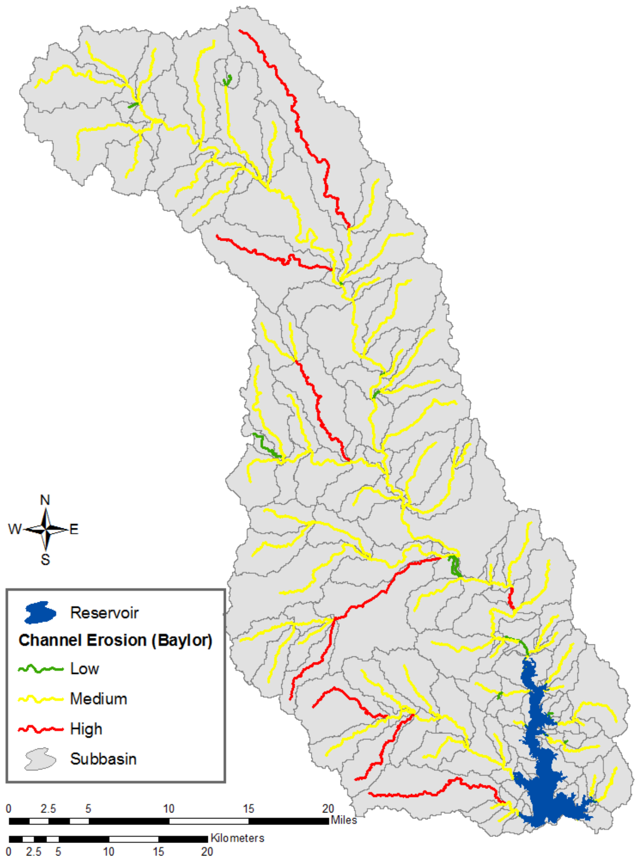


Figure 15. Channel erosion estimation by Baylor

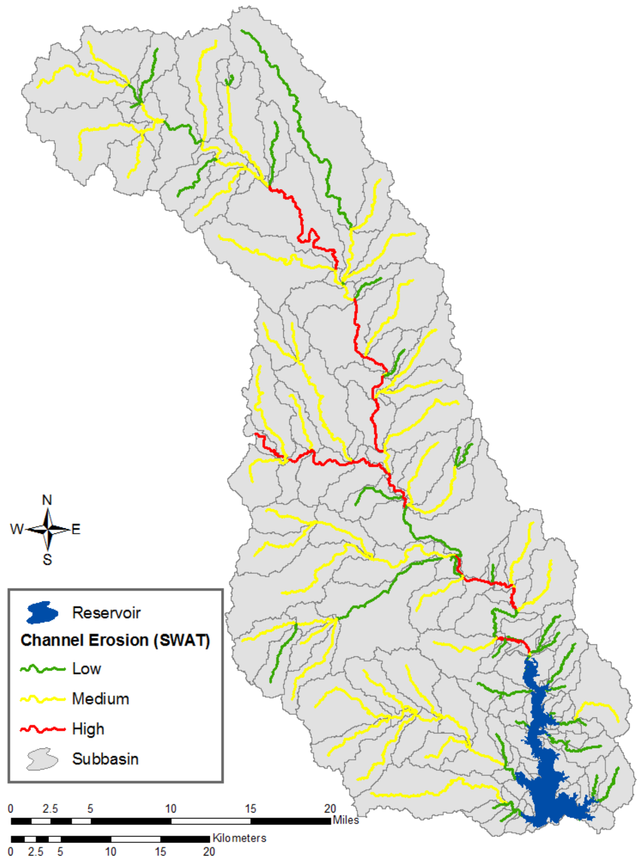


Figure 16. Channel erosion estimation by SWAT

BEST MANAGEMENT PRACTICES SCENARIOS

INTRODUCTION

The SWAT modeling results for Eagle Mountain watershed showed that the annual sediment yield to the lake was about 296,400 metric tons, the annual Total Nitrogen (TN) yield was 1,055,220 kg, and the annual Total Phosphorous (TP) yield was 173,020 kg (Table 17). To reduce the impacts on water quality at the lake, best management practices (BMPs) scenario need to be adopted. Based on the statistical analyses and consent from local stakeholders, the target of TP reduction has been set at 30%. A 30% reduction in TP results in a statistically significant reduction in Eagle Mountain Lake’s Chlorophyll ‘a’ level, a measure of eutrophication. Eighteen BMPs were simulated at the maximum practical rate or at a100% adoption rate in SWAT model, assuming those BMPs were implemented on all suitable land. The 100% adoption rate was also used for sensitivity analyses of each BMP and it provided useful information on the effectiveness of each BMP. To assess the 30% TP reduction goal, each BMP was implemented in the model one at a time until the total TP reduction at the lake reached 30%.

BEST MANAGEMENT PRACTICES (BMP) AND SIMULATION

Eighteen BMPs were implemented in the SWAT model at 100% adoption rate to estimate the effectiveness of the BMPs. Table 19 shows the reduction rate for sediment, TN, and TP by each BMP at 100% adoption rate. The reduction was estimated by implementing each BMP in SWAT model independently and the reduction rate was calculated as the difference in loading from the baseline model (Table 17). The most effective BMP to reduce sediment was riparian buffer (29.4% reduction), for TN the most effective was conversion of cropland to pasture (7.3% reduction) and for TP the most effective was also conversion of cropland to pasture (15.2% reduction).

Table 19. The individual effectiveness of BMPs at 100% adoption rate* as compared to the baseline model

BMPs	Area (ha)	Note	Reduction (%)		
			Sediment	Total N	Total P
1 Filter Strips	7,086	All Croplands	13.0	5.0	12.7
2 Grassed Waterway (10% Cropland)	1,418	Cropland Area in subbasins with more than 10% as cropland	3.8	0.2	3.1
3 Contour Farming	3,499	Cropland larger than 2% of slope	6.7	2.3	6.2
4 Terrace	3,499	Cropland larger than 2% of slope	7.1	2.5	6.8
5 Cropland Nutrient Management	7,086	All Croplands	0.0	-0.2	1.2
6 Cropland to Pasture	7,086	All Croplands	14.2	7.3	15.2
7 Prescribed Grazing	20,300	All Pasturelands	0.5	0.3	1.7
8 Pasture Planting	20,301	All Pasturelands	0.5	0.3	1.7
9 Critical Area Pasture Planting	77,125	Subbasin with more than 75% of Pastureland or Rangeland	1.8	4.6	1.5
10 2000 Ft Buffer	N/A		-4.6	0.7	5.1
11 Riparian Buffer	777	All Channels (Km)	29.4	2.4	3.3
12 Riparian Buffer in Critical Area	84	Channels in High Erosion Category (Km)	14.3	1.3	1.6
13 Graded Stabilization Structures	82,436	All Landuse (except Urban and Water) larger than 3% of slope	4.3	2.8	4.0
14 WWTP Level 2	N/A		0.0	-0.2	0.3
15 WWTP Level 3	N/A		0.0	0.3	0.6
16 Prescribed Burning	26,000	20% of total Rangeland	1.1	0.5	1.8
17 Aerial Herbicide	13,000	10% of total Rangeland	1.1	0.3	1.7
18 FP Sites (Ponds)	N/A	New Ponds in multiple subwatersheds	5.0	5.2	4.4

*Baseline: Sediment – 296,400 t/y, TN – 1,055,220 kg/y, and TP –173,020 kg/y

Cropland BMPs

Croplands are responsible for 31.2% of sediment yield, 14.9% of TN yield, and 32.3% of TP yield although the total area of cropland is only 3.4% of the watershed. Therefore, management practices on croplands are expected to be critical solution to reduce sediment and nutrient loading to the lake.

1) <u>Terrace (NRCS Practice Code: 600)</u>

Terracing is commonly used to decrease soil erosion by reducing surface runoff (Figure 17). Terraces are series of earthen embankments constructed across the field slope at designed vertical and horizontal intervals based on land slope and soil conditions. Construction of terraces involves a heavy capital investment to move large quantities of earth for forming the earthen embankment. Hence it has to be used only if other low cost alternates are determined to be ineffective.

Figure 17. Terrace

In the SWAT model, terraces were assumed to be constructed only on croplands with slopes larger than 2%. In the Eagle Mountain watershed a total of 3,499 ha (8,645 acres, 1.6% of total watershed) are classified as cropland with at least a 2% slop. For these croplands Universal Soil Loss Equation (USLE) support practice factor (USLE_P) was reduced to 0.5 and curve number (CN2) was reduced by 6 from the calibrated value. These values were selected based on the suggested values from the NRCS National Engineering Handbook and SWAT user manual.

The model results at 100% adoption rates for terracing showed an overall load reduction of sediment 7.1%, of TN 2.5%, and of TP 6.8% (Table 19). These overall reductions were based on the reduction at the lake (off-site), thus the reduction at each subbasin where terraces were implemented (on-site) was much higher. Phosphorus is more tightly attached to sediment, less soluble in water and conservative in nature. Hence, the reduction in sediment translates to almost equal reductions in total P. Whereas nitrogen is much more soluble, volatile to the atmosphere and moves readily in the solute phase; therefore the reduction in total N loading at the lake is proportionately less.

2) Contour farming (NRCS Practice Code: 330)

Contour farming involves performing critical farming operations (tillage, planting and other operations that disturb the soil) along the contour of the field. To simulate this BMP in SWAT, contour farming was assumed to be implemented on croplands with slope greater than 2%, the same lands simulated with terraces (Figure 18). For these croplands Universal Soil Loss Equation (USLE) support practice factor (USLE_P) was reduced to 0.5 and curve number (CN2) was reduced by 3 from the calibrated value.

The model results at 100% adoption rates for contour farming showed an overall load reduction of sediment 6.7%, of TN 2.3%, and of TP 6.2% (Table 19). These overall reductions were based on the reduction at the lake (off-site), thus the reduction at each subbasin where contour farming was implemented (on-site) was much higher.

Figure 18. Contour Farming

3) Conversion of Cropland to Grass – Pasture Planting (NRCS Practice Code: 512)

Soil erosion rate predicted for pasture land is about 0.2 t/ac as compared to 5.35 t/ac from cropland. Therefore, conversion of cropland to pastureland could be an effective BMP for sediment and nutrient control (Figure 19).

Figure 19. Pasture Planting

Implementation of this BMP was modeled as replacing all cropland into pastureland in the model. The pastureland in the Eagle Mountain watershed was assumed to be fertilized (67 kg N per hectare) every year with two hay cuttings per year on fertilized pasture. The curve numbers were also changed from cropland to pastureland conditions based on National Engineering Hand Book and SWAT user manual.

The model results at 100% adoption rate for conversion of cropland to pastureland showed an overall loading reduction at the lake of sediment 14.2%, of TN 7.3%, and of TP 15.2% (Table 19). These overall reductions were based on the reduction at the lake (off-site), thus the reduction at each subbasin where conversion was implemented (on-site) was much higher. This BMP was ranked and the most effective BMP among the cropland BMPs.

4) Grassed Waterway (NRCS Practice Code: 412)

A grassed waterway is often used to safely discharge the overland runoff to the main channel thus preventing the formation of gullies (Figure 20). The main function of grassed waterways is to reduce channel bottom erosion and flow velocity to protect channel geometry. It can also be used in conjunction with other conservation measures such as terraces to safely convey excess runoff.

In this study, grassed waterways were implemented only in subbasins that have at least 10% of croplands in the subbasin. It was simulated in the model by increasing Manning's n roughness coefficient in each subbasin from 0.014 to 0.15 to reflect a good channel cover in the tributary.

Figure 20. Grassed waterway

The model results for 100% adoption rate of grassed waterway showed an overall reduction of sediment loading to the lake of 3.8%, TN 0.2%, and of TP 3.1% (Table 19). These overall reductions were based on the reductions at the lake (off-site), thus the reduction at each subbasin where grassed waterway were implemented (on-site) was much higher.

5) <u>Filter Strips (NRCS Practice Code: 393)</u>

Filter strips are strips of dense grass or herbaceous vegetation placed at regular intervals across the slope of the field and at the field edges before discharging the overland flow to a stream (Figure 21). Properly maintained filter strips could effectively trap the sediments and nutrients from the overland flow and creates a good habitat for wildlife and beneficial insects.

Figure 21. Filter strips

SWAT models filter strips as simple edge-of-field vegetation with a trapping efficiency. The trapping efficiency is calculated based on the width of the filter as:

$$trap_{ef} = 0.367 \cdot \left(width_{filtstrip}\right)^{0.2967}$$

For a 15m filter the trapping efficiency is about 82%, i.e. 82% of sediment and nutrients generated from the contributing area to the filter strip is trapped.

The model results at 100% adoption rate for filter strips showed an overall load reduction of sediment at the lake of 13.0%, of TN 5.0% and of TP 12.7% (Table 19). These overall reductions were based on the reduction at the lake (off-site), thus the reduction at each subbasin where filter strips were implemented (on-site) is much higher.

6) Cropland Nutrient Management (NRCS Practice Code: 590)

Phosphorus is often linked to nutrient enrichment and lake eutrophication. Hence, a reduction in application of mineral phosphorus fertilizer could be an effective BMP to prevent lake enrichment. In the model, cropland nutrient management was implemented by reducing P fertilizer application from 34 kg/ha to 25 kg/ha for all croplands in the watershed.

The model results at 100% adoption rate for cropland nutrient management showed overall load reduction at the lake of sediment was 0.0% and TP 1.2%, and an increase loading of TN of 0.2% (Table 19). These overall reductions were based on the reduction at the lake (off-site), thus the reduction at each subbasin where nutrient management were implemented (on-site) is much higher.

Pasture and Rangeland BMP's

Pasture and rangeland account for the majority of the landuse in the Eagle Mountain watershed (69%). Pastureland occupies 9.3% and rangeland occupies 59.7% of the entire watershed. Fertilizer was applied on pastureland at a rate of 67 kg N per hectare. Based on model simulation, pastureland is responsible for sediment loading of 1.57%, TN 2.85%, and TP 7.0% from entire loading at the lake. On the other hand, the percentages of loadings from rangelands are 10.86% for sediment, 44.1% of TN, and 14.46% of TP.

1) Prescribed grazing (NRCS Practice Code: 528), Pasture planting (NRCS Practice Code: 512)

Overgrazing by browsing cattle or machines could impede establishment of healthy and dense grass stands in rangeland and pastures leaving the top soil exposed to erosion. This could be minimized through prescribed grazing. Controlled harvest of vegetation through grazing rotation or prescribed grazing (Figure 22) that allows for establishment of a dense vegetative stand could reduce soil erosion and retain soil nutrients. Further, native or introduced forage species that are well adapted to North Central Texas could be planted periodically to maintain a dense vegetative cover and improve the hydrologic condition of the land. Similarly well adapted perennial vegetation such as grasses, legumes, shrubs and trees could be planted in rangeland with medium to low vegetation cover.

Figure 22. Prescribed grazing

For simulation in the model, pastureland was assumed to be in fair hydrologic condition (USLE_C, cover factor: 0.007). These two BMPs would improve the groundcover of the pasture across the watershed. Implementation of these BMPs was done by reducing the USLE_C factor for pasture across the watershed, which was SWAT's default value for good ground cover of vegetation.

The model results at 100% adoption rate for prescribed grazing and pasture planting showed an overall reduction of sediment loading at the lake of 0.5%, of TN 0.3%, and of TP 1.7% (Table 19).

2) Grassed waterway (NRCS Practice Code: 412) as critical area pasture planting

Grassed waterway (Figure 20) was implemented on subbasins with at least 75% pastureland or rangeland (77,125 ha). The channel Manning's roughness factor was increased from 0.014 to 0.15 to reflect a good channel cover in the tributary.

The model results at 100% adoption rate for critical pasture planting showed an overall reduction of sediment loading at the lake of 1.8%, of TN 4.6%, and of TP 1.5% (Table 19).

3) Prescribed Burning

Conducting prescribed burns of rangeland reduces brush thereby allowing greater cover of grass. Grasslands with good cover are less erodible than pastures with brush; therefore, denser grass reduces runoff and sediment entering the waterbody. In the model, rangelands that touch channels were selected to be candidates. Of the total rangeland acreage, only 20% meet this criteria and where therefore eligible for 100% adoption of the BMP. In the model, prescribed burning was represented by decreasing CN by 5 and decreasing C factor from 0.003 to 0.001.

The model results at 100% adoption rate for prescribed burning showed an overall reduction of sediment loading at the lake of 1.1%, of TN 0.5%, and of TP 1.8% (Table 19).

4) Areal Herbicide Application

Applying herbicide kills brush and other unwanted woody plant and weeds and allows for the re-vegetation of the land with denser grass, leading to better cover of the soil. For the purposes of this study areal herbicide application was applied only along the main channel in 10% of the rangeland. In the model, the representation of the BMP was the same as prescribed burning, which was decreasing CN by 5 and decreasing C factor from 0.003 to 0.001.

The model results at 100% adoption rate for areal herbicide application showed an overall reduction of sediment loading at the lake of 1.1%, of TN 0.3%, and of TP 1.7% (Table 19).

Channel BMP's

Eagle Mountain watershed has about 777 km of channel. The SWAT simulation shows that about 46.6% of total sediment, 15.5% of total N, and 25.1% of total P are coming from channel erosion. Therefore, control of channel erosion is one of the most important practices to reduce the sedimentation rate and to improve the water quality of the lake.

1) Riparian Buffers (NRCS Practice Code: 390, 391)

Riparian area is a fringe of land that occurs along the stream or water courses with grass and herbaceous cover. If the riparian buffer, shown in Figure 23, is not adequately established and farming activities continue to the edge of the stream, the banks become unstable resulting in significant sloughing and channel scour. Establishing and maintaining a good riparian buffer, stabilizing channels and protecting shorelines considerably reduce channel erosion.

Figure 23. Riparian Buffer

The riparian buffer was simulated in SWAT by assuming that a good riparian buffer and channel cover (channel cover factor (CH_COV) in SWAT as 0.1) are established along various stream segments with poor riparian buffers and channel cover.

The model results at 100% adoption rate for riparian buffer showed an overall reduction of sediment loading at the lake of 29.4%, of TN 2.4% and of TP 3.3% (Table 19).

2) Riparian Buffers in critical area (NRCS Practice Code: 390, 391)

Instead of implementing riparian buffer on all channels, implementing them only on critical channels was simulated using the same representation as riparian buffer above. In the Eagle Mountain watershed, there are 84 km of critical channel (categorized as critical in Figure 16), which is about 10.8% of the total channel length.

The model results at 100% adoption rate of riparian buffer in critical areas showed an overall reduction of sediment loading at the lake of 14.3%, of TN 1.3%, and of TP 1.6% (Table 19).

Watershed BMPs

1) Grade Stabilization Structures (NRCS Practice Code: 410)

Grade stabilization structures (Figure 23) are constructed to control the grade and head cutting in channels. These structures are warranted only if the slope changes abruptly within a short distance. Based on the properties of this BMP, graded stabilization structures in this study were implemented in subbasins with slopes greater than 3%. Some portion of these subbasins and tributary channels could have abrupt slopes, which have to be verified by field investigations. In such circumstances grade stabilization structures could considerably reduce soil erosion.

Figure 24. Graded Stabilization Structure

The effect of grade stabilization structures is to reduce the energy of flowing water due to slope. Therefore, grade stabilization structures are simulated in SWAT by reducing the slope of the subbasins. The overland slope that was greater than 3% was reduced to 3%.

The model results at 100% adoption rate for graded stabilization structures showed an overall reduction of sediment loading at the lake of 4.3%, of TN 2.8% and of TP 4.0% (Table 19).

2) Waste Water Treatment Plant Level II and III

There are a total of 14 (2 of them are discharging directly to the lake) WWTPs in Eagle Mountain watershed (Figure 6). The loading by WWTP level II and III is reduced loading rate by better controlling and processing at each plant. WWTP level II and III as BMPs were simulated based on the discharging information for each level.

The model results at 100% adoption rates for WWTP level II showed an overall reduction of sediment loading at the lake of 0.0%, of TN 0.2% increased, and of TP 0.3% (Table 19). The reason that TN with level II was increased over the baseline was that the current discharge of wastewater is often better than 10 mg/L concentration proposed for Level II.

The model results at 100% adoption rates for WWTP level III showed an overall reduction of sediment loading at the lake of 0.0%, of TN 0.3% and of TP 0.6% (Table 19).

3) Flood Prevention (FP) Sites (New ponds)

Seventeen FP sites have been planned in Eagle Mountain watershed and have not yet been constructed and were simulated in the SWAT model as a BMP. A pond traps runoff and provides time for sediment to fall out of the water while it controls the volume of runoff downstream. Each subbasin has pond option to be input as a contributing area in SWAT. To represent a new pond, the new area was added onto the area of contributing to ponds in each subbasin based on the contributing area calculated for new ponds.

The model results at 100% adoption rates for contracting new FP sites showed an overall reduction of sediment loading at the lake of 5.0%, of TN 5.2% increased, and of TP 4.4% (Table 19).

BEST MANAGEMENT PRACTICES (BMP) ADOPTION

1. Implementing BMPs for reduction goal

With TP reduction estimated by SWAT at 100% adoption rate, economic analyses found marginal adoption rates of each BMP and the cost to implement in the watershed. Marginal adoption is the difference between the most likely adoption rate and the current adoption rate in the field. Table 20 shows the rank of BMPs by least cost and their marginal adoption rate.

Based on the economic analyses, BMPs were implemented into the SWAT model until total annual TP reduction reached 30% at the lake. Below is the summary of the methodology for SWAT simulation.

a. Implement least cost BMP on subbasin with highest TP loading (subjected to BMP condition)

b. Run SWAT and calculate TP load reduction at the lake

If total TP reduction of 30% for the watershed is not reached, go to the next lowest cost BMP and implement on subbasin with highest TP loading

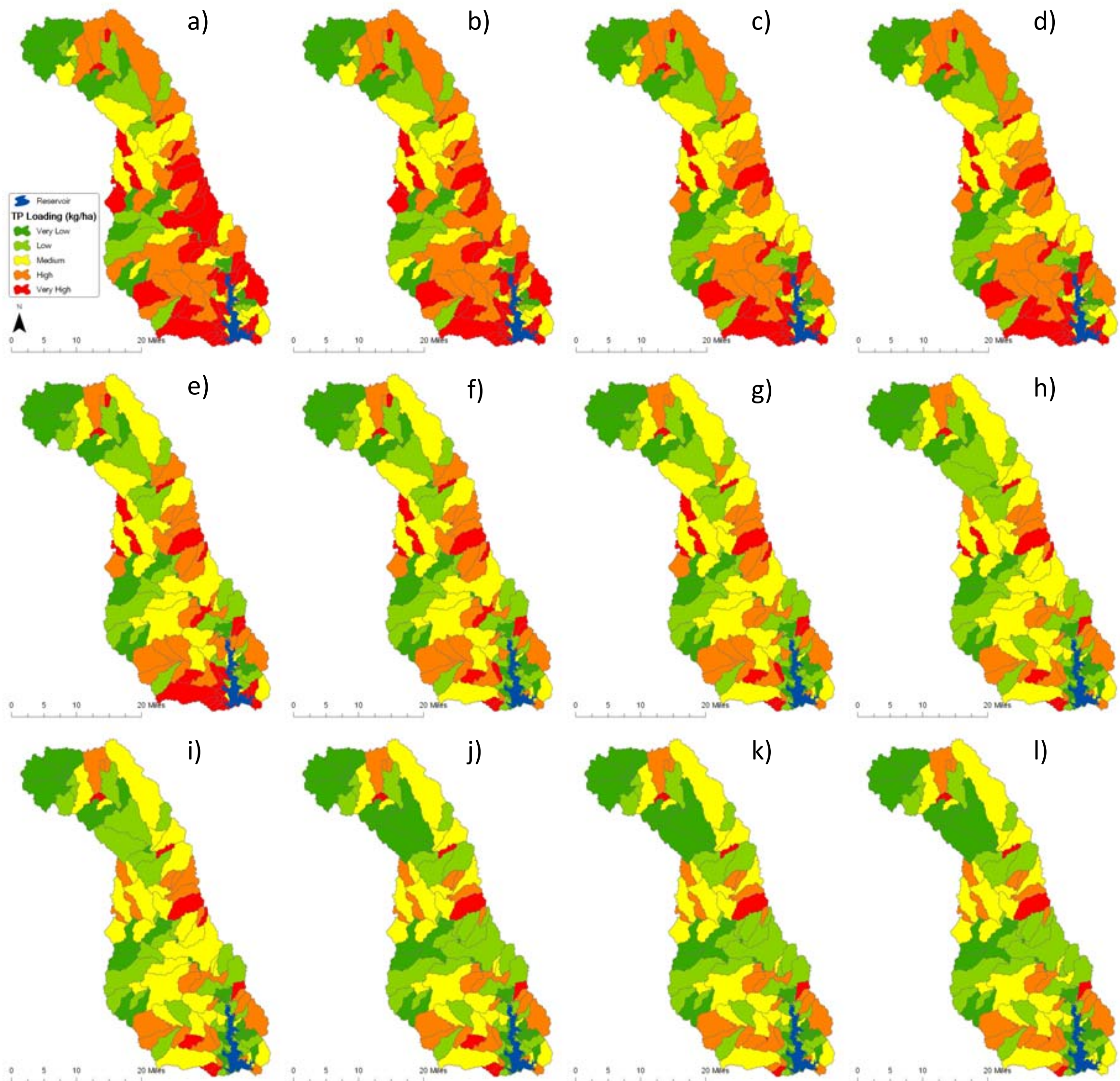
The results show that a total of 13 BMPs are necessary to achieve a 30% TP reduction annually at the lake (Table 20). Sediment, TN, and TP shown in Table 20 are accumulated reduction as each BMP was implemented in order. There are two BMPs that were not simulated in SWAT, P Inactivation with Alum and the wetland on the West Fork of the Trinity River. The reduction rates from P Inactivation with Alum was independent of SWAT model, therefore, the reduction rate was simply subtracted from the previously implemented BMP.

Table 20. Implementation of BMP by the order of cost until the TP reduction reaches at 30%

	BMPs	Adoption Rate	Sediment	Total N	Total P
			Reduction (%)		
1	Graded Stabilization Structures	25%	1.3	1.2	2.1
2	Filter Strips	25%	7.0	3.5	6.0
3	Grassed Waterway	10%	7.0	3.4	7.8
4	Herbicide Application	5%	9.6	5.6	8.5
5	2000 Ft Buffer	60%	8.1	6.1	12.3
6	Terrace	10%	8.5	6.3	14.0
7	Conversion Cropland to Pasture	25%	10.6	7.2	20.5
8	Prescribed Burning	4%	10.8	7.3	21.3
9	P Inactivation with Alum	100%			24.6
10	FP Site	100%	14.9	12.3	28.8
11	Prescribed Grazing (Pasture Planting)	25%	15.0	12.4	29.1
12	Brush Management	20%	15.3	11.1	29.4

2. Spatially distributed effectiveness

The effectiveness of each BMP was simulated not only to reach the TP reduction goal (30%) but also analyzed for spatially distributed impacts. Every time a BMP was simulated/ implemented as shown in Table 20, TP loading maps were re-drawn for subbasin level assessment. Figure 25 shows the sequential, spatially distributed effectiveness of each BMP. The series of maps shows TP reduction in each subbasin compared to the baseline simulation for TP reduction in each subbasin. TP reductions in each subbasin were accumulated reduction as each BMP was added one at a time. Some red colored subbasins remain on the map even with the implementation of 13 BMPs. The reason that no BMPs were implemented in these subbasins was those subbasins did not have chances for BMPs to be implemented due to the condition of the subbasins and the criteria of BMPs.



a): baseline, **b):** Graded stabilization structures, **c):** b) + Filter strips**, d):** c) + Grassed waterway, **e):** d) + Herbicide application, **f):** e) + 2000 ft buffer, **g):** f) + Terrace, **h):** g) + Conversion cropland to pasture, **i):** h) + Prescribed burning, **j):** i) + FP sites, **k):** i) + Prescribed grazing. **l):** k) + Brush management

Figure 25. Spatially distributed effectiveness of BMPs

REFERENCES

Allen, P.M., J. A. Dunbar, S. Prochnow, and L. Zygo. 2006*. Eagle Mountain: Stream Erosion and Reservoir Volume Evaluation*. Baylor University and SDI Inc. April 2006.

Arnold, J.G., P.M. Allen, R.S. Muttiah, G. Bernhardt. 1995a. Automated Base Flow Separation and Recession Analysis Techniques. *GROUND WATER*, Vol. 33, No. 6, November-December.

Arnold, J.G., J.R. Williams, D.R. Maidment. 1995b. A Continuous Water and Sediment Routing Model for Large Basins. *American Society of Civil Engineers Journal of Hydraulic Engineering*. 121(2): 171-183.

Knisel, W.G. 1980. *CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems*. United States Department of Agriculture Conservation Research Report No. 26.

Leonard, R.A. Knisel, W.G., and Still, D.A. (1987), 'GLEAMS: Groundwater Loading Effects of Agricultural Management Systems,' *Transactions of ASAE*, vol. 30, pp. 1403-1418.

Nash, J. E. and Sutcliffe, J. V., 1970, River flow forecasting through conceptual models: Part I - A discussion of principles, *Journal of Hydrology*, 10, 282-190.

Srinivasan, R., T. S. Ramanarayanan, J. G. Arnold, and S. T. Bednarz (1998), Large area hydrologic modeling and assessment. Part II: Model application, *J of American Water Resource*. Assoc., 34(1), 91-101.

Williams, J. R. 1990. The erosion-productivity impact calculator (EPIC) model: A case history. *Phil. Trans. Royal Soc. London* 329: 421-428.

Williams, J.R., A.D. Nicks, and J.G. Arnold. 1985. Simulator for Water Resources in Rural Basins. *J. Hydraulic Engineering*, ASCE, 111(6): 970-986.

Appendix C

Task 2 Economic Analysis

- A draft final report entitled “Evaluating the Economics of Best Management Practices for Tarrant Regional Water District’s Cedar Creek Reservoir” is in the process of being developed and will be completed next quarter.

- A report entitled “Evaluating the Economics of Best Management Practices for Tarrant Regional Water District’s Cedar Creek Reservoir” is in final draft form and is awaiting comments from Tarrant Regional Water District and Dallas Urban Solutions Center.

- An Ag Producers meeting was planned and will be held in mid April to collect the BMP scenarios that are necessary to begin running the economic model. The time that Dr. Johnson began on the project to the time of the Ag Producers meeting will be utilized to review activities that have been conducted and work with TRWD to ensure that their needs are met.

- Upon completion of the data collection period, the model will be run and it is anticipated that inputs for SWAT will be ready by late April.

- A second Ag Producers Meeting is planned for Mid-May to ensure that results are accurate.

Appendix D

COLLEGE OF AGRICULTURE
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Evaluating the Economics of Best Management Practices for Tarrant Regional Water District's Eagle Mountain Lake Watershed

By
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Texas A&M University and Texas AgriLife Extension Service

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Executive Summary

The objective of this assessment was to identify the most cost-effective means of reducing (and/or preventing) total phosphorus (TP) inflows into the Eagle Mountain Lake from a comprehensive set of Best Management Practices (BMPs). Additionally, the reduced total nitrogen (TN), and sediment inflows resulting from adoption of these BMPs was also calculated. To achieve the desired water quality improvements, management consulting engineers indicated that the collective assortment of BMPs needed to reduce TP inflows by approximately 30 percent below current levels. During 2009-2011, Texas AgriLife Extension Service and Texas AgriLife Research scientists, in conjunction with Tarrant Regional Water District (TRWD) managers, NRCS professionals, and others worked to identify a portfolio of BMPs capable of contributing to such reductions. The economics component of this project consisted of integrating the simulation modeled results of nutrient and sediment inflow dynamics with the associated costs of BMP implementation. This BMP cost analysis provides a basis for the evaluation of a suite of BMPs that could be expected to result in meaningful TP inflow reduction. The final task was to identify the cost-effective combination of BMPs that could be expected to achieve the management target of a 30 percent reduction in TP inflow into the Eagle Mountain Lake over a 50-year project period.

Background of the Project

The Tarrant Regional Water District (TRWD) operates five major water-supply reservoirs in the Fort Worth-Dallas area - Benbrook, Bridgeport, Eagle Mountain, Richland-Chambers, and Cedar Creek. As of 2010, TRWD served a total of 1.7 million consumers as its customer base through over 30 municipalities. TRWD's principal customers are Fort Worth, Arlington, Mansfield, and the Trinity River Authority. Firm in its commitment to deliver high quality water to its customers, TRWD has been proactive in monitoring water quality on these reservoirs.

The Eagle Mountain watershed is located in the eastern portion of the Upper West Fork Trinity Basin including Lake Bridgeport and Eagle Mountain Lake; both impoundments of the West Fork of the Trinity River. Bridgeport flow, sediment and nutrient loads were modeled as a point source into the Eagle Mountain watershed. The remaining 860 square miles to the southeast of Lake Bridgeport drain to Eagle Mountain Lake and are the focus of this investigation.

The impetus for a watershed protection plan comes on the heels of a 20-year water quality analysis project performed by TRWD (Tarrant Regional Water District, 2011). Reservoir managers were charged with producing a long term trend analysis of water quality within the lake and watershed and in doing so were able to establish trend analysis of the Chlorophyll-a, sediment, nitrogen, and phosphorus levels. Watershed conditions including soil erosion, land use, and water pollutant loadings have been assessed for Eagle Mountain using both computer models and ambient water quality testing. An examination of the data from the third quarter main pool sites demonstrated a rising trend of Chlorophyll-a in Eagle Mountain Lake at an annual percentage rate of 3.62 percent. Extrapolation of this rate suggests that chlorophyll-a rate will double in 19 years. Eagle Mountain Lake (Segment 0809) is reported in the 2010 Draft Texas Integrated Report for Clean Water Act Sections 305(b) and 303(d) as having elevated Chlorophyll-a levels in various sections of the lake.

Modeling of Environmental Factors

This investigation of the Eagle Mountain watershed examines the impact of various BMPs on total phosphorous (TP), nitrogen (TN) and sediment inflow into Eagle Mountain Lake. The modeling of BMP effectiveness plays an important role in developing a watershed protection plan. The spatially distributed impacts of BMPs can be helpful for decision makers and stakeholders to identify specific remediation target areas and to identify the most suitable solution(s). The mitigation of water quality problems through the implementation of multiple BMPs in a watershed is a classic scenario in the protection of reservoirs. The ability to evaluate the merit of individual as well as a suite of BMPs and determine the cost-effectiveness of these options permits the evaluation of management plans with lower costs and increased flexibility prior to implementation.

Utilization of several modeling techniques has enabled the project team to integrate attributes of the Eagle Mountain Lake watershed and the Eagle Mountain Lake's performance dynamics in handling nutrient and sediment inflows. The Soil and Water Assessment Tool (SWAT) is a watershed and landscape simulation model designed to help decision makers evaluate soil and water resources at the watershed and river basin scales. The SWAT system is a multi-functional modeling tool that can be used to analyze potential management activities within watersheds and evaluate the impact that those practices have on selected environmental factors. The model operates on a continuous, daily-time step, which makes it capable of simulating changes over many years. Simulation of the watershed encompasses all aspects of the hydrologic cycle including land, water, and atmospheric interactions. SWAT mimics the flow of water within the watershed, allowing it to assess water quality and quantity changes due to alterations in global climate, land use, policy, and technology. SWAT was run for a 35 year period on the Eagle Mountain Lake watershed from 1969 to 2004 to estimate annual loadings of TP, TN and sediment to Eagle Mountain Lake.

Daily mass loadings and inflows from the SWAT model were supplied to the Water Quality Analysis Simulation Program (WASP) model to simulate the lake water quality for a 10 year period from 1994 through 2003. WASP provides water quality planners a dynamic tool to assess management strategies such as nutrient reduction. WASP is a finite-difference model used to interpret or predict possible changes in the water quality of ponds, lakes, reservoirs, rivers and coastal waters brought about by pollutants. Use of the WASP modeling techniques allowed project consultants to determine the impact of sediment and nutrients within a horizontally- and vertically-segmented model of Eagle Mountain Lake. WASP was used in the Eagle Mountain planning efforts to systematically determine the necessary phosphorus load reductions that resulted in statistically significant reductions in Chlorophyll-a at a main lake site.

Although the full scope of the project encompasses attention to TP, TN and sediment annual inflows, the primary objective for the economics analysis of the Eagle Mountain Lake watershed was to identify the most economic, cost-efficient means of reducing the current inflows of TP by 30 percent. A first step toward realizing this objective is to review and define all BMPs that have the potential to be technically and economically feasible. Technical feasibility means that the management practice results in measurable reductions in TP inflows. Economic feasibility suggests that the management practice is both likely to be adopted, implemented and maintained and done so in a manner that is financially acceptable. The consideration of potential BMPs began with a list compiled for the Cedar Creek watershed and was modified to remove BMPs that were unsuitable for the Eagle Mountain watershed while adding new BMPs that were deemed to be more appropriate (Rister et al., 2009).

The end result of this organized "sifting process" was an array of BMPs that were initially identified for TRWD's consideration. For each of these BMPs, an array of economic and financial information had to be compiled and integrated in order to assess the relative environmental and economic merits of the alternative practices over the term of the 50-year project period. The information related to each BMP specifically included:

- level of current implementation and magnitude of additional adoption possible;
- the reduction impacts on TP, TN, and sediment inflow expressed in the same units, i.e., as a total percent of the initial inflow levels;
- expected life (i.e., years of productive reduction in TP, TN, and sediment) for the BMP;
- construction period, i.e., what length of time is required to construct and implement the BMP;
- initial investment and practice establishment costs (including incentives) required;
- recurring annual costs required, i.e., operating and maintenance costs;
- intermediate capital replacement costs to insure each BMP reaches its expected useful life; and
- appropriate inflation rate by which to increase future costs.

Description of the Best Management Practices (BMPs)

A short discussion of 24 BMPs identified as potentially suitable for the Eagle Mountain Lake watershed are presented below. A detailed discussion regarding the expected environmental impacts and respective implementation costs for these BMPs over the 50-year project period will be provided in later sections.

Cropland BMPs

<u>BMP 1 Conversion of Cropland to Grass.</u> Conversion of cropland to grass acreage falls under the USDA-NRCS Conservation Reserve Program in which producers receive financial assistance to retire lands from growing annual crops and establish perennial pastures (grass or hay). This practice works to establish a permanent vegetative cover to allow for the utilization of nutrients and minimizes soil disturbance and erosion (USDA National Resources Conservation Service 2010). It is assumed that converted cropland will be used for haying rather than livestock, eliminating the need for fences and water ponds as part of the transition process. For the purposes of this economic analysis, it is assumed the conversion is permanent, extending throughout the 50-year project planning horizon. Overall, one acre of all cropland acres deemed eligible for the practice is considered as the management unit of analysis for this BMP.

<u>BMP 2 Fertilizer/Nutrient Management - 25 percent reduction in P with split applications.</u> This BMP involves a 25 percent reduction in phosphorous application on cropland, with two split applications, one preplant and the other after the crop has emerged. The intent is to manage the amount, source, placement, form, and timing of the application of plant nutrients and soil amendments to minimize agricultural nonpoint source pollution of surface soil and groundwater resources. Soil fertility testing is an important element of nutrient management and this BMP. Soil testing encourages the budget and supply of nutrients for plant production, and proper utilization of manure and organic materials (USDA Natural Resources Conservation Service 2010). For the purposes of this economic analysis, it is assumed this BMP has an expected life of one year. The management unit of analysis is one acre on all cropland acres deemed eligible for the practice.

<u>BMP 3 Establishment of Filter Strips.</u> Filter strips are vegetated areas that are situated between surface water bodies (i.e. streams and lakes) and cropland, grazing land, forest land, or disturbed land. They are generally located where runoff water leaves a field for the purpose of trapping or filtering sediment, organic material, nutrients, and chemicals from the runoff water. Filter strips are also know as vegetative, filter or buffer strips and are commonly about 15 meters in width. Specifically designed vegetative strips slow runoff water leaving a field so that larger particles, including soil and organic material, can settle out. Due to the entrapment of sediment and establishment of vegetation, nutrients can be absorbed into the sediment that is deposited and can remain on the field landscape, enabling plant uptake of the nutrients (USDA National Resources Conservation Service 2010). For the purposes of this economic analysis, this BMP has an expected life of five years. The management unit of analysis is 21 acres, with one acre of filter strip per 20 acres of cropland, on all cropland acres deemed eligible for the practice.

<u>BMP 4 Establishment of Grassed Waterways.</u> Grassed waterways are natural or constructed channels established for the transport of concentrated flow at safe velocities using adequate vegetation. The vegetative cover slows the water flow, minimizing channel surface erosion. When properly constructed, grassed waterways can safely transport large flows of runoff down slopes. This conservation practice improves the soil aeration and water quality due to its nutrient removal through plant uptake and sorption by the soil. Entrapment of sediment and the establishment of vegetation allow nutrients to be absorbed into the trapped sediments and to remain in the agricultural field rather than being deposited into the different waterways. A grassed waterway is often used to safely discharge the overland runoff to the main channel, thus preventing the formation of gullies. Grassed waterways are graded to required dimensions based on the field conditions, while permanent vegetation is established to maintain the grade. Grassed waterways can also be used in conjunction with other conservation measures, such as terraces, to safely convey the excess runoff (USDA National Resources Conservation Service 2010). For the purposes of this economic analysis, this BMP has an expected life of 10 years. The management unit of analysis is 41 acres, with one acre of filter strip per 40 acres of cropland, on all cropland acres deemed eligible for the practice.

BMP 5 Terracing. Terraces consist of a series of earthen embankments constructed across fields at designed vertical and horizontal intervals based on land slope, crop rotation, and soil conditions. Construction of terraces involves a heavy capital investment to move large quantities of earth for forming earthen embankments. Terracing is recommended for land with a grade of two percent or higher (USDA National Resources Conservation Service 2010). For the purposes of this economic analysis, this BMP has an expected life of 10 years. The management unit of analysis is 21 acres, with one acre of terraces per 20 acres of cropland, on all cropland acres deemed eligible for the practice.

Pasture and Rangeland BMPs

BMP 6 Prescribed Grazing. Prescribed grazing is the controlled harvest of vegetation with grazing animals, managed with the intent to improve or maintain desired species competition and vigor of plant communities. This BMP prevents soil erosion by maintaining a permanent vegetative cover on grazed fields and pastures and increases harvest efficiency by ensuring adequate forage throughout the grazing season. Prescribed grazing involves rotating livestock to enable vegetative re-growth and includes the combined use of fencing and stock watering facilities (USDA National Resources Conservation Service 2010). This practice can be used to improve or maintain surface and/or subsurface water quality and quantity. It reduces accelerated soil erosion, maintains or improves soil condition, and can improve or maintain riparian and watershed function. This practice applies to all lands where grazing and/or browsing animals are managed. For the purposes of this economic analysis, it is considered that the adoption of this BMP is permanent. The management unit of analysis is 500 acres on all pasture and rangeland acres deemed eligible for the practice.

BMP 7 Pasture Planting. Pasture planting involves planting (reseeding) of pastures with native or introduced vegetation and allows for the reduction and absorption of nutrients. Grass, forbs, legumes, shrubs, and trees work to restore a plant community similar to historically natural conditions. Further, native or introduced forage species that are well adapted to North Central Texas could be planted periodically to maintain a dense vegetative cover and improve the hydrologic condition of the rangeland. Similarly, well adapted perennial vegetation such as grasses, legumes, shrubs and trees could be planted in rangeland with medium to low vegetative cover (USDA National Resources Conservation Service 2010). For the purposes of this economic analysis, it is assumed that the expected life of this practice is 10 years. The management unit of analysis is 10 acres, with one acre reseeded and the remaining nine acres assumed to have adequate grass cover, on all pasture and rangeland acres deemed eligible for the practice.

BMP 8 Critical Pasture Area Planting. This BMP is similar to BMP7 (Pasture Planting), with two major variations. First, the "critical pastureland area" refers to gullied areas which require mechanical "shaping" prior to the reseeding operation which is not necessary with BMP 7. Second, the density of such critical areas and the associated requisite reseeding is less than that for BMP 7, with only one acre reseeded per 40 acres assumed to have adequate grass cover. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 10 years. The management unit of analysis is 41 acres, with one acre reseeded and the remaining 40 acres assumed to have adequate grass cover, on all pasture and rangeland acres deemed eligible for the practice.

BMP 9 Grade Stabilization - Gully Plugs. Grade stabilization structures are constructed lakeside, along the stream bank, or across a gully or grass waterway with reinforcements placed to reduce erosion and sedimentation from steep embankments that are prone to soil loss during storm events. A dam or embankment drops water to a lower elevation while protecting the soil from gully erosion or scouring. Structures are typically a small dam and basin with a pipe outlet. Structures must be logistically situated for maximum effectiveness. Structures for this BMP are designed as "gully plugs," requiring approximately 4,500 cubic yards of dirt work per structure. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 25 years. The management unit of analysis is one structure with one structure being appropriate for every 1,000 hectares (2,471 acres) of pasture and rangeland acres deemed eligible for the practice.

BMP 10 Prescribed Burning. Prescribed burning is the practice of applying controlled fire to a predetermined area to control undesirable vegetation and improve plant production quantity and/or quality. This practice has been shown to enhance seed and seedling production, facilitate distribution of grazing and browsing animals, and restore and maintain ecological sites. This BMP requires a period of pre-burn restricted grazing to allow for sufficient fuel load and post-burn restricted grazing enabling forage re-growth as well as a formal burn plan that complies with all applicable federal, state and local laws and regulations. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 10 years. The management unit of analysis is 200 acres on all pasture and rangeland acres deemed eligible for the practice.

BMP 11 Brush Management. Brush management is the removal, reduction, or manipulation of woody trees and shrubs to restore desired vegetative cover to protect soil from erosion, reduce sediment, improve water quality, and enhance species diversity. Brush management practices can be accomplished using one or a combination of the following alternatives: mechanical, prescribed burning, chemical/herbicide applications, or biological (i.e. intensive grazing with goats). For the Eagle Mountain Lake watershed, it was determined that a combination of mechanical and chemical applications would be the most likely methods employed. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 10 years. The management unit of analysis is 20 acres on all pasture and rangeland acres deemed eligible for the practice.

Urban BMPs

BMP 12 Phase II Urban Stormwater BMP's. Phase II urban stormwater practices represent a combination of educational programming for residents and the creation and enforcement of ordinances for new development and construction projects. These ordinances typically involve common practices such as utilization of sediment fences, porous pavement, storm water inlet protection, seeding and mulching, and the installation of wet ponds or sediment basins to accommodate stormwater events (Andrews 2011; Ernst 2011). This annual program is assumed to realize an effectiveness of 50 percent. For the purposes of this economic analysis, it is assumed that the expected life of this practice is one year. The management unit of analysis is all urban areas in the Eagle Mountain Lake watershed.

BMP 13 Voluntary Urban Nutrient Management. This BMP uses education and outreach to control the effects of landscaping and lawn care practices on stormwater. Lawns produce significant amounts of nutrient-rich stormwater runoff, and research shows that such runoff can potentially cause eutrophication in streams, lakes, and estuaries. Research also suggests that suburban lawns and municipal properties produce more surface runoff than previously believed. Pesticide runoff can contaminate drinking water supplies with chemicals toxic to both humans and aquatic organisms. This BMP involves a continuing education program combined with annual soil testing by property owners to identify existing soil nutrient needs and discourage over-application of commercial fertilizer. For the purposes of this economic analysis, it is assumed that the expected life of this practice is one year. The management unit of analysis is all urban areas in the Eagle Mountain Lake watershed, except for those within the 2,000 foot boundary surrounding the lake which is the dominion of BMP 14 (Required Urban Nutrient Management).

BMP 14 Required Urban Nutrient Management in 2000 ft. buffer strips around Lake. This BMP focuses on the urban areas of the watershed inside the 2,000 foot boundary area immediately surrounding the Eagle Mountain Lake. Whereas BMP 13 is considered a "voluntary" program for property owners, BMP 14 is required of all property owners within the designated boundary area surrounding the lake. The "required" nature of BMP 14 involves the formal (legal) development of required nutrient management protocols as well as the presence of an inspector whose job it would be to monitor compliance. Similarly to BMP 13, annual soil testing and an educational outreach program would be necessary. For the purposes of this economic analysis, it is assumed that the expected life of this practice is one year. The management unit of analysis is those urban areas within the 2,000 foot boundary surrounding Eagle Mountain Lake.

Channel BMPs

BMP 15. Herbicide Application to Riparian Corridor. This BMP involves the targeted application of herbicide within a 150 foot buffer width along the riparian corridor. Similar to BMP 11 (Brush Management) the purpose of this practice is to reduce, remove or manipulate the density of woody trees and shrubs and restore desired vegetative cover. This BMP is designed to protect soil from erosion, reduce sediment, improve water quality, and enhance species diversity. The herbicide can be applied using an aerial spraying strategy or individual plant treatment. For the purposes of this economic analysis, it is assumed that the expected life of this practice is five years. The management unit of analysis is one mile of riparian corridor (both sides) for all channel areas deemed appropriate for this practice within the Eagle Mountain Lake watershed.

BMP 16 Riparian Buffer Strips - Medium Erosion Areas. The purpose of establishing riparian buffer strips is to establish or maintain a good vegetative buffer and cover in and around the watershed channels. A riparian area is a fringe of land that occurs along the stream or water typically characterized by a dense complex of grass and herbaceous cover. If the riparian buffer is not adequately established and farming activities occur near the edge of the stream, the banks may become unstable, resulting in significant sloughing and channel scour. Establishing and maintaining a good riparian buffer may require fencing (i.e. livestock grazing exclusion) as a complimentary management practice to ensure the establishment of the buffer (USDA Natural Resources Conservation Service 2010). Management practices may also include waterway plantings to stimulate vegetative growth within the riparian corridor. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 20 years. The management unit of analysis is one mile of riparian corridor (both sides) for all channel areas deemed appropriate for this practice within the Eagle Mountain Lake watershed, with the exception of 52.2 miles identified as critical erosion areas. This is the domain of BMP 17.

BMP 17 Riparian Buffer Strips - Only in Critical Areas. Similar to BMP 16, this BMP is focused on the critical areas of the watershed channels requiring substantial rehabilitative structures and associated infrastructure. The remediation practices involved with this BMP include structure development, fencing, and waterway plantings. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 50 years. The management unit of analysis is one mile of riparian corridor (both sides) for the 52.2 miles of channel identified as a “critical area” and deemed appropriate for this practice.

BMP 18 Wetland Development - West Fork Trinity (302.1 acres). Constructed wetlands provide a sediment retention and nutrient removal system utilizing the natural, chemical, physical, and biological processes involving wetland vegetation, soils, and their associated microbial populations to improve water quality. Constructed wetlands are designed to use water quality improvement processes occurring in natural wetlands, including high primary productivity, low flow conditions, and oxygen treatment to anaerobic sediments. Nutrient retention in wetland systems occurs via sorption, precipitation, and incorporation (USDA Natural Resources Conservation Service 2010). This BMP is designated to be implemented on 302.1 acres of the West Fork of the Trinity River. Among the many cost categories associated with a constructed wetland are: land acquisition costs, legal costs, mechanical land work, diversion and reentry structures, annual maintenance, and periodic dredging. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 50 years. The management unit of analysis is one designated wetland project encompassing 302.1 acres.

BMP 19 Wetland Development - Walnut Creek (20.6 acres). This BMP is similar to BMP 18, but this wetland is designated to be implemented on 20.6 acres along Walnut Creek. The purpose for this BMP and general cost categories to obtain the land, establish the wetland, and maintain its functionality are identical to BMP 18. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 50 years. The management unit of analysis is one designated wetland project encompassing 20.6 acres.

In-Lake BMPs

Based on feedback from TRWD personnel, it was noted that BMP 20 (Hypolimnetic Aeration) and BMP 21 (P Inactivation with Alum) are mutually exclusive. In other words, the final management plan could incorporate one of the practices, but not both.

BMP 20 Hypolimnetic Aeration. Hypolimnetic aeration is intended to provide oxygen to the bottom of the reservoir to prevent anaerobic conditions from occurring. Anaerobic conditions allow for the chemical bonds between iron or calcium with phosphorous to break, liberating the phosphorous for algae consumption. A flux of sediment phosphorous has been estimated for Eagle Mountain Lake and aeration could reduce this flux to a certain extent. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 20 years. The management unit of analysis is one designated hypolimnetic aeration project within the Eagle Mountain Lake watershed.

BMP 21 P Inactivation with Alum. The addition of powdered alum at various lake depths is designed to suppress the mixing and transport of P. Alum settles P to the bottom of the reservoir and prevents the utilization of the nutrient by aquatic plant life, thereby preventing the development of eutrophic conditions. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 20 years. The management unit of analysis is one designated P Inactivation with Alum project within the Eagle Mountain Lake watershed.

Watershed BMPs

Waste Water Treatment Plant (WWTP) data were obtained from an October 2008 Alan Plummer Associates Inc. report titled, "Eagle Mountain Wastewater Treatment Facilities Report." This report addressed wastewater treatment facilities discharging directly into the Eagle Mountain Lake or through watershed streams that eventually enter the lake. Plants evaluated included:

- City of Alvord Wastewater Treatment Plant
- City of Azle Ash Creek Wastewater Treatment Plant
- City of Bowie North Wastewater Treatment Plant
- City of Boyd Wastewater Treatment Plant
- City of Bridgeport Wastewater Treatment Plant
- City of Chico Wastewater Treatment Plant
- City of Decatur Wastewater Treatment Plant
- Fort Worth Boat Club Wastewater Treatment Plant
- Garrett Creek Ranch Wastewater Treatment Plant
- Larry Buck RV Park Waste Water Treatment Plant
- City of Newark Wastewater Treatment Plant
- Paradise Independent School District Wastewater Treatment Plant
- City of Rhome Wastewater Treatment Plant
- City of Springtown Wastewater Treatment Plant

No Level II or Level III permits were anticipated for three of the WWTPs to ensure operating parameters because these facilities were below the minimum size threshold flow of 0.02 millions of gallons per day (Fort Worth Boat Club, Garrett Creek Ranch, and Larry Buck RV Park). The remaining 11 WWTPs are the focus of BMPs 22 and 23.

BMP 22 Wastewater Treatment Plant (WWTP) from Level I to Level II quality status.
BMP 22 is an investigation of the effects of permitting the eleven wastewater treatment plants in the Eagle Mountain Lake watershed to a 1 mg/L level of P and 10 mg/L level of N. In the evaluation of the Eagle Mountain Lake watershed WWTPs, the Alan Plummer Associates study team considered three levels of treatment. Level I is the current level of treatment, as dictated by the existing discharge permit limits, with the capacity of the plants assumed to be expanded to satisfy 2050 projected flows. It is assumed that all plants would be upgraded at Level I to satisfy future demand. Achieving Level II quality status includes the costs associated with upgrades necessary to reduce P to 1.0 mg/L and N to 10 mg/L. For each of the 11 WWTPs, the additional costs associated with the necessary upgrades as well as additional operating and maintenance costs are provided in the Alan Plummer Associates report (Alan Plummer Associates, Inc. 2008). For the purposes of this economic analysis, it is assumed that the expected life of this practice is 50 years. The management unit of analysis is one designated project, encompassing the transition from Level I to Level II quality status by all 11 Eagle Mountain Lake watershed WWTPs subject to the permitting regulations.

BMP 23 Wastewater Treatment Plant (WWTP) from Level I to Level III quality status. BMP 23 is similar to BMP 22, but involves additional upgrades to the WWTPs to attain Level III quality status through 2050. Achieving Level III quality status includes the costs associated with upgrades necessary to reduce P to 0.5 mg/L and N to 5 mg/L. For each of the 11 WWTPs, the additional costs associated with the necessary upgrades as well as additional operating and maintenance costs are provided in the Alan Plummer Associates report. These costs are inclusive of the estimates for each WWTP to transition from Level I to Level II and then contain additional expenses (upgrade and operating and maintenance) to transition to the Level III quality standards. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 50 years. The management unit of analysis is one designated project, encompassing the transition from Level I to Level III quality status by all 11 Eagle Mountain Lake watershed WWTPs subject to the stricter permitting regulations.

BMP 24 Flood Protection Sites (Big Sandy and Sandy Creek). BMP 24 addresses the possibility of constructing new ponds to serve as flood protection sites. This BMP involves construction and maintenance of 17 designated new pond sites; 13 located in the Big Sandy area of the watershed and 4 located in the Salt Creek area. In total, the 17 proposed ponds would contain 386 surface area acres, ranging in size from 9 to 43 surface area acres. The purpose of this BMP is to use strategically located ponds as a water retention tool that will reduce erosion and reduce nutrient and sediment runoff into the reservoir. For the purposes of this economic analysis, it is assumed that the expected life of this practice is 50 years. The management unit of analysis is one designated project, encompassing all 17 designated flood protection sites in the Big Sandy and Salt Creek areas of the Eagle Mountain Lake watershed.

Eligible Area for BMP Implementation

SWAT analyses were conducted for each individual BMP in those sub-watershed areas in which the respective BMPs were considered feasible. Potential areas of implementation within the total watershed were identified in these analyses. Some BMPs entailed the implementation of the practice on a "project basis." Specifically, the urban, channel-wetland, in-lake, and watershed BMPs are comprehensive projects that must be "implemented in their entirety" or "not implemented at all." In these cases, the BMPs were considered in relation to the magnitude/scale of the project necessary to produce the intended environmental results. Table 1 identifies the comprehensive list of the BMPs, their BMP category, and the eligible area for the practice within the Eagle Mountain Lake watershed.

Table 1. Best Management Practices (BMPs), Description, Category and Eligible Area in the Eagle Mountain Lake Watershed.

BMP	Description	Category	Eligible Area Total	Eligible Area Unit
1	Conversion of Cropland to Grass/Hay	Cropland	17,509.0	acres
2	Fert. Mgt. - 25% reduced P application	Cropland	17,509.0	acres
3	Establish Filter Strips	Cropland	17,509.0	acres
4	Establish Grassed Waterways	Cropland	3,503.0	acres
5	Terracing	Cropland	8,646.0	acres
6	Prescribed Grazing	Pasture & Range	50,162.0	acres
7	Pasture Planting - reseeding	Pasture & Range	50,162.0	acres
8	Critical Pasture Planting - shaping	Pasture & Range	190,580.0	acres
9	Grade Stabilization - gully plugs	Pasture & Range	203,703.0	acres
10	Prescribed Burning	Pasture & Range	64,247.0	acres
11	Brush Management	Pasture & Range	32,123.5	acres
12	Phase II Urban Stormwater BMPs	Urban	1.0	project
13	Voluntary Urban Nutrient Mgt.	Urban	1.0	project
14	Required Urban Nutrient Mgt.	Urban	1.0	project
15	Herbicide Application - Riparian corridor	Channel	49.5	miles
16	Riparian Buffer Strips - Med Erosion Areas	Channel	288.3	miles
17	Riparian Buffer Strips - Critical Areas	Channel	52.2	miles
18	Wetland Development - West Fork Trinity	Channel	1.0	project
19	Wetland Development - Walnut Creek	Channel	1.0	project
20	Hypolimnetic Aeration	In-Lake	1.0	project
21	P Inactivation with Alum	In-Lake	1.0	project
22	WWTP - Level I to Level II	Watershed	ALL	projects
23	WWTP - Level I to Level III	Watershed	ALL	projects
24	Flood Protection Sites - Big Sandy/Salt Creek	Watershed	17	sites

Phosphorous Removal Efficiency

In addition to the estimate of eligible area for each BMP implementation, the SWAT model also provided an initial estimate of the potential overall reduction in TP, TN, and sediment associated with each BMP. For selected BMPs (those affiliated with the In-Lake category), WASP modeling was used to identify their respective effectiveness levels. For the composite urban category BMPs, TRWD management extrapolated effectiveness levels from journal-published research. For the wetland BMPs in the channel category, SWAT analyses were modified by TRWD management to reflect expected operation procedures. Based on this procedure, it was estimated that the annual average levels of nutrient/sediment inflow into Eagle Mountain Lake were 173,020 kilograms P, 1,055,220 kilograms N and 296,400 tons of sediment. These benchmark inflow levels serve as the baseline for which reduction in nutrient and sediment inflows were measured.

Table 2 provides the initial estimated standards of nutrient and sediment inflow into Eagle Mountain Lake. It then provides a list of the 24 BMPs under consideration and their annual reduction capabilities for TP, TN, and sediment. In terms of TP reduction, the most effective practices were conversion of cropland to grass/hay (15.20%), establishment of filter strips (12.70%), and voluntary urban nutrient management (8.69%). Among the least effective TP reduction practices were: establishment of riparian buffer strips in medium erosion areas, wetland development in the Walnut Creek area, hypolimnetic aeration, and the wastewater treatment plant BMPs; all with less than one percent annual TP reduction capabilities.

Table 2. Best Management Practices (BMPs) and Initial Estimated Standards of Reduction (in percent) of Total Phosphorous (P), Nitrogen (N) and Sediment Levels.

		Initial Estimated Standards		
		Total P 173,020 kg.	**Total N 1,055,220 kg.**	**Sediment 296,400 tons**
			Reduction In:	
BMP	**Description**	**Total P**	**Total N**	**Sediment**
1	Conversion of Cropland to Grass/Hay	15.20%	7.30%	14.20%
2	Fert. Mgt. - 25% reduced P application	1.20%	-0.20%	0.00%
3	Establish Filter Strips	12.70%	5.00%	13.00%
4	Establish Grassed Waterways	3.10%	0.20%	3.80%
5	Terracing	6.80%	2.50%	7.10%
6	Prescribed Grazing	1.70%	0.30%	0.50%
7	Pasture Planting - reseeding	1.70%	0.30%	0.50%
8	Critical Pasture Planting - shaping	1.50%	4.60%	1.80%
9	Grade Stabilization - gully plugs	4.00%	2.80%	4.30%
10	Prescribed Burning	1.80%	0.50%	1.10%
11	Brush Management	1.70%	0.30%	1.10%
12	Phase II Urban Stormwater BMPs	8.00%	0.00%	4.00%
13	Voluntary Urban Nutrient Mgt.	8.69%	6.61%	0.00%
14	Required Urban Nutrient Mgt.	5.10%	0.70%	-4.60%
15	Herbicide Application - Riparian corridor	1.70%	0.30%	1.10%
16	Riparian Buffer Strips - Med Erosion Areas	0.40%	0.30%	4.10%
17	Riparian Buffer Strips - Critical Areas	1.60%	1.30%	14.30%
18	Wetland Development - West Fork Trinity	2.76%	4.17%	5.50%
19	Wetland Development - Walnut Creek	0.44%	0.41%	0.70%
20	Hypolimnetic Aeration	0.53%	0.00%	0.00%
21	P Inactivation with Alum	3.25%	0.00%	0.00%
22	WWTP - Level I to Level II	0.30%	-0.20%	0.00%
23	WWTP - Level I to Level III	0.60%	0.30%	0.00%
24	Flood Protection Sites - Big Sandy/Salt Creek	4.40%	5.20%	5.00%

Current, Most Likely, and Maximum Adoption Rates

The potential reduction in P inflow levels for each BMP is greatly influenced by the current level of implementation attached to each BMP along with the additional area that could be expected to adopt each practice. If a BMP was identified to be highly implemented already, the prospects for additional implementation (and further TP reduction) are greatly limited. However, if a BMP is currently implemented at a low adoption rate, but has the potential to be adopted on a wider scale, then it provides greater TP reduction possibilities.

Lee et al. (2010) showed that the TP reduction capabilities for each BMP could be calculated as:

$$\text{TP reduction} = \text{TP reduction at FA X } \left[\frac{MA}{(1 - CA)}\right]$$

where: FA is the 100 percent adoption rate, MA is the marginal adoption rate, and CA is the current adoption rate. The approach embodied in this equation recognizes that some BMPs have already been adopted for a portion (CA) of the area for which further adoption is being considered. These relationships are presented graphically in figure 1.

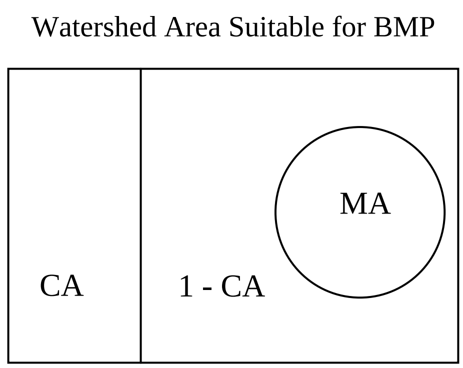

Figure 1. Illustration depicting marginal adoption (MA) area as a subset of the area (1 - CA) in which a Best Management Practice (BMP) is not currently adopted (CA).

An Assumption is that the 100 percent adoption rate is associated only with the remaining portion (1-CA) of the total possible area in the watershed. This is because the model calibration included the existing BMPs, as mentioned earlier. Discussions with project collaborators, stakeholders, and decision-makers responsible for adopting and implementing the BMPs identified in the most-likely marginal adoption (MA) rate, representing that portion of the total area in which a BMP is likely to be implemented, considering property owners' goals and objectives, economic incentives, and other relevant conditions. The relationship described above facilitates translation of the MA proportion of the total remaining area to be treated with the BMP (1 - CA) after eliminating the area already treated (CA) and adjusts the SWAT estimate of TP reduction proportionally.

In April 2011, a meeting was held with Eagle Mountain watershed landowners, stakeholders and local/regional NRCS personnel to discuss the alternative BMPs and identify the current level of adoption for the set of 24 BMPs. Additionally, participants were asked to identify the most likely adoption rates for each practice as well as the feasible adoption rate that could be expected should sufficient cost-share programs and/or incentives be provided. Project team members and several agricultural stakeholders participated in this Delphi technique interview process. Also identified during these discussions were levels of monetary incentive payments that would be required to induce landowners to participate in implementing the various agricultural BMPs. The Delphi process involved the repeated interviewing of the several noted experts until a consensus was reached, representing what is perceived as the most accurate information possible under the existing funding and time constraints. Table 3 presents the best estimates of the current, feasible and most likely adoption rates for each BMP in the Eagle Mountain Lake watershed as defined by the expert panel.

For each BMP, the current adoption rate indicates the expert panel's assessment of existing adoption for the BMP practice within the Eagle Mountain Lake watershed. The most likely adoption rate represents an adoption rate that participants identified as a realistic adoption rate that could be expected with a combined effort of promotion, education and assuming adequate funding is available to construct and maintain the respective BMPs through a 50-year planning horizon. The feasible adoption rate represents the maximum expected adoption rate for each BMP that could be expected. This scenario recognizes the impossibility of convincing all eligible resource managers to participate in a selected practice, even with the presence of financial incentives. For the sake of this analysis, the marginal adoption rate was used and considers the additional implementation of each BMP between the current and most likely adoption rates. The marginal adoption rate reflects the additional implementation (to the current level) for each BMP in the watershed that could be expected if an adequate level of incentives were provided as part of a watershed protection program.

Following the elicitation of the above-noted probable adoption rates for each BMP and the potential spatial areas affected, the original SWAT and WASP estimates of the effectiveness levels for the BMPs in terms of their impacts in reducing TP, TN, and sediment inflows into Eagle Mountain Lake were adjusted. An example of calculating the impact of the marginal adoption of an individual BMP can be seen by examining the information for BMP 5 (Terracing). As shown in tables 2 and 3, the current level of adoption for this practice is 20 percent of the acreage considered suitable for terracing. If terraces were to be implemented on all of the remaining 80 percent of such acreage, then TP would be reduced by 6.8 percent of the targeted inflow. Since the most likely adoption rate for this practice is 30 percent and the current adoption rate is 20 percent, only 10 percent of the available acreage would be available for further adoption (i.e. the marginal adoption rate is 10 percent). Therefore, the projected reduction in TP from BMP 5 (Terracing) is 10% divided by (1 - 20%) times the 6.8% total or 0.125 X 6.8% = 0.85%.

Table 3. Best Management Practices (BMPs) and Estimated Adoption Rates within the Eagle Mountain Lake Watershed.

		Adoption Rates of BMPs			
BMP	**Description**	**Current**	**Feasible**	**Most Likely**	**Marginal**
1	Conversion of Cropland to Grass/Hay	0%	50%	25%	25%
2	Fert. Mgt. - 25% reduced P application	90%	100%	100%	10%
3	Establish Filter Strips	0%	50%	25%	25%
4	Establish Grassed Waterways	20%	60%	30%	10%
5	Terracing	20%	60%	30%	10%
6	Prescribed Grazing	10%	50%	30%	20%
7	Pasture Planting - reseeding	5%	20%	10%	5%
8	Critical Pasture Planting - shaping	30%	75%	40%	10%
9	Grade Stabilization - gully plugs	25%	75%	50%	25%
10	Prescribed Burning	1%	15%	5%	4%
11	Brush Management	10%	60%	30%	20%
12	Phase II Urban Stormwater BMPs	0%	100%	50%	50%
13	Voluntary Urban Nutrient Mgt.	10%	25%	15%	5%
14	Required Urban Nutrient Mgt.	10%	80%	70%	60%
15	Herbicide Application - Riparian corridor	0%	10%	5%	5%
16	Riparian Buffer Strips - Med Erosion Areas	5%	50%	10%	5%
17	Riparian Buffer Strips - Critical Areas	0%	10%	10%	10%
18	Wetland Development - West Fork Trinity	0%	100%	100%	100%
19	Wetland Development - Walnut Creek	0%	100%	100%	100%
20	Hypolimnetic Aeration	0%	100%	100%	100%
21	P Inactivation with Alum	0%	100%	100%	100%
22	WWTP - Level I to Level II	0%	100%	100%	100%
23	WWTP - Level I to Level III	0%	100%	100%	100%
24	Flood Protection Sites - Big Sandy/Salt Creek	0%	100%	100%	100%

Costs for Best Management Practice Implementation

The cost information for each BMP was assessed through consultations with agency professionals and was thoroughly discussed and reviewed among project team members. The sequence and timing of establishment, operation and maintenance costs as well as the expected duration for each BMP was constructed to reflect a 50-year project period. For each BMP considered, additional specifications were declared, allowing the calculation of units (e.g., acres, structures, etc.) that could be imposed on the potentially eligible spatial areas. This was necessary to aggregate the cost of implementing each BMP across the area represented by the marginal adoption rate.

The assorted nuances of each individual BMP required the construction of individual economic budgets for each practice, independent of others that might also be implemented. For each BMP, attention was focused on identifying all relevant costs, regardless of the entity/individual incurring the costs. This included any possible inducement payments required to encourage or secure the participation of resource managers in the Eagle Mountain Lake watershed.

In June 2011, project team members met by teleconference with several members of the local/regional USDA-Natural Resources Conservation Service (NRCS) field staff who administer similar and identical programs for crop and pasture/range lands within the region. Each cost figure and investment timeline assumption was reviewed and adjusted (item by item) (Leal, 2011). Additional details associated with urban, channel, reservoir, and flood protection sites were obtained through a review of cost/investment details associated with the Cedar Creek project. In consultation with TRWD personnel, this data was modified to conform to the specific attributes of the Eagle Mountain Lake watershed. This resulted in a set of cost estimates and investment timing considerations that were determined to be an accurate representation of the costs and investment timing needed to implement each BMP over the 50 year project period.

The following section details the costs used in computing the investments associated with each of the 24 BMPs and evaluating the overall program costs of BMP implementation at the most likely adoption rate for the eligible area in the watershed. Costs were identified in 2011 dollars. For each BMP, a 50-year planning horizon for its most likely adoption area is assumed along with an annual inflation rate of 2.043 percent and a discount rate of 4.20 percent (Office of Management and Budget, 2010) to facilitate calculations of net present values of costs and annuity equivalent values.

Best Management Practice Cost Details

This section identifies the specific costs and assumptions used in constructing budgets for the implementation of the 24 BMPs under consideration. The numbers provided in this section reflect documented costs (if available) or the consensus estimates of the Eagle Mountain Lake watershed project team. These nominal cost estimates and their timing within the project period are provided so that future studies may modify this baseline if cost factors change significantly, an alternative inflation factor is selected or the economic environment differs from the one that existed when these estimates were obtained. In anticipation of some time lag in the implementation of these BMPs, and in recognition of the uncertainty and dynamics of the current economy, an additional 10 percent contingency factor was incorporated when individual BMP costs were estimated.

Cropland BMPs

BMP 1 Conversion of Cropland to Grass. The budgeted costs for BMP 1 include $165.80 per acre in Year 0 for establishment of a perennial hay crop. This figure represented data from the Texas AgriLife Extension crop and livestock budgets for the region with fertilization costs adjusted for prevailing prices. A Year 1 cost of $41.20 per acre represents foregone income from crop production while the hay enterprise is becoming established. A cost of $20.00 per acre was included in Year 1 though Year 50 as an annual incentive payment for converting the cropland to a perennial grass/hay system. The incentive payment at this level was chosen to represent approximately 50 percent of the return that would have otherwise been expected from cropland activities. In Years 2 through 50, a cost of $25.20 was included to compensate participants for the reduced expected return from hay compared to crops. This was based on the weighted average expected return from the cropping patterns in the region (62% wheat for grazing, 27% wheat for grain, and 11% oats/small grains = $41.20/acre) minus the expected return from a hay enterprise ($16.00/acre).

BMP 2 Fertilizer/Nutrient Management - 25 percent reduction in P with split applications. The budgeted costs for BMP 2 include $15,000 to develop, deliver, and repeat educational programming every five years (Years 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45). In Years 1 through Year 50 annual costs for the BMP included $15.00 for every 40 acres for soil fertility testing; $10.00 per acre for the additional trip across the field associated with the split application of fertilizer; and a $20.00 per acre annual incentive payment for implementing this BMP.

BMP 3 Establishment of Filter Strips. The budgeted costs for BMP 3 include $15,000 to develop, deliver and repeat educational programming every five years (Years 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45). Also in Years 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45 there is a cost of $127.00 for seedbed preparation, seeding, and establishment of one acre of filter strip vegetation in the 21 acre unit. In Years 1 through Year 50 an annual cost of $41.20 for one of 21 unit acres was included for foregone income to compensate management for the loss of one cropland acre to filter strip vegetation. Additionally, in Years 1 through 50, an annual cost of $20.00 for one acre in the 21 acre unit was included as an annual incentive payment for implementing this BMP.

BMP 4 Establishment of Grassed Waterways. The budgeted costs for BMP 4 include $15,000 to develop, deliver and repeat educational programming every ten years (Years 0, 10, 20, 30, and 40). Also in Years 0, 10, 20, 30, and 40 there a cost of $127.00 for seedbed preparation, seeding, and establishment of grassed waterway vegetation and $900.00 for mechanically shaping the land for waterways on one acre in the 41 acre unit. In Years 1 through Year 50, annual costs include $41.20 for foregone income (loss of one acre of cropland to grassed waterways) and $20.00 as an annual incentive payment for one acre in the 41 acre unit.

BMP 5 Terracing. The budgeted costs for BMP 5 include $15,000 to develop, deliver and repeat educational programming every ten years (Years 0, 10, 20, 30, and 40). Also in Years 0, 10, 20, 30, and 40 there is a cost of $6,900 for constructing terraces on one acre in the 21 acre unit. In Years 1 through Year 50, annual costs include a $5.00 per acre for added fuel and labor costs associated with farming terraced land applied to all 21 acres in the unit as well as $20.00 as an annual incentive payment for one acre in the 21 acre unit.

Pasture and Rangeland BMPs

BMP 6 Prescribed Grazing. The budgeted costs for BMP 6 include $15,000 to develop, deliver and repeat educational programming every five years (Years 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45). To facilitate the rotational grazing aspect of this BMP, one mile of fence construction at $10,000 is included in Year 0 as well as $7,650 for pond/watering facilities for each 500 acre unit. In Year 26, $18,675 is included for pond cleanout and maintenance for each 500 acre unit. For Years 1 through 50 there is an annual incentive payment of $5.60 per acre applied to all 500 acres in the management unit. The incentive payment at this level was chosen to represent approximately 50 percent of the return that would have otherwise been expected from pasture and rangeland activities.

BMP 7 Pasture Planting. The budgeted costs for BMP 7 include $15,000 to develop, deliver and repeat educational programming every five years (Years 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45). In Years 0, 10, 20, 30 and 40 the budget for this BMP includes $60.00 per acre for one acre in the 10 acre unit for seedbed preparation, seed, and planting costs associated with reseeding pastureland.   For Years 1 through 50 there is an annual incentive payment of $5.60 per acre applied to all 10 acres in the management unit. This recognizes that some level of restricted grazing will be necessary across the entire unit in order for the reseeding activities to be successful.

BMP 8 Critical Pasture Area Planting. The budgeted costs for BMP 8 include $15,000 to develop, deliver and repeat educational programming every ten years (Years 0, 10, 20, 30, and 40). Also in Years 0, 10, 20, 30, and 40, the budget for this BMP includes $1000.00 per acre for one acre in the 41 acre unit for land shaping, seeding, and establishment of grass on pastureland. For Years 1 through 50 there is an annual incentive payment of $5.60 per acre applied to all 41 acres in the management unit; again recognizing the need for some level of restricted grazing on the entire unit for successful establishment of vegetation in the treated area.

BMP 9 Grade Stabilization - gully plugs. The budgeted costs for BMP 9 include $7,200 for pipe and $7,650 for dirt work associated with the construction of the grade stabilization structure in Year 0 and 25. These cost estimates were obtained from local USDA-NRCS field staff and project team members that assisted with the review of the BMPs and their budgeted costs. One grade stabilization structure was identified to be appropriate for every 2,471 acres (1,000 hectares) of eligible pasture and rangeland within the watershed.

BMP 10 Prescribed Burning. Costs for implementing BMP 10 (Prescribed Burning) are extremely variable as a great degree of economies of size exists for this practice. The budget for this BMP was obtained by inflation adjusting actual and complete prescribed burning expenses published by the Samuel Roberts Noble Foundation in Ardmore, Oklahoma (Gee and Biermacher, 2007). Costs for a prescribed burn for a 200 acre area were estimated to be $11.34 per acre and included construction of fire guards, fuel, and labor. This estimate was reviewed and agreed upon by local USDA-NRCS field staff that assist in the implementation of this practice locally. For this BMP budget, these costs were assumed to occur in Years 0, 10, 20, 30, and 40 on all acres of the 200 acre management unit. In addition, the budget also included $8.00 per acre for nine months of grazing deferment that is necessary to produce an adequate fuel load pre-burn and allow adequate pasture recuperation time post-burn. This cost is also assumed to occur in Years 0, 10, 20, 30, and 40 on all 200 acres in the unit.

BMP 11 Brush Management. The budget for this BMP is based on an assumption that 75 percent of the brush management activities would be performed by mechanical means (at an average cost of $175/acre) and 25 percent would be performed through either individual plant treatment or aerial chemical application (at an average cost of $50/acre). The BMP 11 budget incorporated a cost of $143.75 per acre for each acre in the 20 acre management unit in Years 0, 10, 20, 30, and 40.

Urban BMPs

<u>BMP 12 Phase II Urban Stormwater BMP's.</u> The budget for BMP 12 was obtained from TRWD project team members who estimated the annual costs of educational programming and creation and enforcement of ordinances for new developments and construction projects to be approximately $1,793,994.00 annually (Years 1 through 50) for the Eagle Mountain Lake watershed.

<u>BMP 13 Voluntary Urban Nutrient Management.</u> This budget for BMP 13 was obtained from TRWD project team members who estimated the annual costs (Years 1 through 50) to include $150,000 for development and delivery of a continuing education program addressing urban nutrient management and $30,000 to provide supplemental incentives to property owners for soil fertility testing.

<u>BMP 14 Required Urban Nutrient Management in 2000 ft. buffer strips around Lake.</u> This budget for BMP 13 was also obtained from TRWD project team members who estimated initial (Year 0) costs of $150,000 for development and delivery of an initial education program addressing urban nutrient management and $100,000 for legal costs associated with designing and securing the necessary ordinances for implementation of this BMP. Additional annual costs (Years 1 through 50) for this BMP include $25,000 for a continuing public education program; $5,000 to provide supplemental incentives to property owners for soil fertility testing, and $50,000 for salary to fund a position of inspector charged with overseeing compliance with the ordinances.

Channel BMPs

<u>BMP 15 Herbicide Application to Riparian Corridor.</u> The budget for BMP 15 includes a cost of $2,640 per mile for herbicide application ($36/per acre with 73.33 acres/mile) within a 150 foot width along the riparian corridor. It is assumed that this herbicide application would be repeated every five years and be implemented in Years 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45.

<u>BMP 16 Riparian Buffer Strips - Medium Erosion Areas.</u> The budget for BMP 16 includes a per mile estimate of $20,000 required in association with constructing two miles of fence and $5,000 for waterway plantings in Years 0, 20, and 40. Additionally, an annual (Years 1 through 50) incentive payment of $410.65 per mile ($5.60/acre with 73.33 acres/mile) was incorporated as an incentive to prolong the life of the practice through restricted grazing.

<u>BMP 17 Riparian Buffer Strips - Only in Critical Areas.</u> The budget for BMP 17 includes a per mile estimate of $1,000,000 for an initial (Year 0) investment required for physical structure development, constructing two miles of fence, and the requisite waterway plantings. No annual expenditures are anticipated during the remainder of the 50- year project period.

BMP 18 Wetland Development - West Fork Trinity (302.1 acres). The budget for BMP 18 included a number of Year 0 costs including: $10,000 per acre for land acquisition, $150,000 for legal costs associated with wetland development, $35,000 per acre for mechanical land work and shaping, $2,000,000 for construction of a diversion structure, and $1,000,000 for construction of a re-entry structure. Additionally, the BMP budget included $100,000 for annual wetland maintenance in Years 1 through 50 and $9,700 per acre in Years 10, 20, 30, and 40 for wetland dredging expenses.

BMP 19 Wetland Development - Walnut Creek (20.6 acres). The budget for BMP 19 included Year 0 costs of: $15,000 per acre for land acquisition, $150,000 for legal costs associated with wetland development, $35,000 per acre for mechanical land work and shaping, $2,000,000 for construction of a diversion structure, and $1,000,000 for construction of a re-entry structure. As with BMP 18, the budget for BMP 19 included $100,000 for annual wetland maintenance in Years 1 through 50 and $9,700 per acre in Years 10, 20, 30, and 40 for wetland dredging expenses.

In-Lake BMPs

BMP 20 Hypolimnetic Aeration. The budget for BMP 20 was provided by TRWD project team members who estimated capital costs for the hypolimnetic aeration project in the Eagle Mountain Lake to be approximately $150,000 in Years 0, 20, and 40. Annual operating and maintenance costs were estimated to be $25,000 for Years 1 through 50.

BMP 21 P Inactivation with Alum. The budget for BMP 21 was also provided by TRWD project team members who estimated the total costs for the P inactivation with alum project in the Eagle Mountain Lake to be approximately $3,426,562 in Years 0, 10, 20, 30 and 40.

Watershed BMPs

BMP 22 Wastewater Treatment Plant (WWTP) from Level I to Level II quality status. The 2008 estimates detailed in the Alan Plummer Associates report identified the costs for BMP 22 implementation by all 11 WWTPs in the Eagle Mountain Lake watershed to be $969,093 for initial costs of facility upgrades and $93,651 for additional annual expenses associated with operation and maintenance. These 2008 estimates were inflation-adjusted to reflect 2011 dollars resulting in an estimated cost for this BMP of $1,029,710 in Year 0 for initial upgrade costs and $ 99,509 annually (Year 1 through Year 50) for additional operating and maintenance costs.

BMP 23 Wastewater Treatment Plant (WWTP) from Level I to Level III quality status. The 2008 estimates detailed in the Alan Plummer Associates report identified the costs for BMP 23 implementation by all 11 WWTPs in the Eagle Mountain Lake watershed to be $9,993,464 for initial costs of facility upgrades and $367,449 for additional annual expenses associated with operation and maintenance. These 2008 estimates were inflation-adjusted to reflect 2011 dollars resulting in an estimated cost for this BMP of $10,618,562 in Year 0 for initial upgrade costs and $390,433 annually (Year 1 through Year 50) for additional operating and maintenance costs.

<u>BMP 24 Flood Protection Sites (Big Sandy and Sandy Creek).</u> The budget for BMP 24 incorporated estimated costs of $31,500 per surface area acre for flood protection (pond) construction costs in Year 0 for all 386 surface area acres designated in this BMP. Additionally, $77,020 per surface area acre was included in Year 26 for flood protection pond clean out and maintenance. These estimates were based on prior construction costs for similar projects supervised by project team members.

Costs of BMP Implementation at the Most Likely Adoption Rate

Once the requisite information had been secured, developed, and validated, a Microsoft® Excel® spreadsheet was constructed to calculate the net present value (NPV) of all costs over the expected useful life of each BMP for the 50-year project period. In addition, an annuity equivalent value (AEV) was calculated for each of the BMPs, assuming implementation of the marginal adoption rates within the SWAT- (and WASP-) designated sub-watershed areas of the Eagle Mountain Lake watershed. A social discount rate of 4.20 percent was assumed to facilitate calculations of net present values and annuity equivalent values. These two cost calculations are analogous to the concepts of an investment in a residential mortgage. The NPV calculation represents the value of the mortgage (i.e. a $200,000 home), while the AEV calculation would be synonymous with an annual payment with a loan rate of 4.20 percent. In other words, the calculated AEVs represent the annual payment necessary in each of the 50 years of the project period to finance the implementation of the BMP practice/project. Transforming NPV into an AEV facilitates accurate relative comparisons of costs across BMPs.

Table 4 provides the estimated NPVs of costs for each BMP implemented at the respective marginal adoption rate. These values are also broken out to show two components of the NPV for each BMP. The NPV of the initial construction and establishment costs correspond to the Year 0 costs in the 50-year project period sequence. This value represents the upfront investment necessary for initial BMP implementation. The NPV of operating and maintenance costs represents the present value of costs for ongoing operating and maintenance plus intermittent capital replacement costs for each BMP that are incurred during Years 1 through 50.

Because these NPV estimates reflect implementation at the marginal adoption rate, a larger potential area for BMP adoption translates into a higher NPV. Larger NPV estimates for BMPs could be the result of either: high project costs, a project large in size or the adoption of the practice across a large area. In terms of overall BMP implementation costs, the lowest estimated NPVs were BMP 15 (Herbicide Application - Riparian corridor) at $46,945, followed by BMP 4 (Establish Grassed Waterways) at $107,529, and BMP 10 (Prescribed Burning) at $187,874. BMP 12 (Phase II Urban Stormwater BMPs) was the most expensive practice ($60.5 million), followed by BMP 24 (Flood Protection Sites) at $32.4 million, BMP 18 (Wetland Development - West Fork Trinity) at $29.6 million, and BMP 23 (WWTP - Level I to Level III) at $24.9 million.

Table 4. Estimated Net Present Values of Costs for Best Management Practice Implementation with respect to Eligible Area within the Eagle Mountain Lake Watershed.

BMP	Description	Net Present Value of Costs: Initial Construction and Establishment	Operating and Maintenance	Total
1	Conversion of Cropland to Grass/Hay	$ 798,323	$ 6,753,608	$ 7,551,931
2	Fert. Mgt. - 25% reduced P application	$ 16,500	$ 1,886,831	$ 1,903,331
3	Establish Filter Strips	$ 45,619	$ 682,923	$ 728,542
4	Establish Grassed Waterways	$ 26,152	$ 81,377	$ 107,529
5	Terracing	$ 328,991	$ 975,376	$ 1,304,367
6	Prescribed Grazing	$ 406,058	$ 2,228,347	$ 2,634,405
7	Pasture Planting - reseeding	$ 33,053	$ 606,289	$ 639,342
8	Critical Pasture Planting - shaping	$ 527,812	$ 4,890,527	$ 5,418,340
9	Grade Stabilization - gully plugs	$ 336,654	$ 199,559	$ 536,213
10	Prescribed Burning	$ 54,672	$ 133,202	$ 187,874
11	Brush Management	$ 1,015,906	$ 2,475,168	$ 3,491,074
12	Phase II Urban Stormwater BMPs	$ 0	$60,553,355	$60,553,355
13	Voluntary Urban Nutrient Mgt.	$ 0	$ 6,075,608	$ 6,075,608
14	Required Urban Nutrient Mgt.	$ 275,000	$ 2,700,270	$ 2,975,270
15	Herbicide Application - Riparian corridor	$ 7,187	$ 39,758	$ 46,945
16	Riparian Buffer Strips - Med Erosion Areas	$ 396,413	$ 632,392	$ 1,028,804
17	Riparian Buffer Strips - Critical Areas	$ 5,742,000	$ 0	$ 5,742,000
18	Wetland Development - West Fork Trinity	$18,418,950	$11,228,898	$29,647,848
19	Wetland Development - Walnut Creek	$ 4,598,000	$ 3,910,867	$ 8,508,867
20	Hypolimnetic Aeration	$ 165,000	$ 1,023,892	$ 1,188,892
21	P Inactivation with Alum	$ 3,769,218	$ 9,183,383	$12,952,601
22	WWTP - Level I to Level II	$ 1,132,681	$ 3,358,762	$ 4,491,444
23	WWTP - Level I to Level III	$11,680,418	$13,178,438	$24,858,856
24	Flood Protection Sites - Big Sandy/Salt Creek	$13,396,130	$18,983,911	$32,380,041

Table 5 provides the conversion of the NPVs for each BMP into an estimated AEV of costs for each BMP implemented at the marginal adoption rate. The AEVs are also broken out to show the portion of the annual payments attributable to the upfront establishment costs and ongoing operating and maintenance costs for each BMP. The AEV of the initial construction and establishment costs correspond to the annual payments (for 50 years) necessary to pay for the initial practice/project establishment. The AEV of operating and maintenance costs represents the annual payments (for 50 years) necessary to pay for the ongoing operation and maintenance costs associated with each BMP throughout the 50-year project period. Because the SWAT, WASP and other environmental modeling characterize the annual nutrient and sediment inflows (and reduction capabilities), the AEV serves to provide a common measure in terms of annual costs. This common time component lends itself for appropriate utilization in pairing the environmental benefits of the respective BMPs with their estimated costs and serves as the basis for the derivation of relative cost-efficiency rankings of the BMPs.

Table 5. Annuity Equivalent Value of Estimated Costs of Best Management Practice Implementation with respect to Eligible Area within the Eagle Mountain Lake Watershed.

		Annuity Equivalent Value of Costs		
BMP	**Description**	**Initial Construction and Establishment**	**Operating and Maintenance**	**Total**
1	Conversion of Cropland to Grass/Hay	$ 38,444	$ 325,223	$ 363,667
2	Fert. Mgt. - 25% reduced P application	$ 795	$ 90,861	$ 91,656
3	Establish Filter Strips	$ 2,197	$ 32,886	$ 35,083
4	Establish Grassed Waterways	$ 1,260	$ 3,918	$ 5,178
5	Terracing	$ 15,843	$ 46,969	$ 62,812
6	Prescribed Grazing	$ 19,554	$ 107,307	$ 126,861
7	Pasture Planting - reseeding	$ 1,592	$ 29,196	$ 30,788
8	Critical Pasture Planting - shaping	$ 25,417	$ 235,506	$ 260,923
9	Grade Stabilization - gully plugs	$ 16,212	$ 9,610	$ 25,822
10	Prescribed Burning	$ 2,633	$ 6,414	$ 9,047
11	Brush Management	$ 48,921	$ 119,193	$ 168,114
12	Phase II Urban Stormwater BMPs	$ 0	$2,915,974	$2,915,974
13	Voluntary Urban Nutrient Mgt.	$ 0	$ 292,574	$ 292,574
14	Required Urban Nutrient Mgt.	$ 13,243	$ 130,032	$ 143,275
15	Herbicide Application - Riparian corridor	$ 346	$ 1,915	$ 2,261
16	Riparian Buffer Strips - Med Erosion Areas	$ 19,089	$ 30,453	$ 49,543
17	Riparian Buffer Strips - Critical Areas	$ 276,509	$ 0	$ 276,509
18	Wetland Development - West Fork Trinity	$ 886,973	$ 540,732	$1,427,705
19	Wetland Development - Walnut Creek	$ 221,419	$ 188,330	$ 409,748
20	Hypolimnetic Aeration	$ 7,946	$ 49,306	$ 57,252
21	P Inactivation with Alum	$ 181,508	$ 442,230	$ 623,738
22	WWTP - Level I to Level II	$ 54,545	$ 161,743	$ 216,287
23	WWTP - Level I to Level III	$ 562,476	$ 634,614	$1,197,089
24	Flood Protection Sites - Big Sandy/Salt Creek	$ 645,097	$ 914,178	$1,559,275

Efficiency Rankings of Best Management Practices

Three components of research are required to identify useful economic information for TRWD's management to use in identifying and implementing the most-efficient strategies for reducing undesirable nutrient inflows into the Eagle Mountain Lake. Essential for the success of these components is extensive consideration of the characteristics of the Eagle Mountain Lake watershed nutrient and sediment inflow problem and the remediation alternatives identified through SWAT and WASP modeling and previous research by members of the project team. The final component is pairing these environmental metrics with an economic assessment.

Explicit recognition of the initial SWAT effectiveness levels for TP, TN, and sediment for each BMP were incorporated into the spreadsheet, along with the details of the eligible spatial area of the watershed and most likely marginal adoption rate of each BMP. The cost and nutrient and sediment reduction information presented is also transformed to relate the annual cost per unit of TP, TN, and sediment reduction. In calculating these costs per unit of reduction, each item is evaluated independently, assuming all costs are associated with reducing that item (TP, TN, or sediment) and ignoring any allocation of costs toward reducing the others.

Table 6 shows the estimated annual cost of BMPs with respect to reductions in TP, TN, and sediment. The rank ordering of BMPs with respect to the focus of this investigation (TP reduction) will be presented in the next section. However, it is worth noting the BMPs that were deemed most cost-efficient for TN and sediment reduction. For reduction of TN, BMP 3 (Establish Filter Strips): $2.66/kg.; BMP 9 (Grade Stabilization - gully plugs): $3.50/kg.; and BMP 15 (Herbicide Application - Riparian corridor): $14.28/kg were identified as the most cost-efficient BMPs. For reduction of sediment, BMP 3 (Establish Filter Strips): $3.64/ton; BMP 4 (Establish Grassed Waterways): $4.60/ton; and BMP 9 (Grade Stabilization - gully plugs): $8.10/ton were identified as the most cost-efficient BMPs. If multiple environmental objectives were desired for a watershed protection plan, these BMPs would likely enter into the selection framework for consideration.

Each BMP was assessed by its cost per kilogram of TP reduction, and the BMPs were ranked by their costs to identify their relative cost-efficiency. This ranking integrates the annual cost of BMP implementation with the respective efficiency in addressing TP reduction in the watershed. Table 7 provides these relative rankings. The top four BMPs in terms of cost-efficiency for TP reduction are inclusive of the top three cost-efficient practices identified for TN and sediment reduction. This lends credibility to their merit as useful BMPs regardless of the nuisance issue among these three components. The most striking detail of the information reported in table 7 is the wide range of cost-efficiency that exists across the 24 BMPs considered. For implementation of each BMP at the most likely adoption rate in the Eagle Mountain Lake watershed, reductions of TP inflow could cost as little as $6.39/kg reduced (BMP 3 Establish Filter Strips) or as much as $1,431.70/kg (BMP 16 Riparian Buffer Strips - medium erosion areas). This implies that a properly constructed watershed protection plan focusing on TP reduction would be well advised to concentrate its emphasis on the cost-efficient BMPs identified in this ranking. A lot of money could be wasted on inferior projects. The less cost-efficient BMPs on this list might be beneficial endeavors/projects for other objectives, but do not provide the best return on investment if the primary area of concern is reducing TP inflows.

Table 6. Estimated Annual Cost of Best Management Practice Implementation with respect to Reductions in Total Phosphorous (P), Nitrogen (N), and Sediment.

		Annual Cost for Reduction in:		
		Total P	Total N	Sediment
BMP	Description	per kg.		per ton
1	Conversion of Cropland to Grass/Hay	$ 55.31	$ 18.88	$ 34.56
2	Fert. Mgt. - 25% reduced P application	$ 441.45	NA	NA
3	Establish Filter Strips	$ 6.39	$ 2.66	$ 3.64
4	Establish Grassed Waterways	$ 9.65	$ 24.54	$ 4.60
5	Terracing	$ 53.39	$ 23.81	$ 29.85
6	Prescribed Grazing	$ 215.65	$ 200.37	$428.01
7	Pasture Planting - reseeding	$ 209.35	$ 194.51	$415.49
8	Critical Pasture Planting - shaping	$1,005.37	$ 53.75	$489.06
9	Grade Stabilization - gully plugs	$ 14.92	$ 3.50	$ 8.10
10	Prescribed Burning	$ 72.62	$ 42.87	$ 69.37
11	Brush Management	$ 285.78	$ 265.53	$257.81
12	Phase II Urban Stormwater BMPs	$ 421.33	NA	$491.90
13	Voluntary Urban Nutrient Mgt.	$ 389.18	$ 83.89	NA
14	Required Urban Nutrient Mgt.	$ 27.06	$ 32.33	NA
15	Herbicide Application - Riparian corridor	$ 15.37	$ 14.28	$ 13.87
16	Riparian Buffer Strips - Med Erosion Areas	$1,431.70	$ 313.00	$ 81.54
17	Riparian Buffer Strips - Critical Areas	$ 998.83	$ 201.57	$ 65.24
18	Wetland Development - West Fork Trinity	$ 298.97	$ 32.45	$ 87.58
19	Wetland Development - Walnut Creek	$ 538.23	$ 94.71	$197.49
20	Hypolimnetic Aeration	$ 62.43	NA	NA
21	P Inactivation with Alum	$ 110.92	NA	NA
22	WWTP - Level I to Level II	$ 416.69	NA	NA
23	WWTP - Level I to Level III	$1,153.13	$2,306.26	NA
24	Flood Protection Sites - Big Sandy/Salt Creek	$ 204.82	$ 173.31	$180.24

Table 7. Ranking of BMPs by Lowest Estimated Annual Cost for Reduction of Total Phosphorous Inflow into Eagle Mountain Lake.

	Ranking of BMPs by Lowest Estimated Cost	
BMP	**Description**	**Annual Cost per kg. of Total P reduced**
3	Establish Filter Strips	$ 6.39
4	Establish Grassed Waterways	$ 9.65
9	Grade Stabilization - gully plugs	$ 14.92
15	Herbicide Application - Riparian corridor	$ 15.37
14	Required Urban Nutrient Mgt.	$ 27.06
5	Terracing	$ 53.39
1	Conversion of Cropland to Grass/Hay	$ 55.31
20	Hypolimnetic Aeration	$ 62.43
10	Prescribed Burning	$ 72.62
21	P Inactivation with Alum	$ 110.92
24	Flood Protection Sites - Big Sandy/Salt Creek	$ 204.82
7	Pasture Planting - reseeding	$ 209.35
6	Prescribed Grazing	$ 215.65
11	Brush Management	$ 285.78
18	Wetland Development - West Fork Trinity	$ 298.97
13	Voluntary Urban Nutrient Mgt.	$ 389.18
22	WWTP - Level I to Level II	$ 416.69
12	Phase II Urban Stormwater BMPs	$ 421.33
2	Fert. Mgt. - 25% reduced P application	$ 441.45
19	Wetland Development - Walnut Creek	$ 538.23
17	Riparian Buffer Strips - Critical Areas	$ 998.83
8	Critical Pasture Planting - shaping	$1,005.37
23	WWTP - Level I to Level III	$1,153.13
16	Riparian Buffer Strips - Med Erosion Areas	$1,431.70

Identifying the Optimal Suite of Best Management Practices

For the Eagle Mountain Lake watershed, the primary objective is to reduce annual TP inflows into the lake by 30 percent. However, watershed planners wish to monitor the ancillary impact of targeted BMPs on the annual inflows of TN and sediment as well. In determining the optimal solution, this economic analysis considers the technical nutrient/sediment reduction performance of each BMP and the internally-calculated costs per unit of TP, TN, and sediment reductions toward meeting the Eagle Mountain Lake watershed management's objectives.

In order to determine how many BMPs are needed to achieve the 30 percent TP reduction goal, SWAT modeling incorporated sequential adoption of BMPs beginning with full adoption of the most cost-efficient BMP at is marginal adoption rate and then advancing to the next most cost-efficient BMP. The environmental implications of this implementation were successively tabulated to determine if additional BMPs were necessary. BMP implementation was targeted at the sub-basin level which indicated the greatest potential for total P reduction. The process was repeated until the watershed management goal of 30 percent total P reduction was achieved.

This methodology will also assist in implementation of practices by determining the sub-watersheds which demonstrate the best response to selected BMPs.

The suite of BMPs estimated to achieve the 30 percent reduction in total P inflow into the Eagle Mountain Lake based on the previously noted data from SWAT, WASP, and other modeling research of the project team are reported in table 8. This list of BMPs is identified as the cost-efficient BMP suite since the selection was based solely on the BMPs which were found to be the most efficient in terms of lowest cost per unit of TP reduction. A total of 14 of the 24 BMPs considered were found to be necessary to reach the 30 percent target. The table reveals the cumulative costs and incremental nutrient and sediment reduction impacts provided by the BMPs (beginning with the most cost efficient and progressing down the ranked cost-efficient BMP list). For this suite of BMPs, cumulative reductions in TP, TN and sediment inflows totaled 31.3, 14.7 and 20.0 percent, respectively, of current inflow levels.

The estimated NPV (2011 dollars) required to implement the cost-efficient suite of BMPs was found to be $95,183,982. Of this total, a NPV of $38,911,913 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a NPV of $56,272,069 is needed to fund the operating and maintenance costs (Year 1 through 50 investment). While expenses will be incurred initially and throughout the 50-year project period, the $95.2 million NPV estimate represents the upfront funds needed to implement and maintain the suite of BMPs for the entirety of the planning horizon.

The Annuity Equivalent Value (AEV) cost of the cost-efficient suite of BMPs is $4,583,626, representing the annual expenditure necessary each year during the 50-year project period. Of this annual expenditure, a total of $1,873,823 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a total of $2,709,803 is needed to fund the operating and maintenance costs (Year 1 through 50 investment).

Figure 2 provides a chart of the relative contribution to TP reduction from the perspective of the cost-efficient BMP strategy categories. Cropland BMPs are the greatest contributors, providing 44.4 percent of the expected reduction. Watershed BMPs are second in importance contributing 13.4 percent of the total, followed by urban BMPs at 12.1 percent, pasture and rangeland BMPs at 11.2 percent, in-lake BMPs at 10.5 percent, and channel BMPs at 8.3 percent. None of the WWTP BMPs were sufficiently cost-efficient to fit into the comprehensive plan. The takeaway from this illustration is that a comprehensive suite encompassing participation by six distinctly different categories of cooperators is needed to achieve the watershed management plan objectives. Additionally, the combined contributions by agricultural cropland and agricultural pasture and rangeland BMPs (55.6 percent) underscore the importance of programs that secure agriculture’s participation in the Eagle Mountain Lake watershed protection plan.

Table 8. The Suite of Cost-Efficient Best Management Practices that Achieves the 30 Percent Target Reduction of Total Phosphorous (P) Inflow into Eagle Mountain Lake.

		Initial Estimated Standards				
		Total P 173,020 kg.	Total N 1,055,220 kg.	Sediment 296,400 tons		
		Cumulative Reduction Percentages				
BMP	**Description**	**Total P**	**Total N**	**Sediment**	**Cumulative Net Present Value**	**Cumulative Annuity Equivalent Value**
3	Establish Filter Strips	3.9%	2.3%	5.7%	$ 728,542	$ 35,083
4	Establish Grassed Waterways	5.7%	2.3%	5.7%	$ 836,071	$ 40,261
9	Grade Stabilization - gully plugs	7.8%	3.5%	7.0%	$ 1,372,284	$ 66,083
15	Herbicide Application - Riparian corridor	8.5%	5.6%	9.6%	$ 1,419,229	$ 68,344
14	Required Urban Nutrient Mgt.	12.3%	6.1%	8.1%	$ 4,394,499	$ 211,619
5	Terracing	14.0%	6.3%	8.5%	$ 5,698,866	$ 274,431
1	Conversion of Cropland to Grass/Hay	20.5%	7.2%	10.6%	$13,250,797	$ 638,098
10	Prescribed Burning	21.3%	7.3%	10.8%	$13,438,671	$ 647,145
21	P Inactivation with Alum	24.6%	7.3%	10.8%	$26,391,272	$1,270,883
24	Flood Protection Sites - Big Sandy/Salt Creek	28.8%	12.3%	14.9%	$58,771,313	$2,830,158
7	Pasture Planting - reseeding	29.1%	12.4%	15.0%	$59,410,655	$2,860,946
6	Prescribed Grazing	29.1%	12.4%	15.0%	$62,045,060	$2,987,807
11	Brush Management	29.4%	11.1%	15.3%	$65,536,134	$3,155,921
18	Wetland Development - West Fork Trinity	31.3%	14.7%	20.0%	$95,183,982	$4,583,626
	TOTALS	31.3%	14.7%	20.0%	$95,183,982	$4,583,626

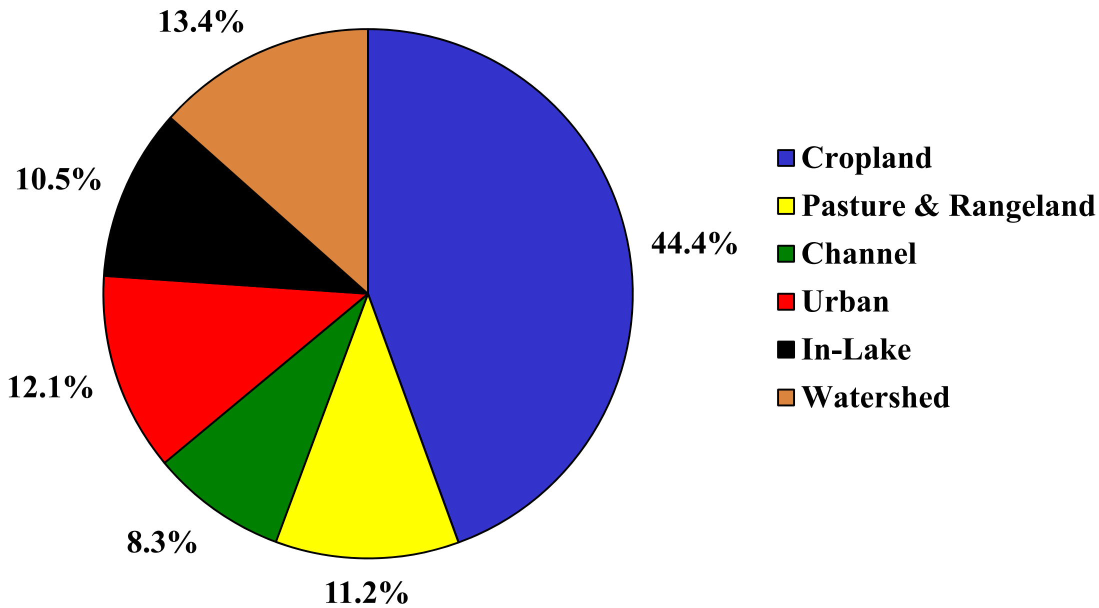

Figure 2. Contribution of Cost-Efficient Best Management Practice Categories Resulting in a 31.3 Percent Total Phosphorous Reduction.

A couple of comments about this suite of BMPs are warranted. This presentation of the cumulative costs and environmental impacts highlights the non-linear nature of costs from increased nutrient and sediment reduction targets. Notice that a 20 percent TP reduction target could be achieved by implementing only 7 of the BMPs (at the same level of adoption) with a NPV of program costs of $13.25 million or an AEV of $638,098 for each year in the 50-year project period. In other words, raising the TP inflow reduction target from 20 percent to 30 percent raises the estimated costs of the watershed protection plan by over 600 percent (NPV increased by $81.93 million; AEV increased by $3.95 million).

Additionally, recall that only one of BMP 20 (Hypolimnetic Aeration) and BMP 21 (P Inactivation with Alum) could be utilized. While both practices appeared in the list as more cost-effective BMPs than others appearing on this list, BMP 21 (P Inactivation with Alum) was chosen because it was more effective with respect to TP reduction. Even though BMP 21 (P Inactivation with Alum) was the least cost-efficient of these two practices, the enhanced TP reduction effectiveness paired with a better cost-efficiency relative to other BMPs necessary to meet the target dictated selection of BMP 21 (P Inactivation with Alum) over the BMP 20 (Hypolimnetic Aeration) alternative.

Finally, several of the BMPs under consideration were, by nature, projects that must be implemented in their entirety or omitted altogether. This includes several BMPs that fall in cost-efficient rank ordering on the borderline of inclusion necessary to produce the explicit 30 percent TP reduction target. By incorporating BMP 18 (Wetland Development - West Fork Trinity), the estimated cumulative TP reduction level advances from 29.4 percent to 31.3 percent. Implementing this BMP is appropriate in terms of strictly adhering to the sequentially preferred cost-effective rank order of BMPs, however, it results in a suite of BMPs that exceeds the 30 percent target at a significant cost increase for the collective BMP program. Based on this unique situation, an alternative solution is provided in order for decision-makers to fully consider an approach that might be deemed more practical, acceptable and/or appropriate.

Table 9 presents a list of BMPs identified as the cost-effective suite which is estimated to achieve a 29.9 percent reduction in TP inflow into the Eagle Mountain Lake. The only difference between this cost-effective suite of BMPs and the cost-efficient list detailed previously is the final BMP included in the watershed protection plan. Rather than adopt BMP 18 (Wetland Development - West Fork Trinity) solely because it is the next in line based on the ranked order of TP reduction cost-efficiency, the more relevant investigation would be identifying which BMP can provide the remaining TP reduction necessary at the lowest overall cost. BMP 18 (Wetland Development - West Fork Trinity) is a large scale project with the potential to contribute to the TP reduction effort. However, it also adds a NPV of $29.65 million to the overall watershed management plan costs or an annual cost (AEV) of $1.43 million. Alternatively, while less cost-efficient at the margin by comparison, BMP 13 (Voluntary Urban Nutrient Management) only adds a NPV of $6.08 million to the overall watershed management plan costs or an annual cost (AEV) of $292,574. It is noted that the 29.9 percent reduction in TP inflow does not fully satisfy the explicit 30.0 percent objective. Therefore, decision-makers can decide whether the 25 percent reduction in overall program costs justify this sacrifice or whether sufficient uncertainty exists (regarding the exact precision of estimates) to support selection of the cheaper alternative.

Table 9. The Suite of Cost-Effective Best Management Practices that Approach the 30 Percent Target Reduction of Total Phosphorous (P) Inflow into Eagle Mountain Lake.

		Initial Estimated Standards				
		Total P 173,020 kg.	Total N 1,055,220 kg.	Sediment 296,400 tons		
		Cumulative Reduction Percentages			Cumulative Net Present Value	Cumulative Annuity Equivalent Value
BMP	**Description**	**Total P**	**Total N**	**Sediment**		
3	Establish Filter Strips	3.9%	2.3%	5.7%	$ 728,542	$ 35,083
4	Establish Grassed Waterways	5.7%	2.3%	5.7%	$ 836,071	$ 40,261
9	Grade Stabilization - gully plugs	7.8%	3.5%	7.0%	$ 1,372,284	$ 66,083
15	Herbicide Application - Riparian corridor	8.5%	5.6%	9.6%	$ 1,419,229	$ 68,344
14	Required Urban Nutrient Mgt.	12.3%	6.1%	8.1%	$ 4,394,499	$ 211,619
5	Terracing	14.0%	6.3%	8.5%	$ 5,698,866	$ 274,431
1	Conversion of Cropland to Grass/Hay	20.5%	7.2%	10.6%	$13,250,797	$ 638,098
10	Prescribed Burning	21.3%	7.3%	10.8%	$13,438,671	$ 647,145
21	P Inactivation with Alum	24.6%	7.3%	10.8%	$26,391,272	$1,270,883
24	Flood Protection Sites - Big Sandy/Salt Creek	28.8%	12.3%	14.9%	$58,771,313	$2,830,158
7	Pasture Planting - reseeding	29.1%	12.4%	15.0%	$59,410,655	$2,860,946
6	Prescribed Grazing	29.1%	12.4%	15.0%	$62,045,060	$2,987,807
11	Brush Management	29.4%	11.1%	15.3%	$65,536,134	$3,155,921
13	Voluntary Urban Nutrient Mgt.	29.9%	11.5%	15.3%	$71,611,742	$3,448,495
	TOTALS	29.9%	11.5%	15.3%	$71,611,742	$3,448,495

The suite of BMPs presented in table 9 follows the previous format and reveals the cumulative costs and incremental nutrient and sediment reduction impacts provided by the BMPs. This information is identical to that of table 8 until the final entry where the substitution of BMP 13 (Voluntary Urban Nutrient Management) for BMP 18 (Wetland Development - West Fork Trinity) is considered. For this suite of BMPs, reductions in TP, TN and sediment inflows total 29.9, 11.5 and 15.3 percent, respectively, of current inflow levels.

The estimated NPV (2011 dollars) required to implement this suite of BMPs was found to be $71,611,742. Of this total, a NPV of $20,492,963 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a NPV of $51,118,779 is needed to fund the operating and maintenance costs (Year 1 through 50 investment). While expenses will be incurred initially and throughout the 50-year project period, the $71.6 million NPV estimate represents the upfront funds needed to implement and maintain the cost-effective suite of BMPs for the entirety of the planning horizon.

The Annuity Equivalent Value (AEV) of the cost-effective suite of BMPs is $3,448,495, representing the annual expenditure necessary each year during the 50-year project period. Of this annual expenditure, a total of $986,850 is necessary to fund the initial establishment and construction costs of the BMPs (Year 0 investment) and a total of $2,461,645 is needed to fund the operating and maintenance costs (Year 1 through 50 investment).

Figure 3 provides a chart of the relative contribution to TP reduction from the perspective of cost-effective strategy BMP categories. Cropland BMPs remain the greatest contributors, providing 46.5 percent of the expected reduction. Urban BMPs are second in importance contributing 14.4 percent of the total, followed by watershed BMPs at 14.1 percent, pasture and rangeland BMPs at 11.7 percent, in-lake BMPs at 11.0 percent, and channel BMPs at 2.3 percent. The same message is conveyed in this illustration; that participation from all BMP categories is needed to achieve the watershed management plan objectives. The importance of securing the participation from agriculture is again important as cropland and pasture and rangeland BMPs account for 58.2 percent of the contributed TP reduction within this watershed protection plan.

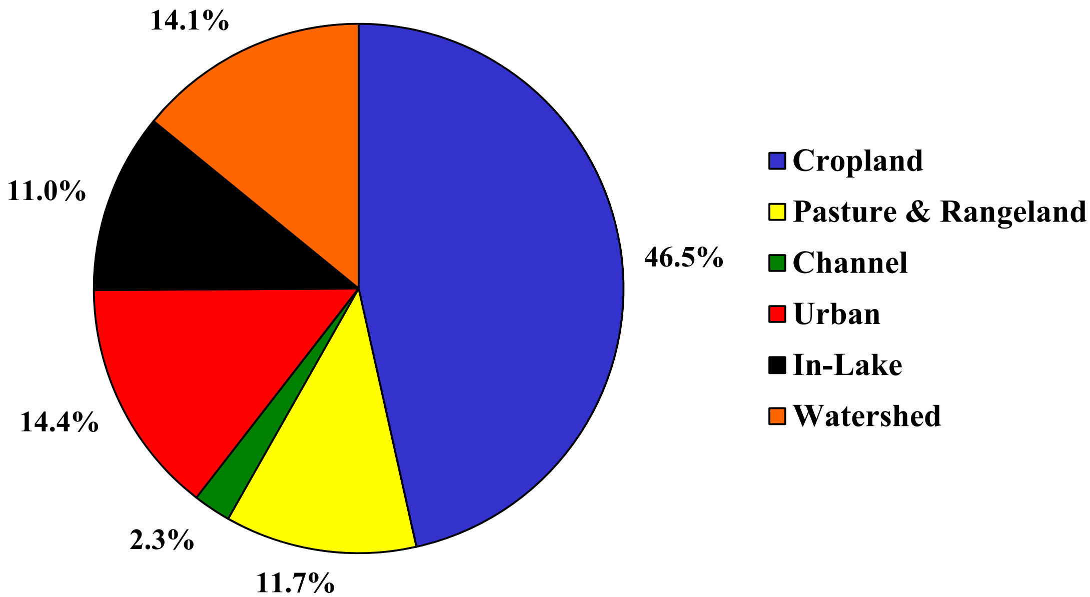

Figure 3. Contribution of Cost-Effective Best Management Practice Categories Resulting in a 29.9 Percent Total Phosphorous Reduction.

Observations Concerning the Implementation of BMPs for a Watershed Protection Plan

This economic analysis of BMPs has revealed a number of important issues that underpin a successful watershed protection plan. Aside from identifying the most cost-efficient and cost-effective combination to achieve the 30 percent TP reduction goal, it highlights the need for broad participation from stakeholders, the funding levels needed to accomplish the plan, the importance of individual BMPs to keep costs reasonable, and the need for a coordinating entity to oversee the plan. Each of these issues is given more reflection below.

Reliance on Participation from Multiple Entities

Projects of the magnitude of the Eagle Mountain Lake watershed protection plan are dependent upon the participation of a wide array of stakeholders and affected entities. Regardless of the strategy chosen to meet the TP reduction goal, participation from several interest groups is an absolute necessity. Obviously, funding availability, decision-makers' planning horizons, future land use and development intentions, the general economic environment, and municipal, county, state, and federal policy are all dynamic factors influencing which BMPs will prove to be most viable. Active involvement, educational outreach and solicitation of guidance from all stakeholders will increase the stakeholder buy-in necessary for the watershed protection plan to be successful.

Funding for BMP Implementation

Successful acquisition of funding to support initial and continuing implementation of management measures is critical for the success of the Eagle Mountain watershed protection plan. While some management measures require only minor adjustments to current activities, some of the most important measures require significant funding for both initial and sustained implementation. All of the BMPs require a long-term commitment; both in terms of financial investment as well as resolute determination from resource owners/managers to assure the BMPs accomplish their potential. Sufficient funding for a project of this magnitude will likely involve multiple approaches to funding, strong partnership alliances to leverage technical, financial, and personnel resources, coordination of those resources, and a plan for the systematic implementation of practices that can be implemented as funding becomes available. This economic analysis identified viable and cost-efficient BMPs that impact multiple stakeholder groups. The available funding sources available to all of these groups will need to be fully exploited in order to secure the financial commitments necessary for this watershed protection plan to achieve the intended objectives.

Significant Variation in the Relative Cost-Efficiency of BMPs

The optimal economic solution will be based on a myriad of factors. When the costs of the respective BMPs are ranked according to cost-efficiency (i.e. cost per unit of TP reduction), the range of cost-efficiency is extensive. This disparity clearly identifies those practices that should be the emphasis of any efforts to reduce TP inflow into the Eagle Mountain Lake, even if funds are not available to finance the entire watershed protection plan. Although the environmental impact associated with reducing TN and sediment was identified, the focus of this analysis was exclusively on TP reduction. If multiple environmental objectives were simultaneously desired, the resulting suite of BMPs identified as optimal for a watershed protection plan would likely be different if the plan required more than four or five BMPs to accomplish.

Impact of Adoption Rates

The optimal suite of BMPs identified in this analysis is greatly influenced by the consensus identification of current and most likely adoption rates for each BMPs. These measures for each BMP, define the marginal adoption rate (i.e. additional eligible area that is likely to adopt a specific BMP). Significant time and effort can be spent investigating which of the borderline BMPs should be included to fully reach the intended target TP reduction levels. However, a review of the cost-efficiency rankings of BMPs in conjunction with the adoption rates suggests that this time would be better spent identifying how a greater level of adoption could be attained for those BMPs that demonstrated the most cost-efficiency. If a higher adoption rate for the most cost-efficient BMPs can be achieved, the potential exists for the costs of the watershed protection plan to be greatly reduced. Higher adoption of more efficient BMPs would replace the need to include higher cost, less efficient BMPs from inclusion the watershed protection plan. While several BMPs included an estimate of an incentive payment to secure participation, thoughtful consideration should be given to the additional participation that could be secured if incentive payments were higher than those assumed in this analysis. There are limits to the amount of financial incentive that can be provided to secure additional adoption of specific BMPs while maintaining cost-efficiency relative to other alternatives. However, those limits should be identified and the differential value built into a plan that would encourage maximum participation for the most cost-efficient BMPs.

Coordination of Watershed Protection Management Plans

Implementation of a model-generated solution on such a large-scale project involving numerous stakeholders with no one central authority is a complex paradigm. Assuming the funding issues discussed previously can be successfully managed, several issues remain to be considered and managed. Targeted implementation of specific BMPs assumes that a coordinating body has the ability to offer participation benefits to certain resource managers without having to accommodate others who might fall outside of the targeted sub-basin area. Alternatively, participation by resource owners lying outside of the targeted sub-basins raises the cost of the program disproportionately to the benefits that are actually obtained. Identifying methods that secure participation of critical BMPs in targeted sub-basins while minimizing participation of non-critical BMPs in non-targeted sub-basins is a challenge that will require thoughtful project design. In addition, the watershed protection plan must also facilitate, encourage and support maximum participation by resource managers to encourage the implementation of the more cost-efficient BMPs beyond the adoption rates assumed in this analysis. Therefore, a viable coordinating entity must be engaged with all stakeholder groups, be proactive and have the ability to monitor the implementation of the specific BMPs that are chosen as part of the overall watershed protection plan.

Conclusion

The purpose of this economic analysis was to evaluate individual BMPs with a primary objective of identifying a combination that could achieve a 30 percent reduction of TP inflows into the Eagle Mountain Lake. This suite of BMPs could be implemented and maintained over the span of a 50-year project period as part of an economically viable Eagle Mountain Lake watershed protection plan. Considering and accepting all of the assumptions developed in the course of the SWAT, WASP, and economic analysis embedded in this analysis, it was determined that the 30 percent target TP reduction level is achievable.

This economic analysis for the Eagle Mountain Lake watershed project extends beyond the SWAT and WASP modeling efforts to evaluate a total of 24 BMPs for potential inclusion in a watershed protection plan. The eligible area for each of these BMPs was identified, their potential to reduce TP, TN and sediment inflows into the lake was identified, current and most-likely adoption rates for each BMP was estimated, and the cost for implementation was calculated to help determine a relative ranking of cost-efficiency. All of this information was synthesized to estimate the expected potential costs associated with adopting and implementing alternative suites of BMPs to collectively meet the 30 percent TP inflow reduction target. Two separate strategies, a cost-efficient suite of BMPs and a cost-effective suite of BMPs, each containing 14 BMPs were highlighted as possible solutions.

The cost-efficient suite of BMPs was estimated to reduce TP, TN and sediment inflow levels by 31.3, 14.7, and 20.0 percent, respectively. For this strategy, the financial cost for achieving a 31.3 percent reduction was identified to be $4,583,626 annually for each of the 50-years in the project period. Up front, (time 0) initial construction costs were estimated to be $38,911,913. While this collection of BMPs is the most cost-efficient (from a $/kg of TP reduced perspective), it exceeds the target TP reduction level at a significant cost because the final BMP included is a large scale project. For this reason, an alternative solution was presented that substituted a smaller scale project as the final BMP for the plan. The cost-effective suite of BMPs was estimated to reduce TP, TN and sediment inflow levels by 29.9, 11.5, and 15.3 percent, respectively. For this strategy, the financial cost for achieving a 29.9 percent reduction was determined to be $3,448,495 annually for each of the 50-years in the project period. Up front, (time 0) initial construction costs were estimated to be $20,492,963. Central to both of these strategies was the participation from several stakeholder groups, specifically agricultural cropland and pasture and range resource managers.

The data assimilation process to support the economic and financial analysis revealed several challenges potentially affecting successful implementation of the optimal watershed protection plan. These challenges include soliciting participation from a diverse stakeholder base, securing sufficient funding to implement the plan, encouraging targeted adoption of the most cost-efficient BMPs and coordinating the complex project details of the overall watershed protection plan.

References

Alan Plummer Associates, Inc. 2008. Tarrant Regional Water District Watershed Project: Eagle Mountain Wastewater Treatment Facilities Report. Austin, TX.

Andrews, D. 2011. Environmental Division, Tarrant Regional Water District, Fort Worth, TX. Personal communications.

Ernst, M.R. 2011. Environmental Manager, Tarrant Regional Water District, Fort Worth, TX. Personal communications.

Gee, K. and J. Biermacher. 2007. Prescribed Burning - What is the Cost? The Samuel Roberts Noble Foundation Research Report. Ardmore, OK. http://www.noble.org/Ag/Research/Articles/PrescribedBurning/index.html Accessed June 2011.

Leal, Alfonso. 2011. Assistant State Conservationist, USDA - Natural Resources Conservation Service, Weatherford, TX. Personal communications.

Lee, T., M. E. Rister, B. Narashimhan, R. Srinivasan, D. Andrews, and M. R. Ernst. Evaluation and Spatially Distributed Analyses of Proposed Cost-Effective BMPs for Reducing Phosphorous Level in Cedar Creek Reservoir, Texas. Transactions of the American Society of Agricultural and Biological Engineers, Vol. 53(2): 1619-1627.

Office of Management and Budget. 2010. "Table of Past Years Discount Rates, Appendix C." Guidelines and Discount Rates for Benefit-cost Analysis of Federal Programs. OMB Circular No. A-94. December.

Rister, E. M., R. D. Lacewell, A. W. Sturdivant, T. Lee, R. Srinivasan, B. Narashimhan, C. Wolfe, D. Waidler, D. Andrews, M. Ernst, J. Owns, B. Lessikar, L. F. Gregory, A. Jones, B. L. Harris, E. K. Seawright, and S. R. Yow. 2009. NCTXWQ project: Evaluating the Economics of Best Management Practices for Tarrant Regional Water District's Cedar Creek Reservoir Watershed. College Station, Texas: Texas Water Resources Institute. Report TR-357.

Tarrant Regional Water District. 2011. Tarrant Regional Water District Water Quality Trend Analysis 1989-2009 Final Report. http://www.trwd.com/Libraries/Water_Quality/Combined_Exec_and_Tech_Reports.sflb.ashx. Accessed August 2011.

USDA Natural Resources Conservation Service. 2010. National Conservation Practice Standards - NHCP. http://www.nrcs.usda.gov/technical/standards/nhcp.html Accessed July 2011.

Appendix E

Task 3 Extension Education

- Cedar Creek Watershed fact sheet development is in the intermediate stage. This deliverable will be completed once BMP runs have been made through the SWAT model and recommendations have been made on how to reduce loadings into the reservoir. This deliverable is 85 percent complete.

- Texas AgriLife Extension is working on the following publications 1) stream processes, 2) Where does the rainfall go?, 3) Utilizing rain gardens for stormwater abatement, 4) Vegetative filter strips, and 5) grassed waterways. These publications are 75 percent complete.

- Officials and volunteers with Texas AgriLife Research, Texas AgriLife Extension, and the Kaufman County Environmental Co-op engaged in a various outreach activities in the Cedar Creek and Eagle Mountain Watersheds. Utilizing the demonstrational apparatus of the Stream Trailer, Enviroscape, and Rainfall Demonstrator audiences were provided instruction in stream erosion, point and non-point source pollution, watershed identity and watershed stewardship. The breakdown of events is listed in the table below.

- The Cedar Creek Watershed fact sheet is ready for submission to Ag Communications for Publishing. This deliverable is 95 percent complete

- The What is the Fate of your Rainfall? factsheet, curriculum guide and flip chart are complete

- The Water Quality factsheet is completed and ready for submission to Ag Communications. This deliverable is 95 percent complete

- Officials and volunteers with Texas AgriLife Research, Texas AgriLife Extension, and the Kaufman County Environmental Co-op continue various outreach activities in the Cedar Creek and Eagle Mountain Watersheds. Utilizing the demonstrational apparatus of the Stream Trailer, Enviroscape, and Rainfall Demonstrator audiences were provided instruction in stream erosion, point and non-point source pollution, watershed identity and watershed stewardship.

- Presentation of Texas AgriLife Extension’s Stream Processes and Rain Garden workshop continues within targeted watersheds and adjacent counties.

- Texas Agrilife Research and Extension Center at Dallas served as a sponsor and partner for the Riparian Workshop held at Texas Christian University on October 12-13. Texas AgriLife Research provided demonstrations of educational apparatus for conference attendees and made presentations on watershed activates in the Cedar Creek and Eagle Mountain Watersheds.

- Aspects of the Cedar Creek Watershed and Eagle Mountain Watershed planning efforts where represented in presentations by Tarrant Regional Water District and Texas

- AgriLife Research at the annual conference of the North American Lake Management Society Meeting November 4-7.

- Project team members continue to seek out opportunities to present the progress and findings with other water professionals through conferences and other speaking engagements.

- Thus far, a total of 14 Stakeholder meetings for the development of the Cedar Creek Watershed Protection Plan have taken place.

- A total of 4 stakeholder meetings for the development of the Eagle Mountian Watershed have taken place and more will be scheduled upon the completion of the economic analysis of proposed best management practices and subsequent computer modeling of forecasted implementation.

- The Texas AgriLife Research and Extension Center at Dallas presented the work of the Cedar Creek Watershed Plan at the EPAs annual drinking water conference. The Plan and partnership were held as an example of collaborative and technically advanced source of water protection.

- Agricultural producers in the Cedar Creek Watershed participated in a one-day workshop on February 11, 2011 which was organized by the Dallas Center. Speakers from Texas AgriLife Extension and USDA-NRCS presented concepts in nutrient management, soil fertility and testing, watershed planning, NRCS funding programs, riparian health and effectiveness of agricultural best management practices to improve water quality.

- The following educational activities were also conducted this quarter:

- The Cedar Creek watershed fact sheet is complete and will be submitted to AgriLife Communications for publishing.

- The Eagle Mountain watershed characterization fact sheet has been drafted. We are waiting for results and information that will be received from the economic study and stake holder meetings to finalize the document and submit it to AgriLife Communications.

- The Water Quality fact sheet is complete and is at AgriLife Communications being published.

- The Grassed Waterways fact sheet is currently under development.

- The Vegetative filter strip fact sheet has been drafted and is under review.

- The Stream Processes fact sheet has been written. Drawings and diagrams for the fact sheet are under development. Once drawings are completed the document will go to AgriLife Communications for publishing.

- Thus far, a total of 14 Stakeholder meetings for the development of the Cedar Creek Watershed Protection Plan have taken place.

- A total of 5 stakeholder meetings for the development of the Eagle Mountain Watershed have taken place and more will be scheduled upon the completion of the economic analysis of proposed best management practices and subsequent computer modeling of forecasted implementation.

- Texas AgriLife Research and Extension conducted an active Spring season of youth and adult outreach emphasizing stormwater education, stream processes, and overall watershed stewardship. AgriLife officials accepted invitations to present at numerous school events, weekend environmental festivals, corporate events, lake clean-up events, and summer camps.

- Texas AgriLife Research officials from the Dallas Research and Extension Center participated as the primary stormwater and watershed instructors at the Trinity River Audubon Society's River Institute workshop for local high school teachers on day one of a three day workshop.

- The draft Eagle Mountain watershed characterization fact sheet is being updated to include the information from stakeholder input and economic study results discussed during the June 24, 2011 Eagle Mountain stakeholder meeting. The finalized document will be submitted to AgriLife Communication

- The Water Quality fact sheet is complete and is at AgriLife Communications being published.

- The Grassed Waterways fact sheet is completed and has been submitted to AgriLife Communications.

- The Vegetative filter strip fact sheet is complete and will be submitted to AgriLife Communications for publishing.
- The Stream Processes fact sheet is complete and will be submitted to AgriLife Communications for publishing.

4/14/2011	Tarrant County Earth Day	Rainfall simulator, enviroscape, and stream trailer. Stormwater and Eagle Mountain Watershed.
4/16/2011	PlanoLiveGreen	Stream Trailer, rainwater harvesting. Watersheds and urban stream processes. Trinity River Basin.
4/22/2011	DFW Airport Environmental Festival	Stream trailer, watersheds, urban stream erosion. Trinity River Basin.
4/23/2011	City of Richardson Trash Bash	Stream trailer, rainwater harvesting. Watersheds, urban stormwater, urban stream erosion. Trinity River Basin

4/27/2011	St. Monica's Catholic School- Dallas	Stream trailer, watersheds, stream erosion. Trinity River Basin
5/9/2011	John Bunker Sands Wetlands Mudbug Festival	Stream Trailer, Cedar Creek Watershed, stream erosion.
5/9/2011	City of Forney Fit Fest	Stream Trailer, Cedar Creek Watershed, stream erosion.
5/12/2011- 5/13/2011	Hunt County Youth Ag Day	Stream Trailer, Cedar Creek Watershed, stream erosion.
5/12/2011	Robert E. Lee Elementary School- Dallas	Stream Trailer, Cedar Creek Watershed, stream erosion.
14-May-11	Eagle Mountain Lake Cleanup	Stream trailer , Eagle Mountain Watershed, stream erosion.
5/16/2011	Lake Dallas ISD- Upper Trinity Regional Water District	Stream Trailer, evniroscape. Watersheds, stream erosion, stormwater
5/17/2011- 5/18/2011	City of Fort Worth Waterama	Stream trailer, Eagle Mountain Watershed.
5/20/2011	Boyd Middle School	Stream trailer, Eagle Mountain Watershed.
5/21/2011	City of Grand Prairie Mayfest	Stream trailer, watershed, Trinity River Basin
6/1/2011	Stream Processes Workshop	Stream Processes, erosion, watersheds, best management practices
6/8/2011	Trinity River Institute- Trinity River Audubon Center, Dallas	Stream Trailer, enviroscape, Rainfall Simulator, Incredible Water Journey. Stormwater, watersheds, Water cycle, Trinity River Basin.

Appendix F

Cedar Creek Watershed Management

Authors: Brent Clayton , David Waidler, Clint Wolfe, Justin Mechell

Cedar Creek Reservoir in north central Texas is identified as a critical resource having aesthetic, recreational, wildlife, water supply, and economic value within the region. To address water quality issues resulting from excessive watershed-based nutrient and sediment loads, reservoir managers are working with local citizens, elected officials, and agency representatives to develop a comprehensive, stakeholder-based watershed protection plan. Utilizing complimentary computer models allowed watershed planners analyze the source and degree of pollutants and to illustrate past, present, and future reservoir conditions resulting from various management scenarios. Economic evaluations of proposed management solutions demonstrate the most efficient use of project funds to foster improvement in reservoir water quality. The resulting watershed protection plan operates as a flexible strategy combining the strategic use of structural best management practices and education and outreach programming for targeted audiences within the watershed. To ensure the success of follows up with water quality monitoring and modeling protocol to ensure success in maintaining the quality of future watershed and reservoir conditions.

Cedar Creek Watershed

A watershed is typically defined as a land area that drains into a common water body, such as a river, lake or ocean. In the case of Cedar Creek, the common body of water is the Cedar Creek Reservoir. Watershed boundaries are determined by topography in which the outermost ridgelines work to divert rainfall and tributary streams into a defined collection point. Watersheds include various land uses, human populations, wildlife, and biological and ecological processes (Figure 1). On a larger scale, watersheds fit into larger river basin systems (i.e. Trinity River Basin).

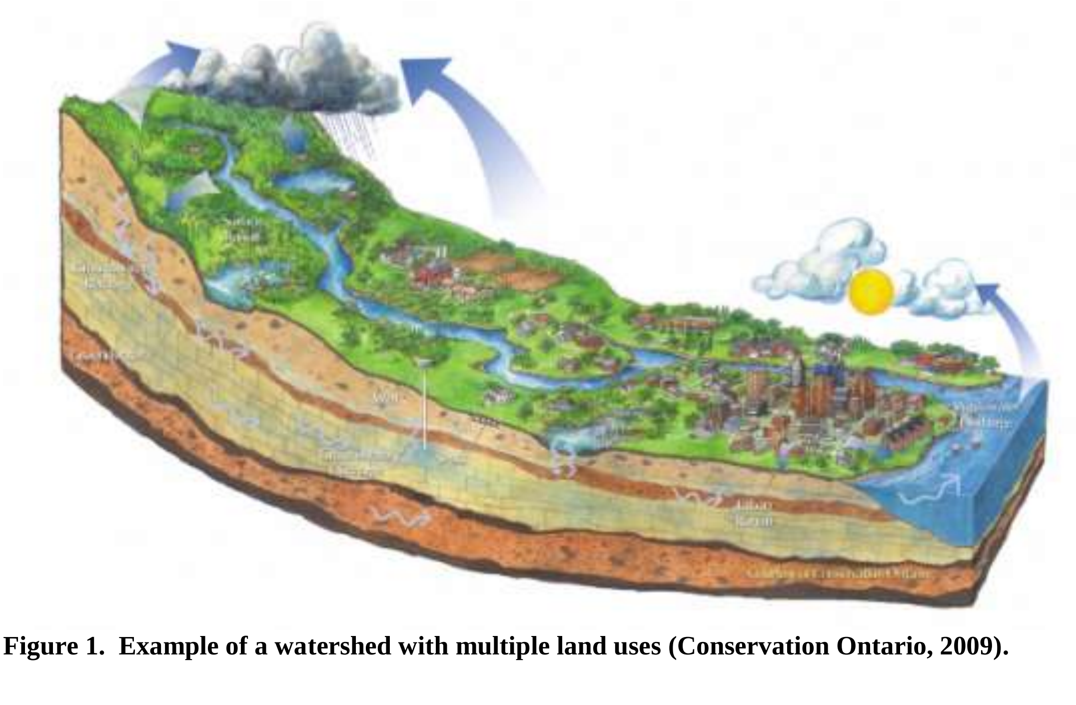

Figure 1. Example of a watershed with multiple land uses (Conservation Ontario, 2009).

The Cedar Creek Watershed is approximately 1,008 square miles, overlapping portions of Henderson, Kaufman, Rockwall, and Van Zandt counties in north central Texas. Cedar Creek Reservoir is owned and operated by the Tarrant Regional Water District and is part of a network of reservoirs and pipelines working to provide raw water supply to over 30 municipalities in north Texas.

Figure 1. Cedar Creek Watershed Municipal and County Boundaries (Spatial Sciences Laboratory 2007)

Figure 2. Example of a watershed with multiple land uses (Conservation Ontario, 2009).

The Trinity River Basin

The Cedar Creek Watershed occupies the upper eastern-most portion of the Trinity River Basin. The Trinity River supplies water to more than 4.5 million people in the Dallas/Fort Worth area and to an additional 4.8 million people in the Houston area. Its basin stretches 360 miles overall across eastern Texas from Dallas and Tarrant counties to the river's mouth near Galveston Bay (Figure 2). Draining a total area of 17,206 square miles, the Trinity River and its tributaries travel a diverse terrain from upland prairies to rolling timberlands and on to the coastal plain.

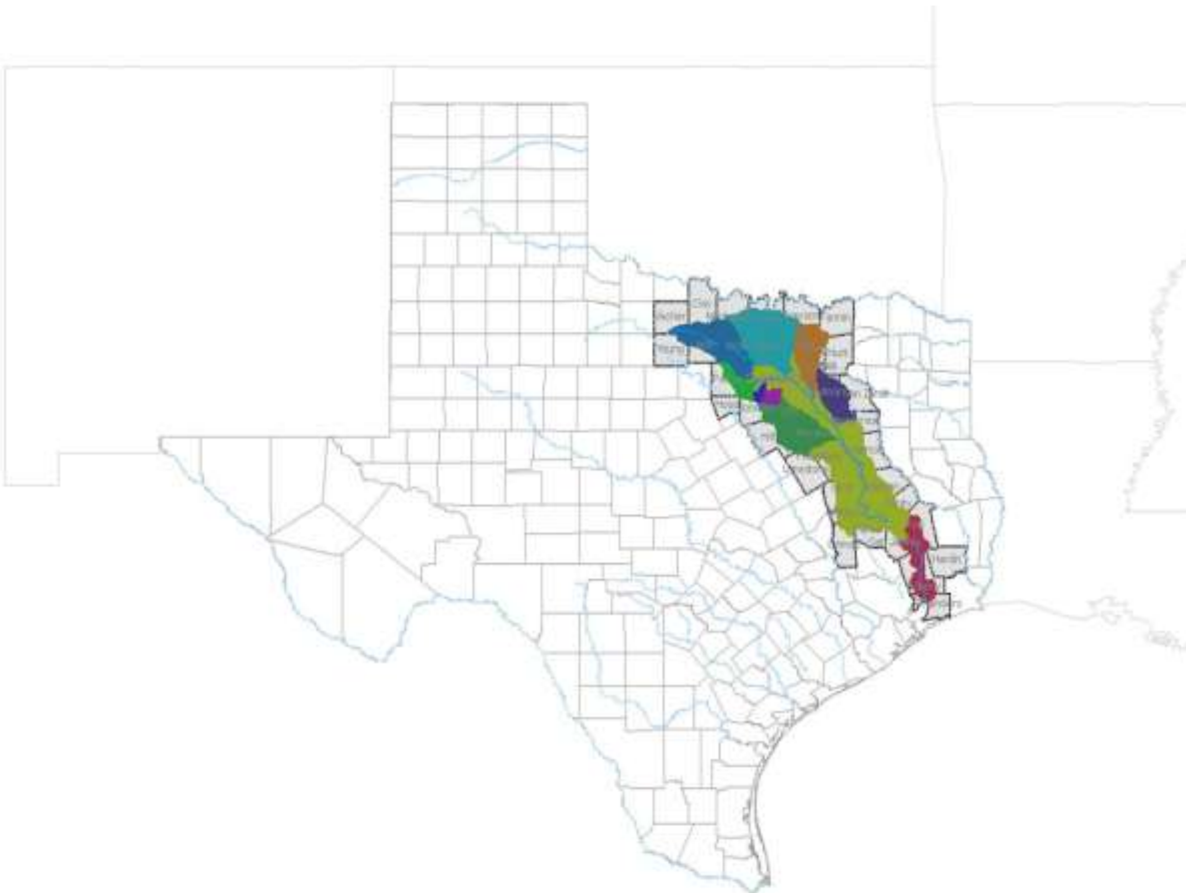

Figure 3. Greater Trinity River basin and its surrounding counties. (TWDB 2007)

Cedar Creek Reservoir

In response to the water needs of the growing north Texas population, Tarrant Regional Water District initiated an effort in the 1960s to develop water resources in rainfall-heavy east Texas. Construction of Cedar Creek Reservoir's Joe Hogsett Dam began in 1960 and was completed in 1965. By 1969, the reservoir had filled to the designed level and currently stores over 678,000 acre feet of water. The untreated, or "raw," water is transported westward toward Fort Worth via a 72-inch pipeline serving TRWD's water customers in route while the remainder is held in Benbrook and Eagle Mountain Lakes. Table 1 lists basic facts about the Cedar Creek Reservoir.

Table 1. Cedar Creek Reservoir facts (Tarrant Regional Water District, 2010).

Surface Area	33,000 acres
Conservation Storage	645,000 acre feet
Watershed Size	1,007 square miles
Shoreline	220.26 miles
Maximum Depth	70 feet

Water Quality

In the late 1980's, the Tarrant Regional Water District (TRWD) initiated routine sampling of the water quality within Cedar Creek Reservoir. Over the last 20 years, this study has indicated an increasing trend in the photosynthetic indicator chlorophyll-*a*. Scientists measure chlorophyll-*a* as an indicator of the amount of algae in the waterbody. The increasing trend of chlorophyll-*a* in Cedar Creek Reservoir has resulted in high levels of pH and could lead to low levels of dissolved oxygen and an abundance of algae. Such conditions may be harmful to the reservoir's recreational, water supply, and wildlife habit uses. As a result, beginning in 2002, Cedar Creek Reservoir was listed on the State of Texas Water Quality Inventory which outlines impaired water as an impetus to management action.

Sources and Causes of Pollution

The high levels of chlorophyll-*a* identified in the lake are a result of high concentrations of watershed based nutrients and sediment. Sediment from overland or channel erosion can serve as a transport mechanism for nutrients such as phosphorus , which fertilizer and promote the growth of the photosynthetic algae. Because these nutrients and sediments lead to harmful algae growth, they are referred to as the pollutant load. The "total pollutant load" in a watershed can be defined as the sum of pollutants from point sources and nonpoint sources. Point source pollution comes from a defined discharge point, which includes activities such as municipal wastewater treatment discharges, industrial waste discharges, and stormwater collection systems. Nonpoint source pollution comes from sources that are spread out across the landscape, which make them more difficult to centrally collect and treat.

Point Source Pollution within the Cedar Creek Watershed

Wastewater treatment plants represent the primary point source discharges within the Cedar Creek watershed. At the time of plan implementation, nine wastewater treatment plants were in operation within the Cedar Creek Watershed. Existing plants employ a variety of methods to achieve compliance with current Texas Commission on Environmental Quality (TCEQ) standards.

Nonpoint Source Pollution within the Cedar Creek Watershed

Despite the growth of urban areas such as Terrell and Rockwall, agriculture continues to be the predominant land use within the watershed. Geographic Information Systems modeling indicates that a full 64 percent of the land area is utilized as pastureland with an additional 6 percent devoted to row crops (Figure 3). This dynamic presents an interesting challenge for watershed planning as nutrients in fertilizers are a significant source of non-point source pollutant loadings. Historically, excessive use of fertilizers on row crops resulted in nitrogen and phosphorus loadings that are transported over the land and into tributaries during periods of heavy rainfall. Additionally, livestock practices that permit the free roaming of cattle into riparian areas as well as overgrazing encourage erosion of stream banks and sedimentation of water bodies.

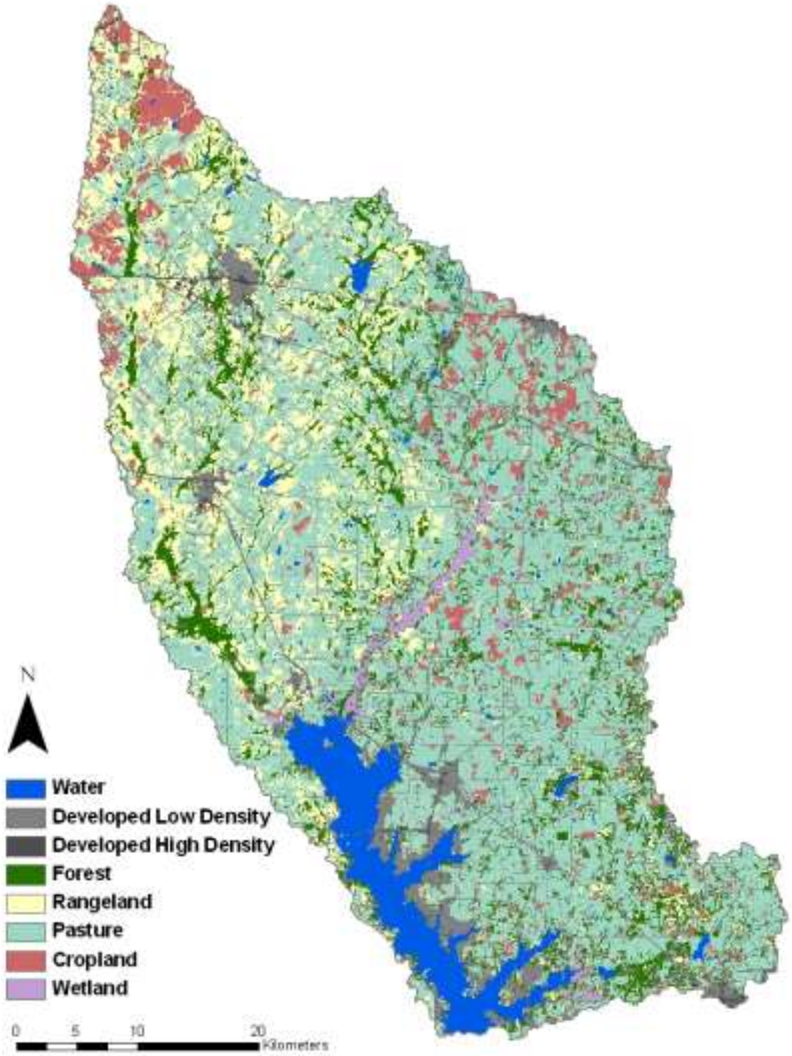

Figure 4. Land uses in the Cedar Creek Watershed (TAMU- Spatial Sciences Laboratory 2007)

Solving the Problem – Watershed Protection Planning

In order to address the rising chlorophyll-*a* level within Cedar Creek Reservoir, a stakeholder-based watershed protection plan has been established to provide a full assessment of watershed conditions and structured course of action for improvement of water quality. Watershed planning as defined by the US Environmental Protection Agency is a stakeholder driven process designed to cultivate the involvement of local citizens and officials. The primary goal of this approach is to develop a formulized strategy for water quality improvement that is not only acceptable to local interests but reflects a level of "ownership" among stakeholders regarding the management of resources.

Development of the stakeholder-based watershed protection plan for Cedar Creek concluded at the end of 2009. The plan has outlined a 10-year implementation strategy to reduce the rising trend of the algae indicator substance chlorophyll-*a* through the use of carefully selected and situated best management practices designed to reduce the flow of nutrients into the reservoir as well as targeted outreach programs for local agricultural producers, municipal officials, homeowners, and youth emphasizing stormwater control, nutrient management, and stewardship,.

Management Measures

Computer modeling of the Cedar Creek watershed allowed the identification of areas within the watershed potentially producing the greatest amount of phosphorus and sediment and for prioritization of these areas for management. This methodology provides a plan to allocate funding for structural best management practices (BMPs) in the future to areas in which the highest impact in pollutant reduction could be achieved. Additionally, these practices have been evaluated to determine each practice's nutrient reduction performance per project dollar allocated. The proposed management solution is based on the stakeholder determined goal of achieving an overall 35% reduction of watershed-based phosphorus. Through computer modeling, watershed planners have determined the priority areas within the watershed for implementation of selected best management practices of filter strips, grade stabilization structures, prescribed grazing measures, wastewater treatment plant upgrades, grassed waterways, and the subsidized conservation of croplands into pasture. Additionally, the project leadership has prioritized the development of an informational and outreach program directed toward multiple audiences with the goals of enhancing watershed literacy and stewardship. Listed below are summaries of the various management practices proposed in the watershed protection plan as economical options.

Land-Use Specific BMPs – Crop Land

Despite accounting for only 6.17% of the land use in the Cedar Creek Watershed, croplands account for a large portion of the nutrient loadings. The croplands located in the Kings Creek area flowing through southern Rockwall and northwest Kaufman Counties contribute a significant amount of the nutrients and sediment that exist in Cedar Creek Reservoir. In total, 42 percent of phosphorus loadings and 23 percent of nitrogen loadings originate on watershed crop lands. The selected crop land BMPs are filter strips, grade stabilization, grassed waterways, terracing, and pasture planting.

Proposed Practice: Filter Strips

A filter strip is an area of vegetated land located between a surface water body and an area developed by people (i.e. cropland, grazing land, etc.). This area, also known as a buffer strip or vegetative filter, is situated where surface runoff leaves a disturbed land (Figure 4). The filter strip slows down that runoff, allowing large particles to settle and pollutants to be absorbed or degraded before they enter the water body (Green and Haney[1]).

Figure 5. Filter Strip (Photo courtesy of USDA NRCS)

Proposed Practice: Grade Stabilization

Grade stabilization structures are constructed lakeside and streambank reinforcements (Figure 5). They are placed to reduce erosion and sedimentation from steep embankments that are prone to soil loss during storm events. Structures must be logistically situated for maximum effectiveness.


Figure 6. Grade Stabilization Structure (Photo courtesy of USDA NRCS)

Proposed Practice: Grassed Waterways

A grassed waterway is a channel that transports concentrated flow from surrounding lands at a reasonable velocity by using grasses and other vegetation (Figure 6). It can be natural or a purposely constructed BMP. By slowing down the velocity of the water, the potential for erosion is reduced. Similar to a filter strip, the vegetation removes sediment and pollutants from entering water bodies downstream. The grassed waterway is different from filter strip because it slows down and filters channeled water instead of surface runoff (Green and Haney[2]).


Figure 7. Grassed Waterway (Photo courtesy of USDA NRCS)

Proposed Practice: Terracing

Terraces are series of earthen embankments constructed across fields at designed vertical and horizontal intervals based on land slope, crop rotation, and soil conditions (Figure 7). Construction of terraces involves a heavy capital investment to move large quantity of earth for forming earthen embankments. Hence it should be considered only if other low cost alternates are determined to be ineffective. Terracing is recommended for land with a grade of 2% percent or higher.

Figure 8. Terracing (Photo courtesy of USDA NRCS)

Proposed Practice: Pasture and Range Planting (Conversion of Cropland to Pasture)

The planting of pastures and crop lands with native or introduced vegetation allows for the absorption of nutrients and reduction of runoff. Grass, forbs, legumes, shrubs and trees work to restore a plant community similar to historically natural conditions but still account for the nutritional needs of livestock and native species (Figure 8).

Figure 9. Pasture Planting (Photo courtesy of USDA NRCS)

Land-Use Specific BMPs – Pasture and Rangeland

Rangelands and pasturelands account for the majority land use within the Cedar Creek Watershed. While the runoff pollution on pastures is low compared to urban and cropland areas, BMPs are still necessary where there may be overgrazing and producers have demonstrated to use significant amounts of nutrient-laden fertilizers to enhance forage. When pastures or rangeland are overgrazed, there is not enough vegetation to capture and absorb pollutant runoff. One practice that can reduce overgrazing is prescribed grazing.

Proposed Practice: Prescribed Grazing

Prescribed (a.k.a. rotational) grazing is a method of pasture management where livestock are rotated to different pastures at regular time frames (Figure 9). This maintains the health of vegetation and allows for establishment of a dense stand which reduces soil erosion and retains soil nutrients.

Figure 10. Prescribed Grazing (Photo courtesy of USDA NRCS)

Urban Stormwater Management

Urban areas account for only 6.4% of the total land area in the Cedar Creek Watershed. However, runoff from streets, roofs, and other hard surfaces can carry several harmful pollutants, including the nutrients that impact Cedar Creek Reservoir. This runoff, made worse during major rain events, is referred to as stormwater.

Under the Clean Water Act, major urban areas have to obtain a permit from the EPA to discharge stormwater into streams as part of the Municipal Separate Storm Sewer System (MS4) program. At this time, no municipalities within the Cedar Creek Watershed currently are large enough to require such permits. However, portions of southern Rockwall County may face annexation by the City of Rockwall, which currently operates under a Phase II permit of the MS4 guidelines.

Because of the limited and geographically dispersed populations of many of the watershed municipalities, stakeholders involved with urban issues have recommended a strategy of working to implement rules and ordinances on a county or watershed level. Such measures would include regulation of construction and road improvement practices, regular inspection and repair of onsite sewage facilities, and restrictions on the fertilization and irrigation of large properties such as city-owned athletic complexes. Another proposed strategy is to focus primarily on communities adjacent to Cedar Creek Reservoir to discourage fertilizer use among residents. This suggestion is under serious consideration in the form of a management proposal for a 2000 foot buffer strip surrounding the reservoir in which fertilizer use can be discouraged.

> **Proposed Practice: 2000 Foot buffer Strip Surrounding Lake (Urban Nutrient Management)**
> This proposed strategy would help to manage the amount, source, placement, form, and timing of the application of plant nutrients and soil amendments to minimize urban nonpoint source pollution of surface and groundwater resources. Preliminary soil testing is also an important element of nutrient management. The practice encourages the proper use of phosphorus based fertilizers, proper blends of fertilizers to be available to watershed consumers, and the encouragement of landscaping techniques that require limited fertilizer and irrigation.

City-Specific Wastewater Treatment Plant Management Measures

As the population of the Cedar Creek Watershed expands, so too has the demand for wastewater treatment facilities. Modeling of wastewater treatment plant discharges and recommended upgrades for the watershed plan are based on the nine plants in operation and evaluated in a 2007 Alan Plummer Associates, Inc. report (APAI, 2008). Point source discharges from wastewater treatment plants are regulated by the Texas Commission on Environmental Quality as part of a regulation and permitting process. A proposed series of graduated improvements to each operating plant has been outlined in the Plummer report. A total of 44 structural improvements were proposed, each accounting for an individual plant’s current permit status and suggesting specific structural improvements to reduce pollutant discharges beyond current requirements. It is possible that in the future as watershed populations grow, the associated addition of new wastewater treatment plants will mandate that upgrades be made to existing plants to meet more rigorous discharge standards.

Education and Outreach

The Cedar Creek Watershed Protection Plan is a complex, in depth, integrated tool for improving water quality in the reservoir. However, its success requires more than the implementation of structural water quality improvement practices. To enhance these efforts, an education and outreach campaign was developed to inform the public and to increase stewardship of watershed resources.

The driving force for the development of the Cedar Creek watershed education and outreach campaign is to provide information to targeted audiences such as youth, homeowners, agricultural producers, and recreationists that will assist in reversing the trend of nutrient and sediment loadings that have contributed to the impairment of Cedar Creek Reservoir. The goal of the Cedar Creek Reservoir Watershed educational program is to provide information to watershed stakeholders regarding the status of the reservoir and watershed and future conditions. Emphasis will be placed on the concept that the activities of people living in the watershed and around the lake will impact reservoir water quality. It will encourage personal action such as limiting landscape fertilizer use, septic system maintenance, and litter prevention.

Summary

The Cedar Creek Watershed Protection provides a holistic framework for addressing the water quality impairments in Cedar Creek Reservoir. Planning efforts have demonstrated that each person living, working, or playing in the watershed can contribute to the water quality of the reservoir. As a result of watershed planning efforts, major sources of pollutants are identified and prioritized, the implementation of structural best management practices to reduce their loading to the reservoir have been outlined, and the combined effort is demonstrated to show a significant improvement in reservoir quality.

References

APAI (Alan Plummer Associates, Inc). 2008. Tarrant Regional Water District Watershed Project : Cedar Creek Reservoir Wastewater Treatment Facilities Report.

Conservation Ontario. (2009). *Graphics*. Retrieved October 25, 2010, from Conservation Ontario: http://www.conservation-ontario.on.ca/resources/graphics/index.html.

Green, C.H. and R. Haney[1] (n.d.). *Filter Strips*. Retrieved February 21, 2011, from SERA-17: http://www.sera17.ext.vt.edu/Documents/BMP_Filter_Strips.pdf.

Green, C.H. and R. Haney[2] (n.d.). *Grassed Waterways*. Retrieved February 21, 2011, from SERA-17: http://www.sera17.ext.vt.edu/Documents/BMP_Grassed_Waterways.pdf.

NRCS. (n.d.). *NRCS Photo Gallery*. Retrieved November 3, 2010, from Natural Resources Conservation Service: http://photogallery.nrcs.usda.gov/.

Tarrant Regional Water District. (2010). *Cedar Reservoir Information*. Retrieved February 21, 2011, from http://www.trwd.com/CedarCreekMap.aspx.

Texas Water Development Board (2007). *Graphics.* Retrieved May 1, 2011, from Texas Water Development Board : http://www.twdb.state.tx.us/mapping/index.asp.

Spatial Sciences Laboratory- Texas A&M University (2007). Modeling Report for Cedar Creek Watershed.

Vegetative Filter Strips

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Vegetative Filter Strips

Vegetative filter strips are areas of planted or indigenously established permanent dense vegetation usually perennial grasses or timber along croplands, drainage channels, streams or other water bodies. Their main function is removal of sediments, nutrients, mainly nitrogen and phosphorus, pesticides, organic matter, pathogens and other contaminants from runoff. While vegetative filter strips are effective as a stand-alone best management practice (BMP), using them as part of a conservation plan that includes terracing, water, fertilizer, and pest management and soil testing, is recommended for more extensive benefits.

Figure 1: Vegetative Filter Strip (Source: Tulsa County Conservation District)

How Do Vegetative Filter Strips Treat Runoff?

Vegetative filter strips should be designed to allow runoff to be dispersed as uniform sheet flow. This allows the filter strip to remove sediments, soluble nutrients, chemical and organic matter from runoff before it reaches the adjacent water body. These pollutants are removed from runoff water by the following processes:

- Deposition
- Infiltration
- Biological and chemical processes

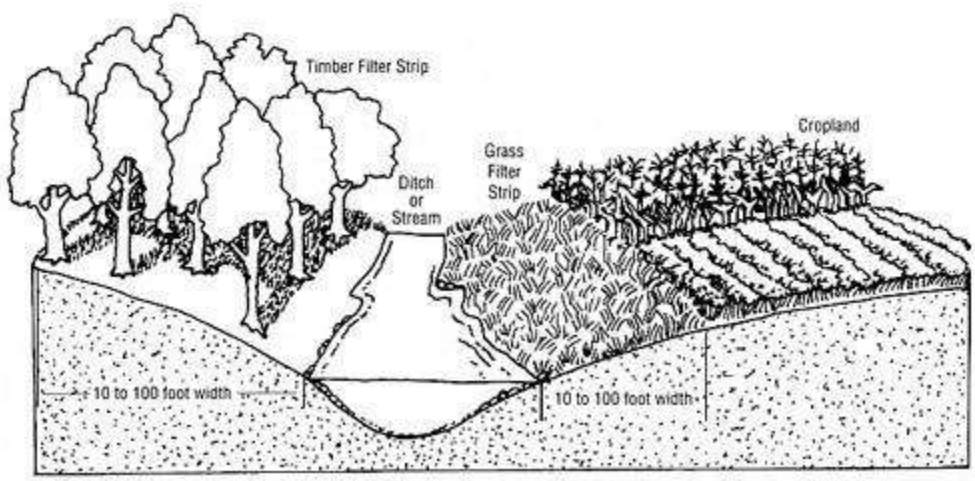

Figure 2: Filter strip design (Source: The Ohio State University Extension Service)

Deposition

As runoff enters the filter strip, it is slowed down causing sediments to settle. Large and medium size particles (e.g., sand, silt, soil aggregates) are usually deposited in the first few feet of the filter strip. Finer particles such a clay require a longer distance. This distance depends on the volume and velocity of the runoff as it enters the filter strip. The removal of sediments also results in the removal of sediment-bound pollutants such as phosphorus, ammonium and some pesticide residues.

Infiltration

As runoff velocity decreases, infiltration in the vegetative filter strip increases. The infiltration rate depends primarily on the soil texture. Clayey soils have low infiltration capacity while gravelly sandy soils have a high infiltration capacity. Organic matter and plant residues increase the infiltration capacity of the soil. In addition, a developed root system improves soil structure and porosity, which in turn increases infiltration. As water moves vertically, more sediment is deposited. Soluble nutrients such as nitrate move into the soil and could be taken by the plants or immobilized by biological and chemical processes in the soil. If the soil has a high infiltration rate, like gravelly sands, soluble pollutants could travel with water and reach an underground aquifer, or reach the adjacent stream through the soil in a process called interflow.

Biological and Chemical Processes

As nutrients and pesticides enter the soil, biological and chemical processes cause the break down or transformation of these compounds. The new compounds could either be taken by plants, volatilize in to the air (e.g, denitrification), or get immobilized in the soil. In some cases, compounds could be broken down into forms that are more soluble in the water, and may end up in the stream.

Applications and Limitations

Vegetative filter strips can be used under most circumstances where there is a need for reducing pollution of surface water emanating from contaminated non-point sources and/or discharges from point sources. This implies that vegetative filter strips have a place in agricultural, urban and industrial areas and well as in riparian zones where they can be used as an 'outer zone' of a stream buffer. Limitations of vegetative filter strips include the following:

- They require land that could otherwise be put to a different use. Hence, they can be costly in terms of the land and establishment costs.
- They are only very effective if runoff water flows through them as a uniform sheet limiting their range of use.
- They are unlikely to treat highly contaminated discharges from storm sewers, swales and channels
- In dry areas where vegetative filter strips need irrigation to survive, irrigation cost may surpass the water quality benefits.
- They provide no direct water quality benefits in areas that produce small quantities of runoff.

How Effective Are Vegetative Filter Strips?

The effectiveness of a filter strip depends on various factors. These include:

- Soil texture
- Width of the vegetative filter strip
- Field slope length
- Field slope
- Type of flow
- Rainfall intensity and frequency
- Field cover or vegetation management practices

Soil Texture

The size of soil particles and other materials suspended in runoff affects the ability of vegetative filter strips to capture them. As runoff flow velocity is slowed in a vegetative filter strip, the larger soil and organic particles filter out first, leaving the smaller clay particles in suspension. These usually move down with infiltrating and percolating water into the soil profile because of their tendency to remain in suspension for longer periods of time. This suggests that vegetative filter strips installed on soils with very low infiltration rates may be limited in their ability to filter suspended clay in runoff flowing through them.

Width of Vegetative Filter Strip

The width of the filter strip is the most important factor affecting its efficiency. The United States Department of Agriculture (USDA) Natural Resources and Conservation Service (NRCS) recommends a minimum ratio of 70:1 of field slope length to filter strip width. The width of the filter strip should be the largest possible that would trap sediments and soluble nutrients, while not removing a large portion of land from production. NRCS recommends various widths based on the field slope, soil type, and the target pollutants. If the target contaminants are sediments and sediment bound contaminants, the minimum filter strip widths are listed in Table 1.

Table 1. Minimum filter strip flow widths to reduce sediment, particulate organics, and sediment adsorbed contaminant loading in runoff (Source NRCS, USDA).

Length of Flow (Feet)				
Land Slope of Contributing Area	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
0 - 1 %	20	20	22	24
>1 - 3 %	20	25	28	30
>3 - 5 %	24	30	33	36
>5 - 8 %	28	35	40	42
>8 - 10%	32	40	44	48

Hydrologic Soil Group Descriptions:
A -- Well-drained sand and gravel; high permeability.
B -- Moderate to well-drained; moderately fine to moderately coarse texture; moderate permeability.
C -- Poor to moderately well-drained; moderately fine to fine texture; slow permeability.
D -- Poorly drained, clay soils with high swelling potential, permanent high water table, claypan, or shallow soils over nearly impervious layer(s).

If the main contaminant in the runoff is a water soluble chemical (e.g., nitrate) or pesticides, filter strips will need to be wider as listed in Table 2 because wider filter strips are needed to increase infiltration:

Table 2. Minimum filter strip flow widths to reduce dissolved contaminants in runoff (Source NRCS, USDA).

Length of Flow (Feet)				
Land Slope of Contributing Area	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
0 - 1 %	30	30	33	36
>1 - 3 %	40	50	55	60
>3 - 5 %	56	70	77	84
>5 - 8 %	72	90	100	108
>8 - 10%	96	120	132	144

In case pathogens are the target contaminant, longer trapping time (as compared to sediments) is required to allow for biological and chemical processes to kill the microbes. The recommended widths are listed in Table 3.

Table 3. Minimum filter strip flow widths to reduce pathogens in runoff (Source NRCS, USDA).

Length of Flow (Feet)				
Land Slope of Contributing Area	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
0 - 1 %	20	25	28	30
>1 - 3 %	24	30	33	36
>3 - 5 %	32	40	44	48
>5 - 8 %	48	60	66	72
>8 - 10%	100	125	137	150

Special recommendations are also available for concentrated animal feeding operations (Table 4) and treating wastewater from an animal waste management system (Table 5) using filter strips.

Table 4. Minimum filter strip flow widths to reduce to reduce dissolved contaminant and particulate loading from a CAFO feedlot (Source NRCS, USDA)..

Length of Flow (Feet)				
Land Slope of Contributing Area	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
< 2 %*	48	60	66	72
> 2 - 4 %	72	90	100	108
> 4 - 6 %	96	120	132	144
> 6 %	Not Recommended too steep	Not Recommended too steep	Not Recommended too steep	Not Recommended too steep

* Slopes < 2 % are recommended only if a solid removal system, such as a sediment basin, is functioning above the filter strip area, the discharge is designed to spread the effluent evenly over the top of the filter strip, and the cross slope area is nearly flat.

Table 5. Minimum filter strip flow widths for treatment of wastewater as part of an animal waste management system (Source NRCS, USDA). .

Length of Flow (Feet)				
Land Slope of Contributing Area	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
< 2 %*	60	75	83	90
> 2 - 3 %	80	100	110	120
> 3 - 4 %	120	150	165	180
> 4 - 5 %	160	200	220	240
>5 - 6 %	240	300	330	360
> 6 %	Not Recommended too steep	Not Recommended too steep	Not Recommended too steep	Not Recommended too steep

* Slopes < 2 % are recommended only if a solid removal system, such as a sediment basin, is functioning above the filter strip area, the discharge is designed to spread the effluent evenly over the top of the filter strip, and the cross slope area is nearly flat.

Field Slope Length

The field slope length represents the total drainage area contributing runoff to the filter strip. The larger the field slope length, the greater the runoff volume and flow rate. This results in lower sediment deposition and infiltration rates. Larger slope length will require wider filter strips to effectively retain sediments and soluble nutrients.

Field Slope

The higher the field slope, the higher the runoff velocity flowing into the vegetative filter strip. High velocity flow also causes higher erosion rates and thus carries more sediment into the filter strip. This results in lower deposition rates and lower infiltration. Wider vegetative filter strips are needed as the field slope is higher. For slopes above 10%, filter strips are not recommended for any use. When filter strips are used for concentrated animal feeding operations (CAFO) or for treatment of wastewater as part of an animal waste management system, they are not effective for field slopes above 6%.

Type of Flow

The general assumption made on vegetative filter strips as a best management practice is that runoff water flows through them as a sheet (i.e. laminar flow). Field observations however show that sediment deposition on field edges often leads to the concentration of flow. This phenomenon narrows the flow path of runoff to only a small segment of the filter strip, increase flow velocity of the water and reduces the efficacy of the filter strip. Hence maintaining filter strip efficiency requires ensuring that water enters them as sheet flow.

Rainfall Intensity

The ability of a vegetative buffer strip to capture runoff is also influenced by rainfall intensity and its antecedent moisture content. Frequent rainfalls saturate filter strips and reduce their capacity to infiltrate water and hence their efficiency at mitigating runoff of sediments and other contaminants.

Field Cover or Vegetation Management Practices

Field management practices that affect residue cover are also a factor in the effectiveness of vegetative filter strips. For example, a corn-corn rotation or a corn-grain sorghum rotations using disk plow tillage and beans-corn rotation using chisel tillage can be less effective than a corn-corn rotation using chisel tillage or no tillage, which leaves a good residue cover. Another important factor affecting the efficacy of filter strips is its height relative to the depth of runoff moving through it. Runoff depth in excess of filter strip vegetation height results in the vegetation being pushed down in an orientation parallel to the direction flow of the runoff. When this happens, water flows faster through the filter strip and decreases its ability to capture pollutants in runoff.

Various studies have evaluated the effectiveness of filter strips in trapping pollutants. The results from various experiments evaluating the retention of sediments, nitrogen, phosphorus, and pesticides are shown in Table 6. Sediment retention varied from 65%-97%. Nitrogen retention varied from 0-72%. Phosphorus retention was 27-79%. Pesticide retention varied from 74-99%. All these figures are compared to systems without a vegetative filter strips.

Table 6. Results of several research experiments evaluating the effectiveness of vegetative filter strips in capturing sediments, nitrogen, phosphorus and pesticides.

Study Location	Soil Texture	Slope (%)	Filter Strip Width (feet)	Pollutant	% reduction
Virginia	Silt loam	11-16	15	Sediment	70%
			30		84%
			15	Total Nitrogen	54%
			30		73%
			45	Total Phosphorus	61%
			60		79%
Maryland	Sandy loam	3-4	15	Sediment	66%
			30		83%
			15	Total Nitrogen	0%
			30		48%
			15	Total Phosphorus	27%
			30		46%
Iowa	Silt loam	7	10	Sediments	72%
			20		83%
			30		97%
		12	10		88%
			20		90%
			30		96%
Virginia	Silt loam	4-12	13		65%
			26		65%
Iowa	Silt loam	3-6	15		72%
			30		76%
Italy	Silt loam	2	10	Terbuthylazine	74%
			20		99%
			10	Metolachlor	81%
			20		99%
Texas	Clay	2	10	Atrazine	22%
				Metolachlor	25%

How to Design a Filter Strip

Location

Vegetative filter strips should be placed along streams, drainage ditches and canals, ponds, lakes and sinkholes. Filter strips need to be built such that the flow entering is shallow and uniform. Therefore, the runoff needs to reach the filter strip before it concentrates in small channels that form along the field slope. This is best achieved by having the filter strip follow the contour line of the field. If the flow is already concentrated, terracing and grassed waterways should be used rather than vegetative filter strips.

Vegetation Selection

Vegetation to be used in filter strips should be native or adapted to local climatic conditions. It should provide a uniform ground cover as well as a fibrous root system to increase soil stability. The vegetation could consist of a single species or a mixture of grasses, legumes and/or other forbs. Species selected should have stiff stems and high stem density at the ground surface. Stem density should be no less than 1 inch of stem spacing. Table 7 lists Texas specific vegetation, seeding rates, planting dates and suitable soils for filter strips. Seeding rates could vary among varieties. Many local plant species might also be suitable for your specific region. Consult with your local USDA-NRCS office for an exhaustive list of plants suitable for your own area.

Table 7. Vegetation, seeding rates, planting dates and suitable soils for filter strips in Texas (Source NRCS, USDA)..

Name	Seeding rate	Planting dates	Soil				
	lbs/acre		coarse	moderately coarse	medium	moderately fine	Fine
Perennial Grasses							
Bermuda	3.0	12/1-6/1	x	x	X	x	x
Bluestem, yellow	1.2-2.0	12/1-6/1		x	X	x	x
Bristlegrass	3.0	12/1-6/1	x	x	X	x	x
Buffalograss	8.0	12/1-6/1	x	x	X	x	x
Dropseed	1.0	12/1-6/1	x	x	X	x	
Eastern gamagrass	10.0-15.0	12/1-6/1		x	X	x	
Grama	1.5-4.5	12/1-6/1	x	x	X	x	x
Indiangrass	4.5	12/1-6/1	x	x	X	x	x
Kleingrass	1.5	12/1-6/1		x	X	x	x
Lovegrass	1.5	12/1-6/1	x	x	X		
Panicum	2.0	12/1-6/1	x	x	X	x	x
Sacaton	1.0	12/1-6/1			X	x	x
Sorghum	12.0	12/1-6/1	x	x	X	x	x
Switchgrass	2.0-3.5	12/1-6/1	x	x	X	x	x
Perennial Forbs, Legumes, Shrubs							
Alfalfa	20.0	8/15-11/1	x	x	X	x	
Awnless bushsunflower	2.6	12/1-6/1		x	X		
Engelmanndaisy	15.0	8/15-11/1			X	x	x
Illinois bundleflower	13.6	12/1-6/1	x	x	X	x	x
Maximilian sunflower	3.0	12/1-6/1		x	X	x	x
Prairieclover	3.0	12/1-6/1		x	X	x	x
Annual Grasses							
Forage sorghum	10.0-15.0	3/15-8/15	x	x	X	x	x
Grain Sorghum	15.0	3/15-8/15	x	x	X	x	x
Millet	15.0	3/15-8/15		x	X	x	x
Oats	40.0	8/15-11/1	x	x	X	x	x
Rye	40.0	8/15-11/1	x	x	X	x	x
Triticale	40.0	8/15-11/1	x	x	X	x	x
Wheat	40.0	8/15-11/1	x	x	X	x	x
Annual Forbs, Legumes, Shrubs							
Clover	3.0-20.0	8/15-11/1		x	X	x	x
Partridge pea	13.4	12/1-6/1	x	x	X	x	
Sunflower	5.0-15.0	12/1-6/1	x	x	X	x	x
Sweetclover	10	8/15-11/1		x	X	x	x

Installation

The installation of vegetative filter strips is similar to that of pasture or meadow. As a result, most considerations taken during installation of pastures and meadows apply to vegetative filter strips. But, land preparation in terms of grading and soil surface preparations may be necessary prior to installation to ensure proper function of the vegetative filter strips. Important issues to consider after choosing the type of vegetation is evaluating soil fertility through soil testing and the method of seeding. The fertility status of the soil determines fertilizer or lime needs and the amounts required for the job. Vegetative filter strips can be seeded using either conventional or no-till practices. Regardless of the tillage practice, it is essential to place seeds properly and have good seed-to-soil contact. When employing conversional seeding methods it is advisable to (1) follow soil test recommendations with regard to liming and fertilization, (2) broadcast lime and fertilizer and incorporate thereafter (3) establish firm seed beds and (4) plant seeds to about ¼ inch (i.e. shallow planting) with a drill or any other appropriate equipment followed by cultipacking. Seeds can also be broadcast and culipacked to ensure seeds are in good contact with the soil. In contrast, no-till operations only require fertilizer broadcast and no-till drill planting. Depending on weather conditions, supplementary irrigation may be required to support good filter strip vegetation establishment. If the plant species chosen for the vegetative filter strip establishes slowly, a 'companion' crop like spring oats, wheat, or rye may be planted to help control erosion and weeds until the filter strip species is fully established.

Maintenance

Vegetative filter strips usually require little maintenance though it is necessary for effective performance. It is important to limit traffic in filter strip areas as a compaction control measure. In cases where flow spreaders are used, efforts should be made to keep them level to ensure effective functioning. Though optional, if possible, the performance of vegetative filter strips should be monitored after their installation as a way to measure success and/or determine the need for further maintenance. Table 8 summaries some of the maintenance needs of vegetative filter strips and their solutions**.**

Table 8. Maintenance activities and needs of vegetative filter strips and how to achieve them.

Activity	Frequency	Observable Problem or Purpose of Activity	Corrective Measure
Inspection	Regularly	Signs of erosion (e.g. channeling, rills)	Fix bare areas and reseed, interseed or sod
		Sediment accumulation	Remove sediment. If accumulation is > 6 inches deep cultivate and reseed affected areas to maintain sheet-like flow of water across the vegetative filter strip
		Water stressed vegetation	Irrigate as needed
		Tall vegetation (> 10 inches).	Mow from frequently to occasionally at 4 to 10 inch height when dry. Remove clippings to avoid nutrient build up.
		Presence of noxious weeds	Use appropriate herbicides to kill noxious weeds if necessary
Soil test	Periodically	To determine soil fertility status	Apply nutrients if necessary according to soil test recommendations

Benefits

Vegetative filter strips provide several social and economic benefits. The social benefits which are environmental in nature include erosion control, stable stream banks and ditches, improved water quality and wildlife habitats, and better natural beauty along water ways. In contrast, economic benefits are direct monetary gains farmers realize from the sale of hay or timber from filter strips. Other avenues that offer direct financial returns on vegetative filter strips to farmers include incentive programs like the Conservation Reserve Program (CRP) and the Environmental Quality Incentive Program (EQUIP).

Cost

There are three major costs associated with vegetative filter strips. These include the cost for (1) renting land, (2) seed or sod and fertilizers and (3) equipment and labor. However, land rental costs the most. While costs associated with seed or sod and fertilizer purchase may be incurred only during installation, the others will occur throughout the life of the filter strip. Owing to differences in the value of land, soil fertility, planting and management practices, and anticipated use of filter strip vegetative materials, the cost of this best management practice may vary from place to place. Research in Missouri estimates the cost of vegetative filter strips at $62.4 per acre per year.

References and Additional Resources

Eck, K.J. Vegetated filter strips for improved water quality. Purdue University Cooperative Extension Service. AY-285

Grismer, M.E., A.T. O'Geen, D. Lweis. 2006. Vegetative filter strips for nonpoint source pollution control in agriculture. University of California Division of Agriculture and Natural Resources Publication 8195.

Leeds, R., L.C. Brown, M.R. Sule and L. VanLieshout. 1994. Vegetative filter strips: Application, installation and maintenance. Ohio State University Extension. AEX-467-94.

Liu, X, X. Zhang and M. Zhang. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis.

Nakao, M., B. Sohngen, L. Brown and R. Leeds. 1999. The economics of vegetative filter strips. Ohio State University Extension. AE-0006-99.

USDA. 1997. Filter Strips. Natural Resources Conservation Service. Conservation Practice Worksheet No.393.

Qiu, Z. 2003. A VSA-based strategy for placing conservation buffers in agricultural watersheds. Environmental Management 32(3):299-311

Stream Processes and Restoration:

An Introduction

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Streams are a natural part of the landscape that consists of a body of fresh water with a current, confined within a stream bed and stream banks. Streams and rivers transport water and sediments from high elevations to lakes, estuaries and oceans situated downstream.

Streams and rivers are an important part of the **water cycle**. The water cycle describes the continuous movement of water on, above or below the surface of the earth, in a closed loop, though processes such as evaporation, advection, condensation and precipitation.

The area of land that drains to a stream or river is known as its **watershed**. Any rain that falls in a watershed evaporates back into the atmosphere, is infiltrated into the soil or runs off the land and moves downslope. Water then concentrates in low areas and forms small channels, called **ephemeral channels** that only carry water during rainfall runoff. Downstream from ephemeral channels are **intermittent streams**, which transport water during the wet season. Partially supplied by groundwater welling up to the top (**baseflow**), they disappear during the dry season, when the groundwater level drops. **Perennial streams** are formed when the baseflow is large enough to sustain stream flow throughout the year.

The size and shape (**morphology**) as well as flow characteristics of the stream depends on the area of the watershed, soil type, topography and land use. However, even though streams vary in shape and size, all streams have a few common characteristics. All streams have a left and right bank (looking downstream), and streambeds made of a mixture of bedrock, rocks, pebbles, gravel, sand and silt or clay. Streams also share structural characteristics such as pools, riffles, meanders, steps, flood plains and terraces. These characteristics are naturally formed by interactions between the geology, topography, climate and vegetation of the area.

Streams perform a variety of functions in the landscape. In addition to transporting water and sediments, they also provide habitat for many aquatic organisms, including fish and aquatic invertebrates. Trees and vegetation on stream banks act as food source for these animals and help regulate temperature of the channel. The structural features such as pools and riffles help maintain habitat diversity, oxygenation and refuge from predators. Impaired streams lose such structural and functional diversity, leading to progressive imbalance in the system. Hence, while restoring impaired streams, it is important to use natural channel principles in the design.

Bankfull discharge and stage

In the process of defining the channel form, one of the most important aspects is the bankfull discharge. Bankfull discharge is defined as the flow that transports the majority of a stream's sediment load over time and forms the channel. It is also referred to as the effective discharge or dominant discharge. The bankfull stage can be determined morphologically as the point at which flooding occurs on the flood plain, or the incipient point of flooding (Figure 1) .

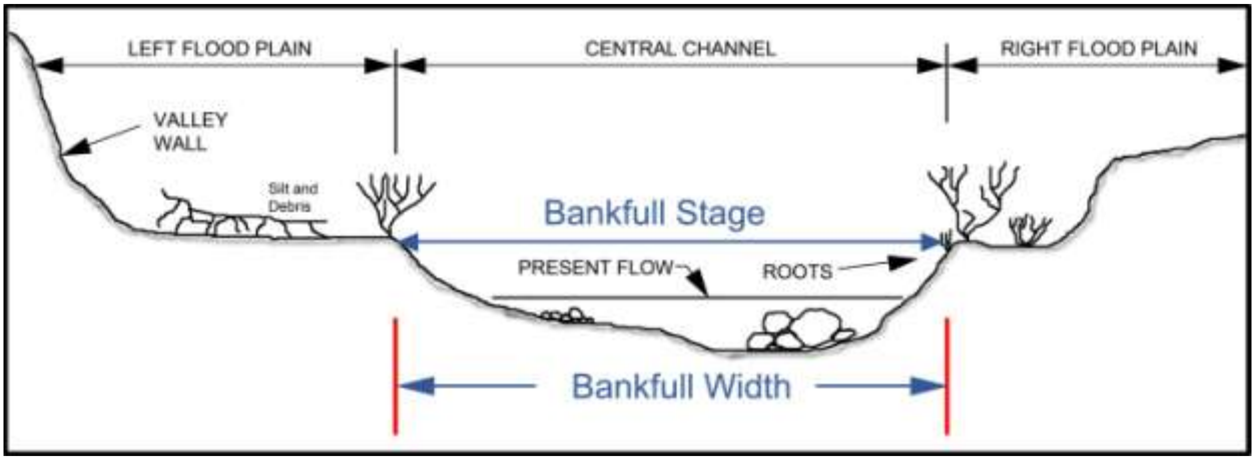

Figure 1. Bankfull stage and discharge

Natural Channel Stability

Stable streams maintain their form and function while moving slowly across the landscape, by maintaining features such as dimension, pattern and profile of the stream channel. Stable streams are able to transport the normal sediment load that comes from the watershed. However, watershed or local scale disturbances in sediment or flow rates can result in channel bed erosion (**degradation**) by scouring or increases in height due to sediment deposition (aggradation), which in turn results in stream instability. Figure 2 provides a conceptual illustration of this concept. The product of sediment load and sediment size is proportional to the product of stream slope and discharge. A change in any of these variables could cause the stream channel to change in shape and structure.

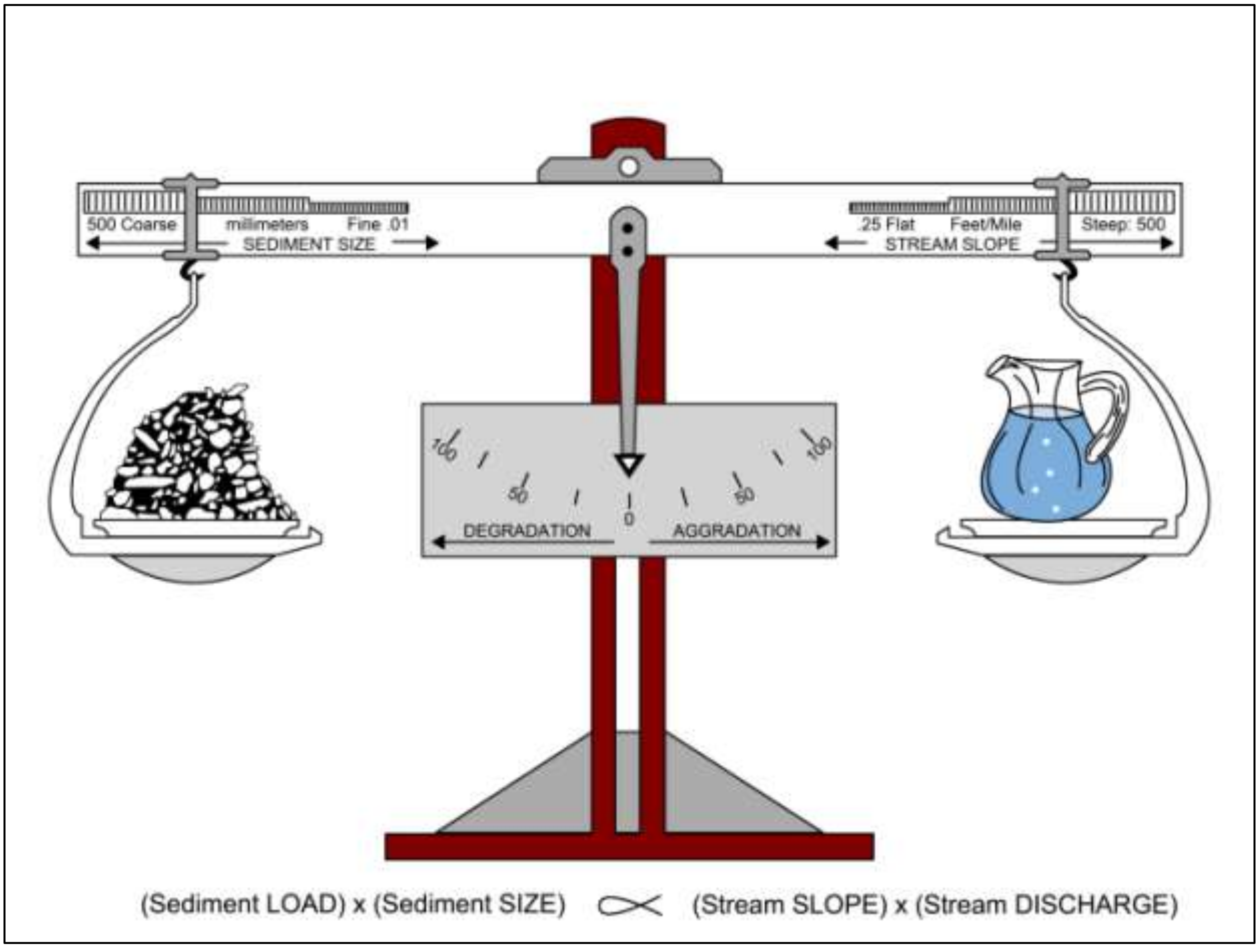

Figure 2. Factors that affect natural channel stability (adapted from Lane E.W. 1955)

Channel dimension and characteristics

The channel dimension of a stream is the cross sectional area of stream at bankfull measured at a stable riffle in stream. Width of stream increases as you go downstream. In arid regions, streams are wider than similar watershed size streams located in humid areas due to lack of vegetation and erosion. The mean depth of the stream varies within stream depending on channel slope and the spacing of riffles and pools.

Streams generally follow a sinuous path across a floodplain. The sinuosity of a stream is defined as the channel length along the deepest part of the channel (**the thalweg**). Sinuosity increases as the slope of the landscape decreases. A meander bend has higher resistance and lower channel gradient compared to a straight reach. The stream pattern can be defined by measuring the meander wavelength, radius of curvature, amplitude and belt width (Figure 3).

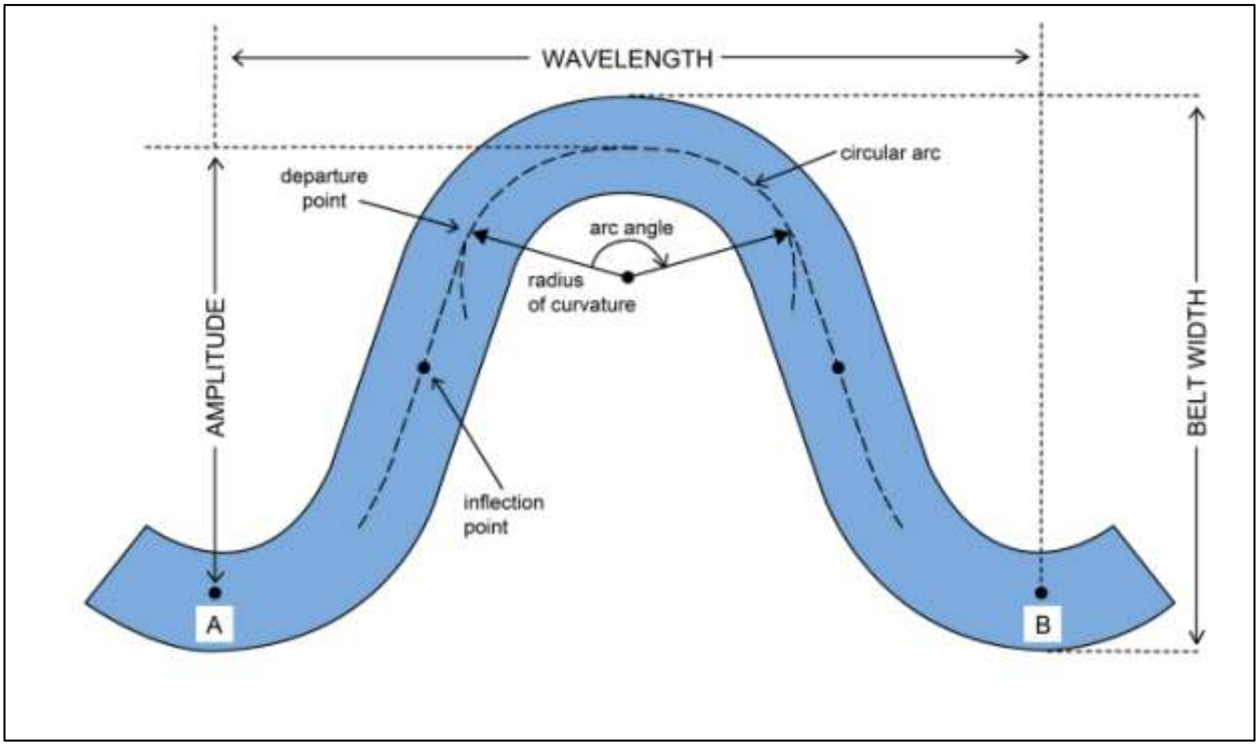

Figure 3. Meander pattern geometry (Adapted from Rosgen, 1996)

Channel features

Stream channels have sequential patterns of riffles and pools or steps and pools, which are required to maintain stream function (Figure 4). **Riffles** are features on the stream bed that consist of gravel or rocks and are shallow and steep in gradient compared to the average gradient of the stream. Thus, at low flows, water flows faster over a riffle creating valuable oxygenated habitat for aquatic organisms, as well as act as a scour feature. **Pools** are found on the outer part of the meander bend between riffles. Pools are deeper than the average channel depth and have a flatter slope. At low flows, material gets deposited at pools. A **run** is defined as the section of the stream between riffles and pools, while a **glide** is the section between pools and riffles.

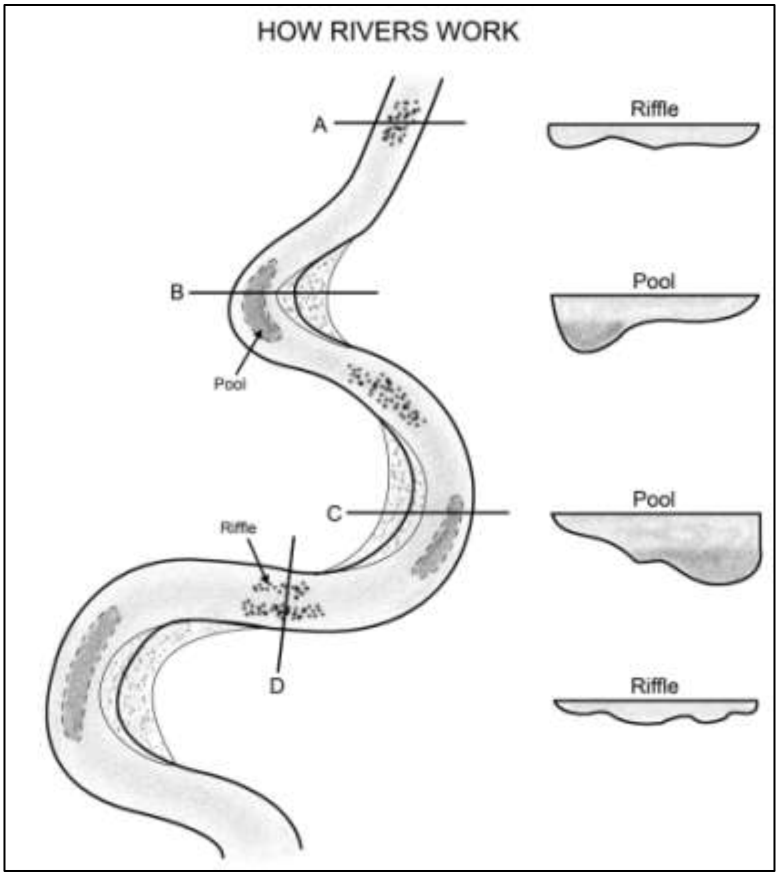

Figure 4. Channel features

Natural Stream Restoration

Streams may need to be restored for many reasons, including issues with flood control, erosion problems or degrading fish and wildlife habitat. It is beneficial to use a natural channel design that takes into account biological components. Natural stream restoration utilizes a **reference reach**, a previously defined relatively short segment of the river, which can be used as a template for stable and biologically diverse stream channel. The goal of such a restoration is to encourage sediment and water movement without aggradation or degradation, in a manner that results in habitat improvement and increased diversity in the stream channel.

Stream Assessment

One of the first steps in stream restoration is an assessment of the existing conditions of the stream channel. Data obtained from this assessment are used to determine the condition of the reach that is under consideration for restoration (**project reach**). The information is also used to subsequently determine the potential for restoration as well as to formulate a restoration plan. The stream assessment is done using a variety of procedures, which are outlined below.

a. Watershed Area Measurement: Geographic information systems along with topographic maps are used to determine the watershed boundary and to calculate its area. It may be necessary to calculate the drainage area at both the upstream and downstream ends of the project reach.
b. Land Use Survey: The current and historical land use type of the watershed is determined in this step. Aerial photographs, county records, topographic maps and zoning maps are examples of the resources used for determining land use. This information is used to determine the kind of regional curve to be used for bankfull verification (see below).
c. Bankfull Identification: The height of water or stage during bankfull flow is the point at which flooding occurs on the floodplain. Bankfull can be determined using a series of steps including field indicators such as scour lines and benches and regional curves.
d. Channel Dimension: The cross sectional view of a stream, specifically its bankfull cross sectional area (bankfull width determined by mean bankfull depth) measured at a stable riffle, is its channel dimension. Stream width is determined by the occurrence and magnitude of discharge, the material the stream bed and bank is made of
e. Channel Profile: The longitudinal slope of the stream comprises its profile. As we go downstream, the channel slope typically increases while the size of the bed material typically decreases. Channel slope is inversely proportional to slope, with steep streams having lower sinuosity than flat streams. The channel profile can be irregular because of differences in bed material as well as structural differences such as riffle to pool spacing. Water surface profile matches the bed profile at low flows, while during high flow the water surface profile becomes more uniform.
f. Pattern: Stream pattern includes criteria such as stream sinuosity, meander wavelength, radius of curvature and belt width (Figure 3).Aerial photographs (1:24000 scale or better) or measured slope ratios are used for determining these measurements.
g. Substrate Analysis: The composition of the stream bed and banks (substrate) influences the channel form and hydraulics, rates of erosion, and sediment supply. Steep mountain streams with boulders behave differently from a low gradient streams that have a bed of sand. Therefore stream substrate analysis, also called pebble count, is an important criterion in stream evaluation and restoration. Three commonly used methods include a reach wide pebble count where a total of 100 pebbles from throughout the longitudinal reach is sampled, another where 100 pebbles are sampled at a single cross section and a third method that involves sampling of 100 pebbles at a riffle, but only from an area that is in contact with water (wetted perimeter) at normal flow. The first method is used for stream classification, the second for cross sectional analysis and the third for calculating sediment entrainment and velocity.
h. Estimating Bankfull Discharge and Velocity: The volume of water flowing through a stream channel cross section at bankfull stage per unit time is known as its bankfull discharge volume. Bankfull discharge (Q_{bkf}) is estimated using Mannings equation, below:

$$\boldsymbol{Q = \frac{1.49}{n} \mathrm{AR}^{2/3}\, \mathrm{S}^{1/2}}$$

where:

Q= Bankfull discharge (cfs)

A= Bankfull Cross sectional area at stable riffle (ft^2)

R= Hydraulic Radius of the riffle cross section at bankfull stage (ft)

S= Average channel slope (ft/ ft)

n= Manning's Roughness Coefficient

Hydraulic radius is determined using the formula **R= A/WP,** where WP is the wetted perimeter of the channel bottom at bankfull stage measured in feet. Cross sectional area and wetted perimeter can be calculated using the cross section survey data. Manning's roughness coefficient (n) is estimated by using Chow's coefficients for various channel substrate and vegetation characteristics (1959).

Velocity is determined by using the following equation:

$$V=Q/A$$

Where

V= Bankfull velocity (fps)

Q= Discharge (cfs)

A= Bankfull cross sectional area at stable riffle (ft^2)

i. Assessing Riparian Conditions: An initial assessment of the floodplain topography and soil is conducted during this step. Features such as ditches, pools, sloughs, wetlands, knolls, steep banks and old crop rows are noted. Length and width of valley is recoded, as well as proximity to utilities, roads and other structures, if the stream is urban in nature.
Soils type and texture is noted and described, using county soil survey classifications. Soils can also be tested for its nutrient content, for any help with planning the vegetation requirements of the site.
Plants at the site are surveyed, and type, size and relative abundance of each species is recorded. Native and non-native plants are noted and flagged for transplanting or removal, as needed. Appropriate on –site vegetation can be used for re-vegetating the site after restoration for minimal costs.

Stream Classification:

Streams are classified in order to explore similarities and differences between them, so that the natural processes and function of different types of streams could be assessed, as well as to understand and mitigate potential changes in stream conditions in the event of environmental changes. One of the more widely used stream classification methods based on differences in channel morphology is called the Rosgen Stream Classification System (Rosgen, 1996). The objectives of this type of classification are:

- Predicting stream behavior from its appearance.
- Developing hydraulic and sediment relationship for a specific type of stream.
- Providing a mechanism to extrapolate site specific data to stream reaches with similar attributes.
- Providing a consistent frame of reference for inter disciplinary communication of stream morphology and condition.

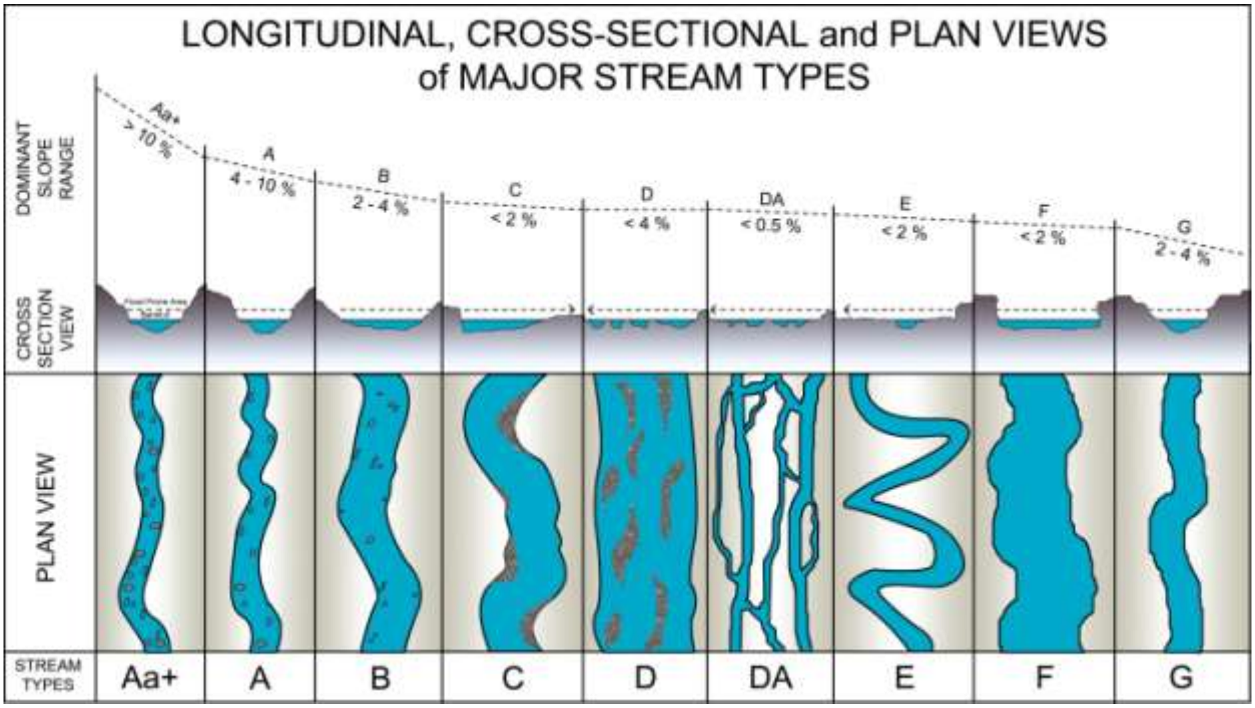

Figure 5. Level I assessment of streams under the Rosgen method (Adapted from **Rosgen, 1996)**

The Rosgen method of classification is divided into four hierarchical levels as follows:

1) Level I: A broad level geomorphic characterization that utilizes maps and visual assessments of valleys, landforms, stream shape, slope and channel pattern to delineate stream patterns. At this level streams are categorized into types A, B, C, D, DA, E, F or G (Figure 5).
2) Level II: Morphological descriptions based on field determined reference reach information. Level II includes the following steps
   a) <u>Determine single or braided channel</u>: This can be done by field observations or aerial photos. A braided channel consists of three or more distinct channels. Anything below is considered a single channel. The stream types for braided channels are D and DA.
   b) <u>Calculate entrenchment ratio</u>: A measure of channel incision, the entrenchment ratio can be calculated by dividing the **flood prone width** by the **bankfull width**. The flood prone width can be determined by measuring the width at twice the maximum depth of the channel at the bankfull stage. Low entrenchment ratios indicate channel incision, while a higher entrenchment ratio indicates a well-developed floodplain.

c) Calculate width to depth ratio: The width to depth ratio is obtained by dividing the bankfull width by the mean bankfull width. The mean bankfull depth is the cross sectional area at bankfull divided by the bankfull width. In the Rosgen system, the width to depth ratios greater than 12 are types B, C and F. Stream types A, E and G have width to depth ratios less than 12. Among the braided streams, the type D has a width to depth ratio greater than 40, while the type DA has a width to depth ratio less than 40.

d) Determine sinuosity: The sinuosity of a stream can be obtained by dividing the stream length with the straight line valley length. This information can be obtained from large scale aerial photographs with scales 1:24000 or more. The greater the number, the higher the sinuosity. Sinuosity is related to slope. Natural streams with steep slopes have lower sinuosity while streams with low slopes have high sinuosity.

e) Measure water –surface slope: Measure the water surface from the top of one riffle to the top of another at least 20 bankfull widths downstream. The channel slope is calculated by dividing the difference in elevation between the two riffles by the length of the channel between the two as measured along the thalweg. This is considered the average slope. Stream types A and B have the steepest slopes while types E and DA typically have the lowest slopes.

f) Determine the median size of the bed material: A pebble count is used to determine the median size of the particle (d_{50}) of the bed material. Fifty percent of particles are larger than d_{50} and 50% are smaller. A reachwide pebble count is conducted by randomly sampling 100 pebbles from a stream reach across the bankfull width. A cumulative frequency plot of the bed material size yields the $d_{50.}$

3) Level III: This stage examines the stream state or condition as pertains to its stability, the need for restoration and its potential for restoration. It is critical to examine the morphology of reaches upstream and downstream of the project reach to determine if the stream is moving towards stability and instability and if the cause of the instability is local or more widespread.

a) Watershed scale instability: Various factors can affect the watershed to cause instability in the stream, causing erosion or deposition. Development of the watershed and stream channelization are some of the common causes of watershed scale instability. These factors need to be addressed before bank stabilization or habitat improvement can be attempted.

b) Local (Reach) Instability: Local instability refers to erosion and deposition not caused by instability in the watershed, such as erosion along the outside banks of a meander bend. Local instability also occurs due to factors such as channel constriction, flow obstructions, and loss of riparian vegetation.

Channel Stability Assessment:

Channel Evolution: A common sequence of physical adjustments happen in many streams following a disturbance such as those caused by channelization, urbanization and removal of riparian vegetation. This sequence is called channel evolution (Figure 6). According to models that describe channel evolution, the sequence of events is initiated once a disturbance happens that increases the channel incision, thus increasing the stream power that causes degradation. Incision leads to highly steep banks, which collapse and fall into the river once a critical height is reached, leading to widening of the banks. Eventually the stream begins to aggrade a new low flow channel begins to form in the sediment deposits. By the end of the sequence, a stable stream with a dimension, pattern or profile is formed in the deposited material. Recognizing at which stage of channel evolution is the stream under study can be helpful in assessing the stream restoration actions needed.

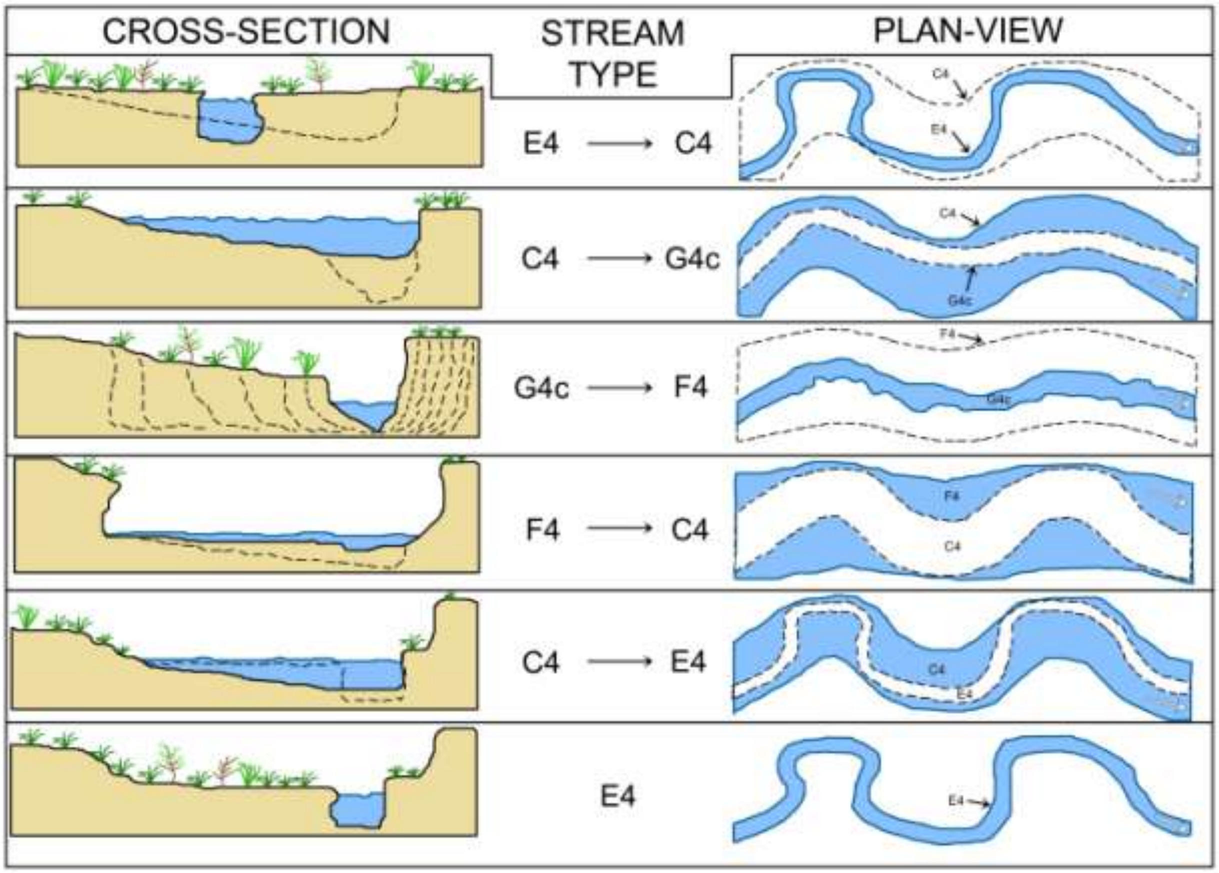

Figure 6. An example of channel evolution occurring in a type E4 stream channel (Adapted from Rosgen, 1996)

Streambank Erosion: Streambanks erode due to shear stress caused by moving water. Banks that are too weak to resist gravitational forces can collapse, and are referred to as being geotechnically unstable. The physical properties of a streambank that can cause bank failure include bank height, bank angle, surface protection, soil material and soil stratigraphy. Rosgen (1996) developed the Bank Erodibility Hazard Index as a way to assess the potential for bank erosion along a reach. A general indication of erosion potential of 'Low, Medium and High' is assigned according to factors including bank height in relation to bankfull depth, bank angle, density of roots, bank surface protection , percentage of bank height with roots, soil stratification and particle size(Figure 7).

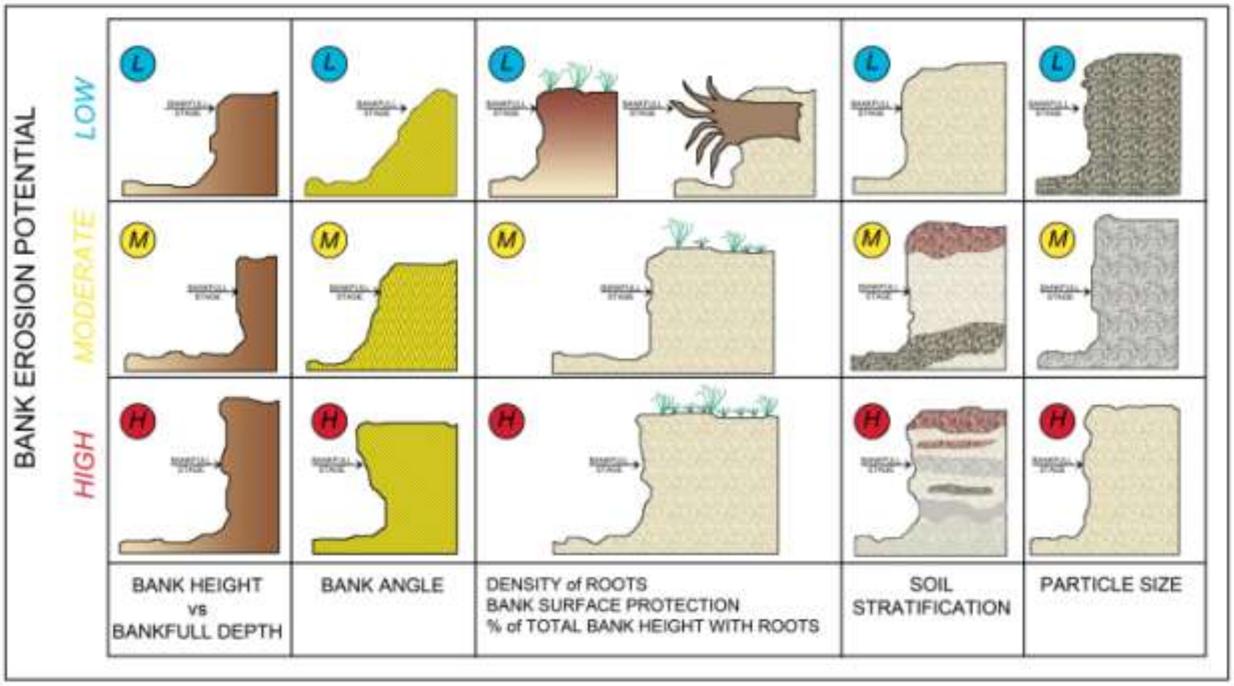

Figure 7 Bank Erodibility Factors (Adapted from Rosgen, 1996)

For example, if the banks are made of bedrock or boulders, the bank erosion potential will be 'Low', despite having no vegetative protection and root mass. However, gravel or sand banks will be much more likely to erode, and merit an erosion potential of 'High', unless they have elevated surface vegetation protection and root mass.

Restoration Options for Incised Streams

Factors such as loss of riparian vegetation, straightening of channels and changes in watershed land – use cause channel incisions, which typically render streams unstable. Such incised channels are good candidates for stream restoration projects. Incised streams have a bank height ratio greater than 1.0 ft/ft, indicating the bankfull stage is below either bank. Moderately incised (bank height ratio between 1.4 and 1.8 ft/ft) and severely incised streams (bank height ratio>1.8ft/ft) are considered unstable and would need to be restored.

Restoration options need to be considered in priority order before a design can be finalized. The options are described below.

1) <u>Priority 1: Establish bankfull stage at the historical floodplain elevation</u>
   A Priority 1 restoration aims to replace the incised channel with a new, stable stream at a higher elevation. A new channel is excavated to match the dimension, pattern and profile typically found in the watershed, using the reference reach data. The new channel is typically and E or C stream with bankfull stage located at the ground surface of the original floodplain. The increase in streambed elevation also may increase the water table elevation, which may restore or enhance wetland conditions in the floodplain. It can be constructed during dry conditions, while stream flow

continues in the original incised channel. The new channel can be stabilized with structures and vegetation before water is directed into the new stream.

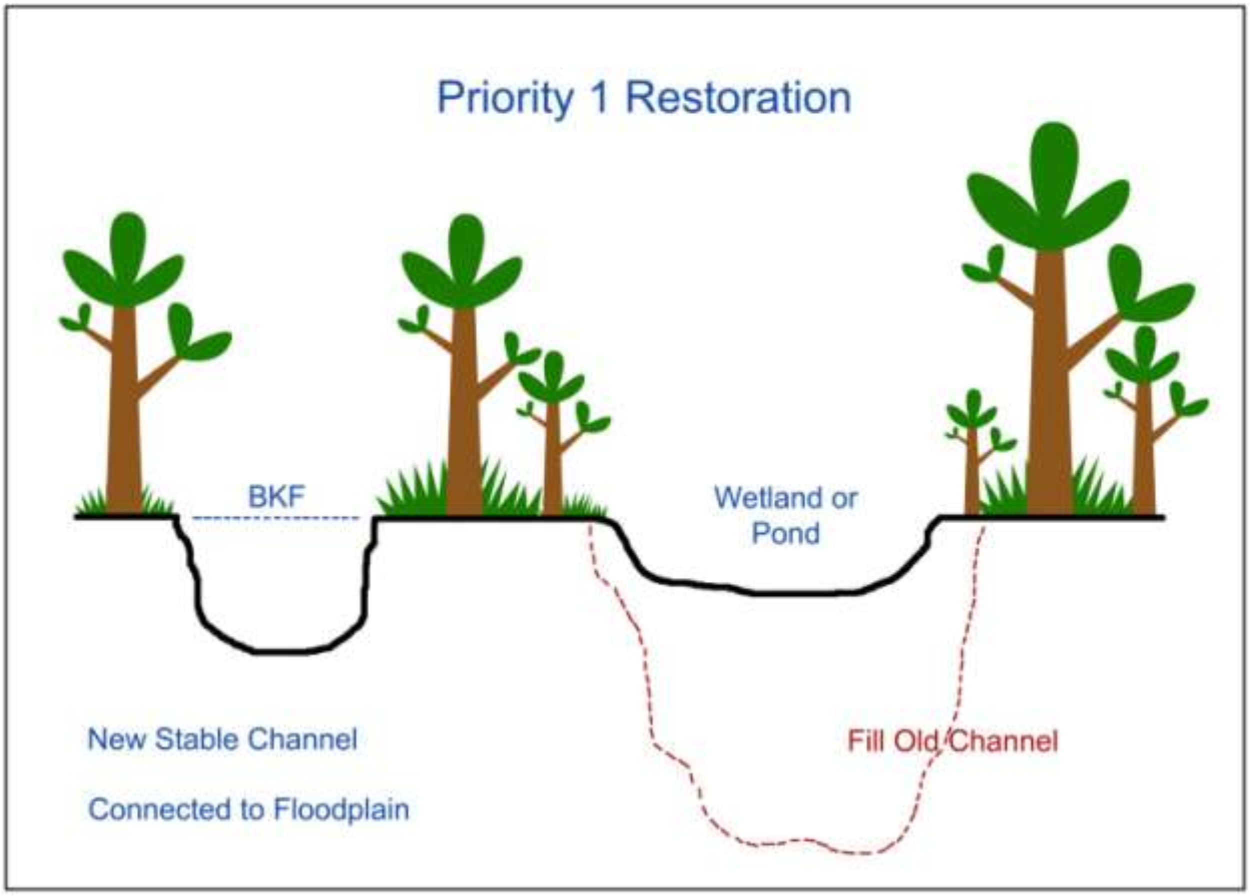

Figure 8. Priority 1 Restoration with the old eroded channel outlined in red dashed line (Adapted from NCSU Stream Restoration Design Handbook)

A Priority 1 project can result in the most long term stable stream system, if conducted properly. It may also be the least expensive to construct.

However, it is constrained by surrounding land use. It requires sufficient land area on one or both sides of existing channel to construct the new meandering channel. Most of these projects will result in higher flood stages above bankfull discharge near and downstream of the project. Another thing to consider is that the excavated soil from building the new channel will not be sufficient to fill the old channel, and hence additional fill material may need to be brought in.

2) Priority 2: Create a new floodplain and stream pattern with the stream bed remaining at current elevation

A Priority 2 restoration is recommended when a narrower area is available for the floodplain or there is a high risk of flooding. Under the Priority 2 restoration, a new stable stream and floodplain is created at the current channel-bed elevation. This is done by excavating a new channel and floodplain, with the dimension, pattern and profile that is consistent with what is suggested by reference-reach data, ensuring proper fit with the watershed. The new channel tends to be an E or C stream with bankfull stage located at the elevation of the newly excavated floodplain.

A Priority 2 project may be more expensive and complex to construct than a Priority 1 project. However, because the new floodplain is constructed at a lower elevation, Priority 2 projects may actually decrease the potential for flooding, with the stream corridor created by the excavated floodplain enhancing riparian wetlands.

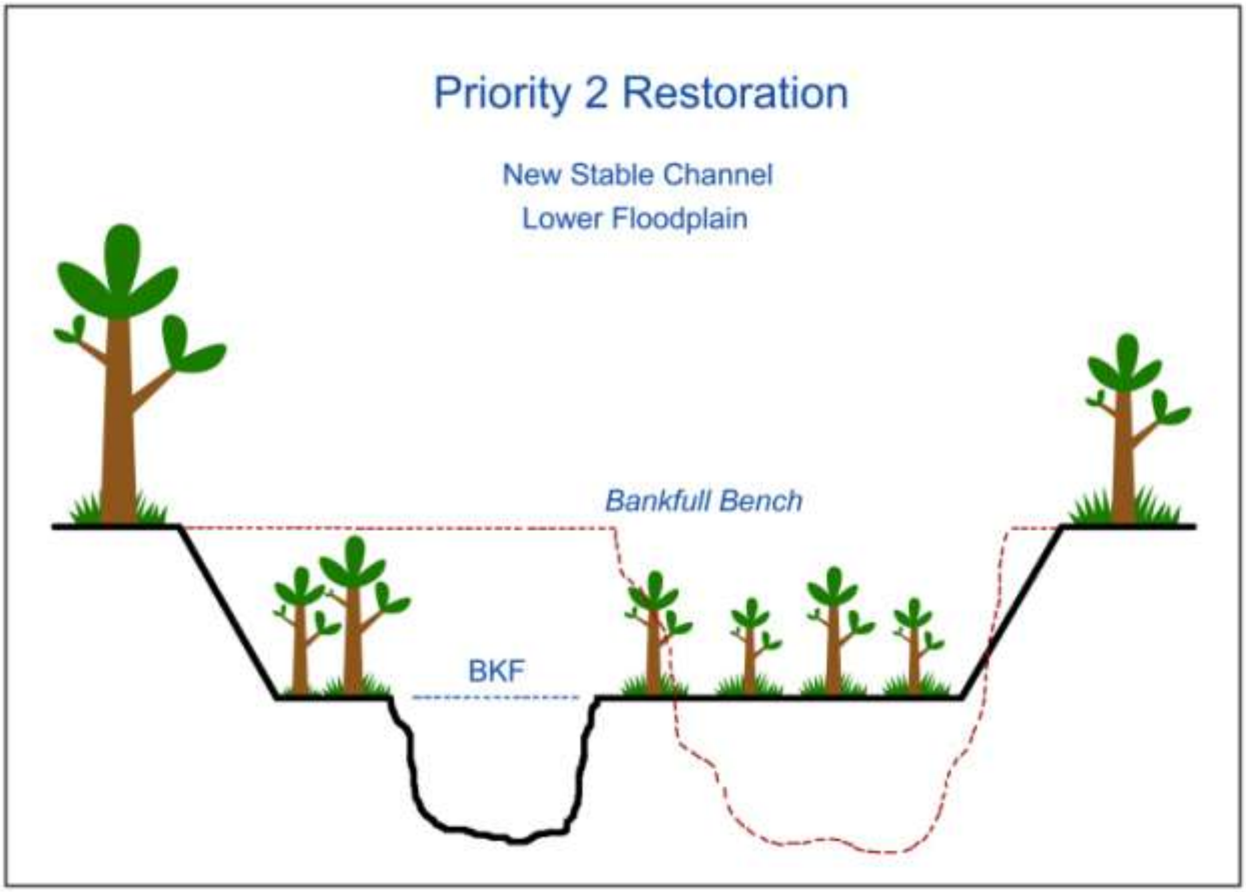

Figure 9. Priority 2 Restoration with the old eroded channel outlined in red dashed line (Adapted from NCSU Stream Restoration Design Handbook).

The Priority 2 restoration creates a surplus of excavated material that needs to be disposed of appropriately. As in Priority 1, a Priority 2 type restoration is also constrained by availability and suitability of surrounding land to accommodate the widening of the stream corridor.

3) <u>Priority 3: Widen the floodplain at the existing bankfull elevation</u>

A Priority 3 restoration is suggested when surrounding land use restricts the widening of the stream corridor as in Priority 1 and 2. This type of restoration aims to widen the floodplain at the existing channel elevation by excavating a floodplain bench on one or both sides of existing stream channel at the elevation of the existing bankfull stage. Reference- reach data may be used to enhance its dimension and profile.

The channel eventually constructed under a Priority 3 restoration tends to be a type B or Bc with a low slope, with the bankfull stage located at the elevation of the newly widened floodplain. Typically a Priority 3 project does not increase sinuosity of the channel due to the land constraints that usually necessitate such type of restoration, even if the valley and watershed conditions require a more meandering E or C channel. In such cases in stream structures such as cross vanes (see below) may be required.

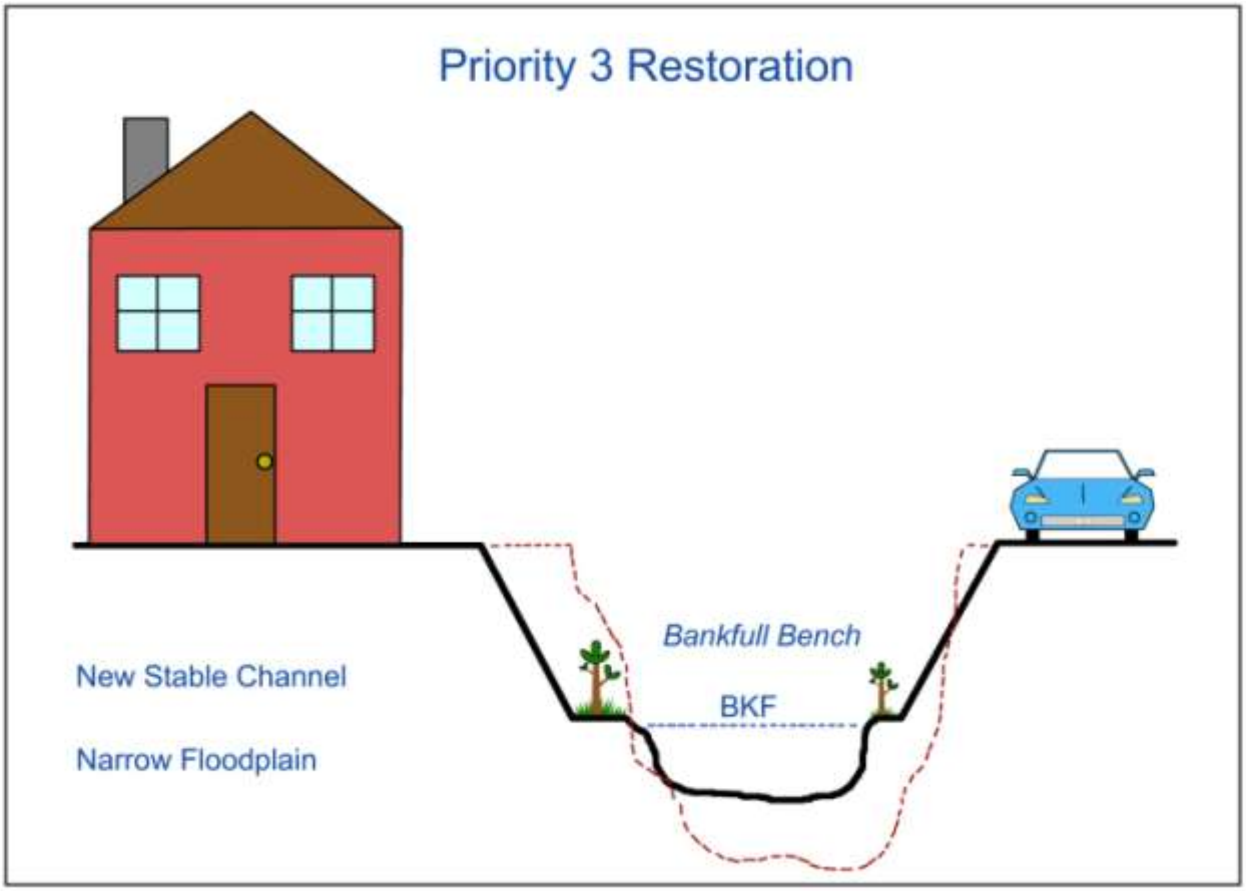

Figure 10. Priority 3 Restoration with the old eroded channel outlined in red dashed line (Adapted from NCSU Stream Restoration Design Handbook)

A Priority 3 project may require more structural measures and maintenance, than either Priority 2 or Priority 1 projects. Consequently it may be more expensive to construct, depending on valley conditions and structural requirements. These projects have minimal impact on flooding potential of existing channel.

Priority 3 Projects do not result in extra cut material or require change to surrounding landscape. They also do not affect the elevation of the water table in the area.

4) <u>Priority 4: Stabilize existing stream banks in place</u>
   Stream banks may be stabilized in place using a variety of structures that aim to harden one or more streambanks. Such projects are categorized as Priority 4, and should be attempted only when the other 3 options are not available due to physical or economic reasons. Traditionally, the different

structures used to protect streambanks have been riprap, concrete lining, gabions, bio-engineering or combinations of these. However, these projects do not correct the dimension, profile and pattern of the stream, and consequently are subject to the same shear stress that the stream was subject to prior to restoration. Inspection and maintenance are therefore necessary to ensure long term success.

Priority 4 projects (and sometimes Priority 3 projects) use a variety of stabilizing structures. Prior to installing these structures, a complete morphologic assessment of the stream reach as well as the watershed must be done. Use of native material and site specific structures are encouraged. For example, boulders are more appropriate for a stream with a rocky stream bed, and logs are a more appropriate stabilizing structure for a stream with a sand bed and flat slope. However, all in-stream structures should be able to maintain a stable width-depth ratio, maintain enough shear stress to move large particles, decrease near bank velocity, shear stress or stream power, maintain channel capacity and maintain fish passage at all flows. Some in-stream structures are installed for site specific goals, such as improving fish habitat, being visibly compatible with natural channels, reducing road fill erosion or preventing sediment deposition.

A few recommended in-stream structures are described below:

a) Root wads

A root wad is the root mass or root ball of a tree, including a portion of the trunk, that is installed trunk first into the toe of the bank, as low as possible. Root wads strengthen the streambank by deflecting stream flows away from the bank, as well as by structurally supporting the bank. Also, they provide habitat for fish and other aquatic animals, as well as food for aquatic invertebrates.

Figure 11. Installation of root wad (NCSU Water Quality Group)

b) Vanes

Vanes come in four types: single vanes, J-hook vane, cross vane and W-weir. Vanes are usually constructed using boulders, although they can also be constructed using large tree trunks. They are oriented upstream at a 20-30 degree angle off the bank. Vanes should be highest next to the bank, starting at or slightly below bankfull. Vanes should point upstream. The length of a single vane structure may span up to half of the base-flow channel depth Single and J- hook vanes protect the streambank by redirecting the thalweg away from the streambank and toward the center of the channel. Additionally, they create scour pools, increase oxygenation and provide cover, thus improving in-stream habitat. Cross vanes and W-weirs serve similar purposes, but also maintain the grade of the streambed, in both meandering and step-pool streams. W-weirs can also be designed for additional features such as to facilitate irrigation diversions, maintain recreational boating, and increase sediment transport at bridge crossings.

Figure 12. Cross vane in Asheville, NC.

c) Stream crossings

Crossings are designed to minimize negative impact to a stream from bridges and other crossings, while facilitating transport across the stream. Typically, arch culverts or bridges are used to minimize floodplain restrictions. Crossings are designed in a way that maintains the consistency of dimension, pattern and profile, and specifically maintaining bankfull width and width to depth ratio.

Riparian Buffer

Vegetation is an important aspect of stream restoration. Appropriately planted riparian areas tend to improve the chances of successful bank stabilization, flood control, and habitat enhancement. A reach-wide assessment of vegetation is recommended prior to any construction, in order to assess suitability of existing vegetation to provide adequate riparian buffer, identify problematic or special features to improve and enhance the project, and to gather ecological data for restoration planning.

Soil conditions are another important aspect of planning appropriate riparian vegetation. Soils need to tested for nutrient content, compactness and composition. The soil may need to treated or remedied as needed, using methods such as tilling, mulching or liming.

Several planting methods are used in restoration projects for creating or enhancing the riparian vegetation which include:

a) Salvaging existing vegetation- Planting salvaged vegetation from the site tends to be the most cost effective and successful method, since plants are adapted to the local conditions. Transplants may include small trees and bushes such as sycamores, alders, elderberry and spice bush. Rushes and sedges also tend to be good candidates, especially along the edge of the water where woody vegetation may not be appropriate. Woody vegetation may be transplanted at bankfull elevation and above. Plants need to be transplanted at the same depth that they were originally growing.
b) Live staking- Stakes are small branches or libs cut from larger trees or shrubs, and planted on-site. Stakes could be harvested from existing vegetation, or brought in from surrounding land owners or nurseries. Silky dogwood and willow are good species for live staking. Stakes are usually installed 2 to 4 feet apart in areas where erosive forces are highest, such as along meander bends or behind in-stream structures.
c) Bare root plantings- Bare root plantings recommended on large restoration sites. The soil used is native soil. Such plantings are more economical, but might have lower survival rates. Plants should be chosen from local nurseries or from growers that sell plats suited to the particular site.
d) Permanent seeding- Planting seeds among other planning material enhances diversity. It is recommended to use site specific combinations of grasses and herbaceous flora that are native or adapted. Site conditions and project requirements will determine the vegetation needs and installation methods.

Monitoring and Evaluation

Stream restoration projects need to be monitored and evaluated to assess the success of the restoration and to reveal the need for adjustments in design parameters, installation procedures and stabilization methods.

Monitoring plans should be designed to determine if grade control and stabilization structures are functioning as needed, check channel stability by measuring dimension, pattern and profile of the stream, determine streambank erosion rates and biological response, and if specific objectives of the restoration project have been met. The information collected should be made available to professionals in the field to ensure continued improvement in the restoration project.

References and Additional Resources

1. Stream Restoration Design. USDA NRCS E-Directives, available at: http://directives.sc.egov.usda.gov/viewerFS.aspx?id=3491

Eagle Mountain Watershed Management

Brent Clayton, Justin Mechell, David Waidler, Clint Wolfe

Eagle Mountain Lake in north central Texas is identified as a critical resource having aesthetic, recreational, wildlife, water supply, and economic value within the region. To address water quality issues resulting from excessive watershed-based nutrient and sediment loads, lake managers are working with local citizens, elected officials, and agency representatives to develop a comprehensive, stakeholder-based watershed protection plan. Utilizing complimentary computer models to analyze the source, and degree of pollutants enables to illustrate past, present, and future lake conditions resulting from various management scenarios. Economic evaluations of proposed management solutions demonstrate the most efficient use of project funds to reduce water quality within the lake. The resulting watershed protection plan operates as a flexible strategy combining the use of effective structural best management practices, education and outreach programming for targeted audiences within the watershed. Implementation of the plan will be supported by a scheduled regimen of water quality monitoring and modeling protocol to ensure success in maintaining the quality of future watershed and lake conditions.

Eagle Mountain Watershed

As part of the upper Trinity River Basin, The Eagle Mountain watershed covers 860 square miles and overlies portions of Wise, Parker, Clay, Jack, and Tarrant Counties (Figure 1). The Eagle Mountain watershed represents the eastern portion of the Upper West Trinity Watershed (HUC# 12030101). Eagle Mountain Lake is an impoundment of the West Fork of Trinity River.

Figure 1. Eagle Mountain Watershed.

A watershed is typically defined as a land area that drains into a common water body, such as a river, lake or ocean. In the case of Eagle Mountain, the common body of water is the Eagle

Mountain Lake. Watershed boundaries are defined by topography in which the outermost ridgelines work to divert rainfall and tributary streams into a defined collection point. Watersheds include various land uses, human populations, wildlife, and biological and ecological processes (Figure 2). On a larger scale, watersheds fit into larger river basin systems (i.e. Trinity River Basin).

Figure 2. Example of a watershed with multiple land uses (Conservation Ontario, 2009).

The Trinity River Basin

The Trinity River supplies water to more than 4.5 million people in the Dallas/Fort Worth area and to an additional 4.8 million people in the Houston area. Its basin stretches 360 miles overall across eastern Texas from Dallas and Tarrant counties to the river's mouth near Galveston Bay (Figure 3). Draining a total area of 17,206 square miles, the Trinity River and its tributaries travel a diverse terrain from upland prairies to rolling timberlands and on to the coastal plain.

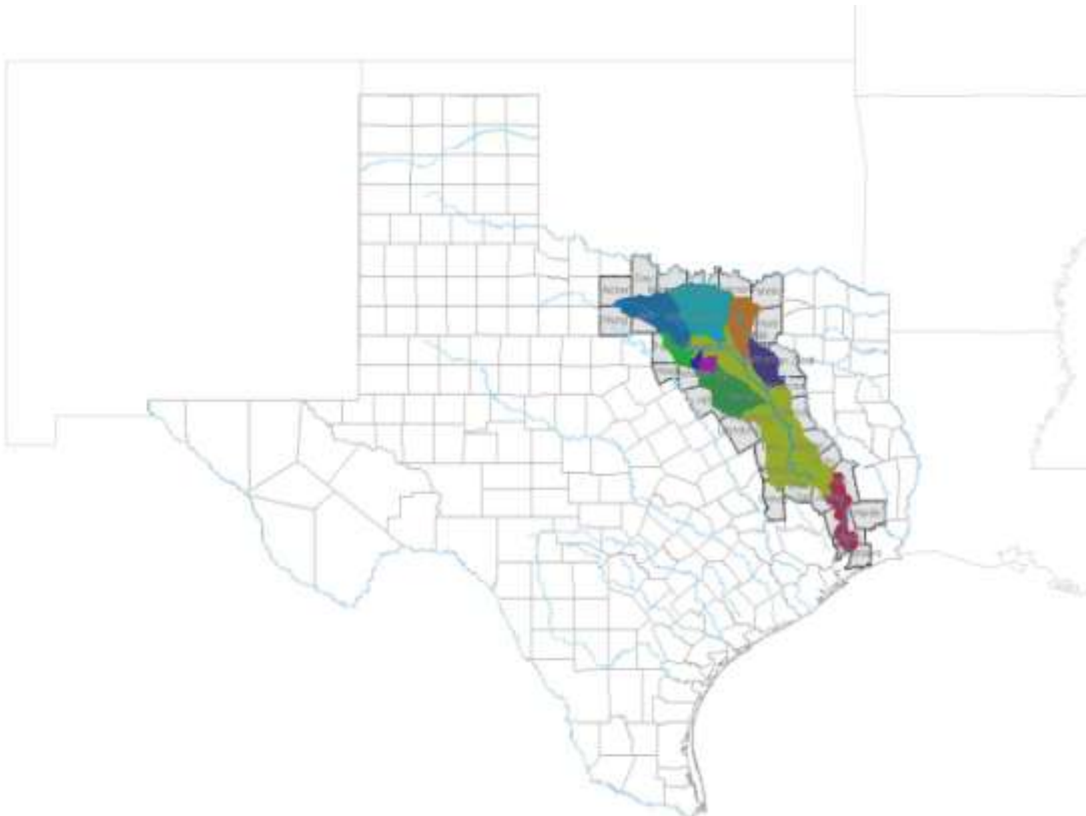

Figure 3. Greater Trinity River basin with surrounding counties (Texas Water Development Board).

Eagle Mountain Lake

Flooding events during the 1920's in the City of Fort Worth prompted the formation of the Tarrant Regional Water District (TRWD). This district is not only responsible for managing the extensive flood control networks in North Central Texas, but supplies water to over 1.7 million people in that area. Eagle Mountain Lake was constructed in 1932 through the funding of general obligation bond as a flood control and water supply measure. It is currently one of four major reservoirs owned and operated by the TRWD, also including Cedar Creek Reservoir, Lake Bridgeport, and Richland-Chambers Reservoir. The majority of the lake lies in Tarrant County, just north of Fort Worth.

Table 1. Eagle Mountain Lake facts

Surface Area	8,702 acres
Conservation Storage	182,505 acre feet
Watershed Size	860 square miles
Shoreline	83.5 miles
Length	11 miles
Width	3.25
Maximum Depth	50.9 feet

Water Quality

In the late 1980's, the Tarrant Regional Water District (TRWD) initiated routine sampling of the water quality within Eagle Mountain Lake. These tests found an increasing trend in the photosynthetic indicator chlorophyll-*a*. Scientists measure chlorophyll-*a*, which is the predominate type of chlorophyll in blue green algae, as an accurate indicator of the amount of algae in the water column. The increasing trend of chlorophyll-*a* has led to high levels of pH and could lead to low levels of dissolved oxygen and an abundance of algae. This can be harmful to the lake's recreational, water supply, and wildlife habit uses. Algal abundance roughly doubled during the 19-year study period.

Sources and Causes of Pollution

The high levels of chlorophyll-*a* identified in the lake are a result of high concentrations of nutrients and sediment that drain from the surrounding watershed. Sediments carry nutrients, which fertilizer and promote the growth of the photosynthetic algae. Because these nutrients and sediments lead to harmful algae growth, they are referred to as the pollutant load. The "total pollutant load" in a watershed can be defined as the sum of pollutants from point sources and nonpoint sources. Point source pollution comes from a defined discharge point, which includes activities such as municipal wastewater treatment discharges, industrial waste discharges, and stormwater collection systems. Nonpoint source pollution comes from sources that are spread out across the landscape, which make them more difficult to centrally collect and treat.

Point Source Pollution within the Eagle Mountain Watershed

Wastewater treatment plants represent the primary point source discharges within the Eagle Mountain watershed. Population increases within watershed counties have increased the number of wastewater treatment plants that discharge into watershed tributaries and directly into the lake. At the time of plan implementation, 14 wastewater treatment plants were in operation within the Eagle Mountain watershed (Figure 4). Existing plants employ a variety of methods to achieve compliance with current Texas Commission on Environmental Quality (TCEQ) standards.

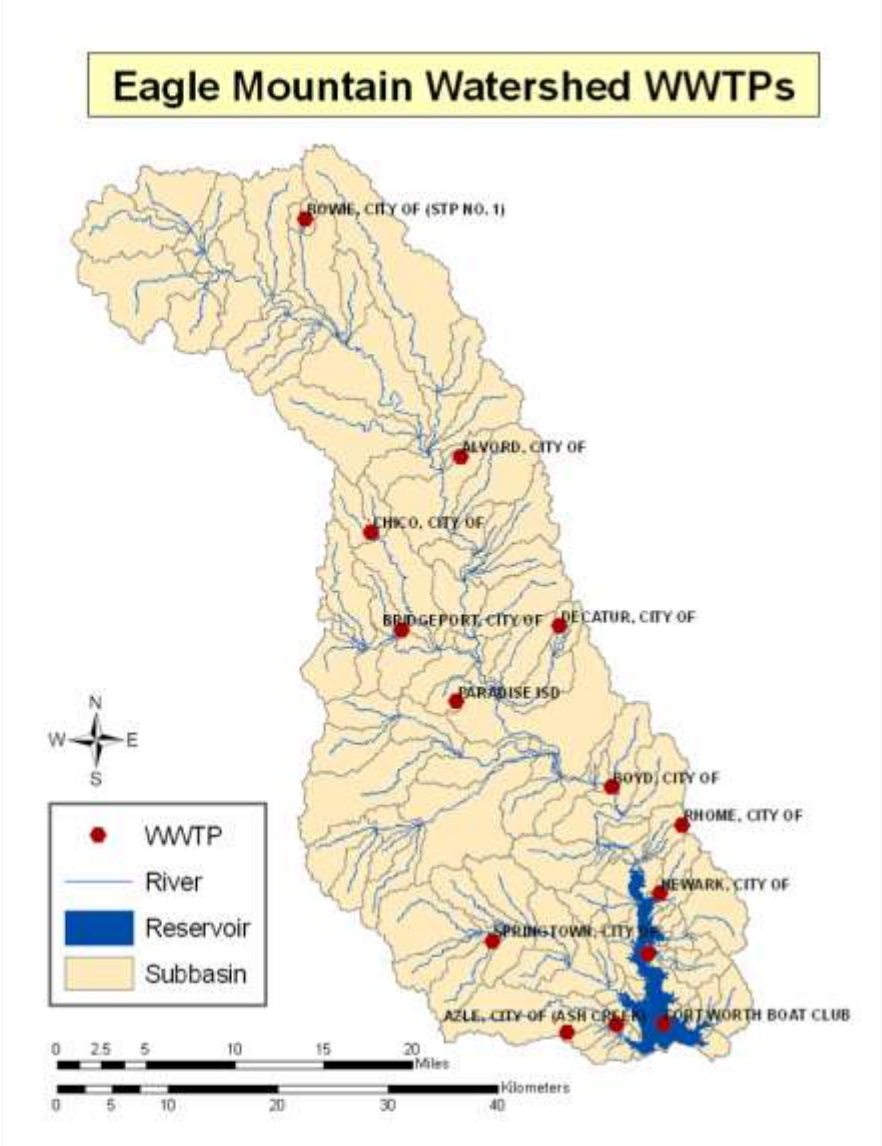

Figure 4. Wastewater treatment facilities within the Eagle Mountain watershed (TAMU-SSL, 2009).

Non-Point Source Pollution within the Eagle Mountain Watershed

Within the Eagle Mountain watershed, non-point sources derive from urban and agricultural land uses. Though there has been significant growth in the counties of Tarrant, Wise, and Parker, agriculture continues to have the most land area. Modeling done by Geographic Information Systems indicates that over 58% of the land area in the watershed is grassland or in pasture and 4.7% is in cropland. This dynamic presents an interesting challenge for watershed planning as nutrients in fertilizers are a significant source of non-point source pollutant loadings. Historically, excessive use of fertilizers on row crops resulted in nitrogen and phosphorus loadings that are transported over the land and into tributaries during periods of heavy rainfall.

Solving the Problem – Watershed Protection Planning

In order to address the rising chlorophyll-*a* level within Eagle Mountain Lake, a stakeholder-based watershed protection plan has been established to provide a full assessment of watershed conditions and to develop a structured course of action for improvement of water quality. Watershed planning, as defined by the US Environmental Protection Agency, is a stakeholder driven process designed to promote the involvement of local citizens and officials. The primary goal of this approach is to develop a watershed protection plan that is not only acceptable to local interests but reflects a level of "ownership" among stakeholders regarding the management of resources.

Watershed planning for Eagle Mountain began in 2008 and is working toward a proposed 10 year implementation phase to limit the rising trend chlorophyll-*a* through the use of best management practices and targeted outreach programs designed to reduce the flow of phosphorus into the lake. Watershed planning efforts for Eagle Mountain Lake are guided by a stakeholder agreed upon goal of 30% watershed phosphorus reduction. It is forecasted that the best management practices targeted for phosphorus reduction will also realize an ancillary reduction of watershed based sediment and nitrogen loadings.

Management Measures

Computer modeling of the Eagle Mountain watershed allowed the identification of areas within the watershed potentially producing the greatest amount of phosphorus and sediment and for prioritization of these areas for management. This methodology provides a plan to allocate funding for structural best management practices (BMPs) in the future to areas in which the highest impact in pollutant reduction could be achieved. Additionally, these practices have been evaluated to determine each practice's nutrient reduction total per project dollar allocated. The proposed management solution is based on the stakeholder determined goal of achieving an overall 30% reduction of watershed-based phosphorus. Utilizing the computer model Soil and Water Assessment Tool, , watershed planners have determined the priority areas within the watershed for implementation of selected best management practices of grade stabilization structures, filter strips, grassed waterways, herbicide application, terracing, and the subsidized conservation of croplands into pasture. Additionally, the project leadership has prioritized the development of an informational and outreach program directed toward multiple audiences with the goals of enhancing watershed literacy and stewardship. Listed below are summaries of the various potential management practices proposed in the watershed protection plan as economical options.

Proposed Practice: Filter Strips

Filter strips are vegetated areas that are situated between surface water bodies (i.e. streams and lakes) and cropland, grazing land, forestland, or disturbed land. They are generally located where runoff water leaves a field with the intention that sediment, organic material, nutrients, and chemicals can be trapped or filtered from the runoff water (Figure 4). Filter strips are also known as vegetative filter or buffer strips.

Figure 4. Filter Strip (Photo courtesy of USDA NRCS)

Proposed Practice: Grade Stabilization

Grade stabilization structures are constructed lakeside and streambank reinforcements (Figure 5). They are placed to reduce erosion and sedimentation from steep embankments that are prone to soil loss during storm events. Structures must be logistically situated for maximum effectiveness.


Figure 5. Grade Stabilization Structure (Photo courtesy of USDA NRCS)

Proposed Practice: Grassed Waterways

Grassed waterways are natural or constructed channels established for the transport of concentrated flow at safe velocities using adequate vegetation (Figure 6). The vegetative cover slows the water flow, minimizing channel surface erosion. When properly constructed, grassed waterways can safely transport large flows of runoff down slopes. This conservation practice can reduce sedimentation of nearby water bodies and pollutants in runoff. The vegetation improves the soil aeration and water quality due to its nutrient removal through plant uptake and sorption by the soil.

Figure 6. Grassed Waterway (Photo courtesy of USDA NRCS)

Proposed Practice: Terracing

Terraces are series of earthen embankments constructed across fields at designed vertical and horizontal intervals based on land slope, crop rotation, and soil conditions (Figure 7). Construction of terraces involves a heavy capital investment to move large quantity of earth for forming earthen embankments. Hence it should be considered only if other low cost alternates are determined to be ineffective. Terracing is recommended for land with a grade of 2% percent or higher.

Figure 7. Terracing (Photo courtesy of USDA NRCS)

Proposed Practice: Pasture and Range Planting (Conversion of Cropland to Pasture)

The planting of pastures and crop lands with native or introduced vegetation allows for the absorption of nutrients and reduction of runoff. Grass, forbs, legumes, shrubs and trees work to restore a plant community similar to historically natural conditions but still account for the nutritional needs of livestock and native species (Figure 8).

Figure 8. Pasture Planting (Photo courtesy of USDA NRCS)

Land-Use Specific BMPs – Pasture and Rangeland

Rangelands and pasturelands account for the majority land use within the Eagle Mountain Creek Watershed. While the runoff pollution on pastures is low compared to urban and cropland areas, BMPs are still necessary where there may be overgrazing and producers have demonstrated to use significant amounts of nutrient-laden fertilizers to enhance forage. When pastures or rangeland are overgrazed, there is not enough vegetation to capture and absorb pollutant runoff. One practice that can reduce overgrazing is prescribed grazing.

Proposed Practice: Prescribed Grazing

Prescribed (a.k.a. rotational) grazing is a method of pasture management where livestock are rotated to different pastures at regular time frames (Figure 9). This maintains the health of vegetation and allows for establishment of a dense stand which reduces soil erosion and retains soil nutrients.

Figure 9 Prescribed Grazing (Photo courtesy of USDA NRCS)

Land-Use Specific BMPs – Voluntary Urban Nutrient Management

Urban areas account for 9.57% of the total land area in the Eagle Mountain Watershed. Runoff from streets, roofs, and other hard surfaces can carry several harmful pollutants, including the nutrients and sediments that impact Eagle Mountain Lake. This runoff, made worse during major rain events, is referred to as stormwater.

A proposed method of managing stormwater to reduce nutrient pollution is through voluntary urban nutrient management. This includes educating the public about proper landscaping a lawn management that can reduce excessive use of fertilizers.

Education and Outreach

The success of the Eagle Mountain Watershed Protection Plan requires more than the implementation of structural water quality improvement practices. To enhance these efforts, an education and outreach campaign was developed to inform the public and to increase stewardship of watershed resources.

The driving force for the development of the Eagle Mountain watershed education and outreach campaign is to provide information to targeted audiences such as youth, homeowners, agricultural producers, and recreationists that will assist in reversing the trend of nutrient and sediment loadings that have contributed to the impairment of Eagle Mountain Lake. The goal of the Eagle Mountain watershed educational program is to provide information to watershed stakeholders regarding the status of the lake and watershed and future conditions. Emphasis will be placed on the concept that the activities of people living in the watershed and around the lake will impact lake water quality. It will emphasize the use of best management practices on a personal level.

Summary

The Eagle Mountain Watershed Protection Plan provides a holistic framework for addressing the water quality impairments in Eagle Mountain Lake. Planning efforts have demonstrated that each person living, working, or playing in the watershed contributes to the water quality status of the lake. While major sources of pollutants were identified and prioritized for implementation of structural best management practices to reduce their loading to the lake, the establishment of a targeted educational program will work to raise awareness and motivate citizens to each do their part to protect this valuable water resource.

About the North Central Texas Water Quality Project

The North Central Texas Water Quality Project is a collaborative effort of the Texas Water Resources Institute, Texas AgriLife Research, Texas AgriLife Extension Service, Texas Commission on Environmental Quality, Texas State Soil and Water Conservation Board, and Tarrant Regional Water District. Funding for the project comes from the Environmental Protection Agency and the United States Department of Agriculture-Natural Resources Conservation Service.

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References

Conservation Ontario. (2009). *Graphics*. Retrieved October 25, 2010, from Conservation Ontario: http://www.conservation-ontario.on.ca/resources/graphics/index.html.

Green, C.H. and R. Haney[1] (n.d.). *Filter Strips*. Retrieved February 21, 2011, from SERA-17: http://www.sera17.ext.vt.edu/Documents/BMP_Filter_Strips.pdf.

Green, C.H. and R. Haney[2] (n.d.). *Grassed Waterways*. Retrieved February 21, 2011, from SERA-17: http://www.sera17.ext.vt.edu/Documents/BMP_Grassed_Waterways.pdf.

NRCS. (n.d.). *NRCS Photo Gallery*. Retrieved November 3, 2010, from Natural Resources Conservation Service: http://photogallery.nrcs.usda.gov/.

Tarrant Regional Water District. (2010). *Eagle Mountain Lake Information*. Retrieved April 21, 2011, from http://www.trwd.com/EagleMountainMap.aspx.

Appendix G

Task 4 Administration

- TWRI continually updates the Web site created specifically for the North Central Texas Water Quality Project. The Web site can be accessed at the following address: http://nctx-water.tamu.edu.

- The FY 09 project ended on September 23, 2010 but the FY10 project began July 9, 2010. This overlap caused contracting to be delayed until FY09 funds had been exhausted.

- A Project Coordination with all project partners and TRWD was held on January 13, 2011 in Ft. Worth to discuss the status of the project, paths forward and ways to best meet the needs of TRWD. It was determined that a new Economist was needed to meet the timeline of the project. TWRI was in search of the new Economist to work closely with TRWD to meet their needs.

- TWRI will host a minimum of MONTHLY conference calls with the project team throughout the duration of the project to ensure that project activities are being met. These conference calls will be held on the second Tuesday of every month at 9:00am

- TWRI has located a new economist, Jason Johnson, who has begun participating in the monthly project coordination meetings and will participate in stakeholder meetings in the future.

- The project website continues to be updated as activities are conducted.

- Quarterly Report 3 was turned in to NRCS on April 11, 2011.

- Monthly conference calls have been held on the second Tuesday of every month where all project partners discussed the work that has been ongoing for their respective task as well as how the project will move forward. These calls were very effective as substantial progress in the project has been made.

- The project website continues to be updated as activities are conducted.

- Quarterly Report 4 was turned in to NRCS on July 15, 2011.