Lake Granger and San Gabriel River Watershed Protection Plan

Developed by:

Brazos River Authority

November 2011

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Funding for the development of this Watershed Protection Plan was provided through a federal Clean Water Act §319(h) nonpoint source grant to the Brazos River Authority from the Texas State Soil and Water Conservation Board and the U.S. Environmental Protection Agency.

November 2011

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

The US Army Corp of Engineers (USACE) began construction of Lake Granger in 1972 as a water supply and flood control reservoir. In 1980 when Lake Granger first started impounding water, initial storage calculations estimated that the volume of the lake at conservation pool to be 65,510 acre feet (ac ft). The estimated storage capacity was based on calculations from topographic maps of the area of impoundment.

In 1999, the United States Department of Agriculture-Natural Resources Conservation Service (NRCS) conducted a Soil and Water Assessment Tool (SWAT) based study of sedimentation into Lake Granger due to concerns of excessive siltation into the lake and impacts to water supply and drinking water treatment. The study concluded that a combination of conversion of highly erodible croplands to grassland and employment of terracing, minimum tillage, and contour farming would potentially reduce sediment loading by up to 20%.

The objective of the Lake Granger and San Gabriel River Watershed Protection Plan is to identify and implement strategies that reduce sediment into the watershed. The goals are to reduce sediment loading into Lake Granger by 20% and decrease total suspended solids (TSS) concentrations by 30%.

In 2007, Texas AgriLife Research began a three year volumetric survey and study to document success of soil conservation efforts put in place by the Little River-San Gabriel Soil and Water Conservation District (LR-SG SWCD) as part of this watershed protection plan. The preliminary survey utilized technology that demonstrated that the initial pre-impoundment lake volume was approximately 56,189 ac ft; an approximate 10,000 ac ft under estimation from the original 1980 engineering design of 65,510 ac ft.

The results of the preliminary survey conducted in 2007 showed the lake capacity to be 51,144 ac ft and the concluding 2010 survey showed a further reduction in lake capacity to 49,971 ac ft; an approximate sedimentation rate of 328 ac ft/year.

Upon initiation of the Lake Granger and San Gabriel River Watershed Protection Plan (WPP) in 2006, the LR-SG SWCD began providing technical assistance and financial incentives to local landowners for the development and implementation of Water Quality Management Plans (WQMPs) within the watershed. In total, 81 WQMPs were developed that collectively treated 12,215 acres.

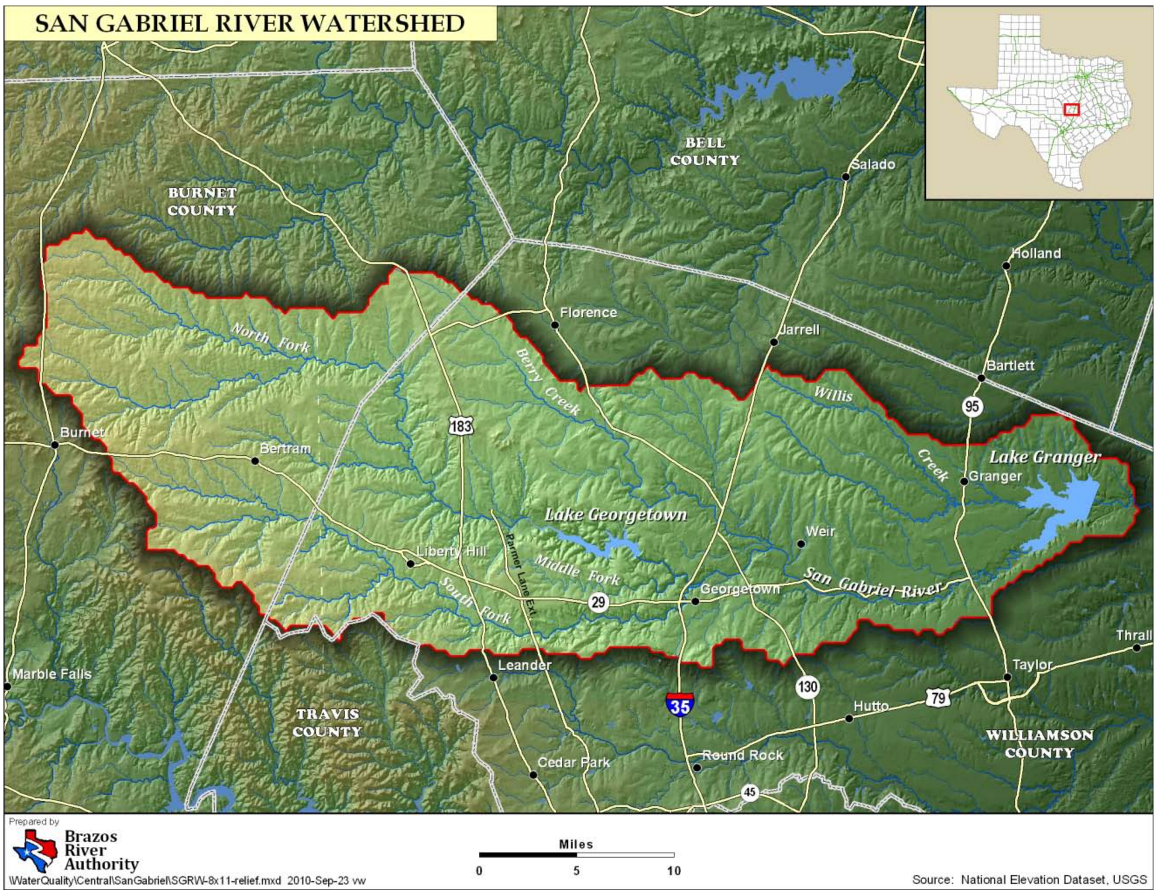
Determining the success of the implementation plan is difficult as it is unclear if the currently employed WQMPs have significantly reduced sedimentation into Lake Granger due to the size of the watershed. It is likely that a more substantial and robust implementation effort will be necessary to adequately address sedimentation concerns in Lake Granger. With funding and continued land-owner participation, additional WQMPs may be employed that may demonstrate a more positive impact on loading into Lake Granger.

Numerous sources of funding, technical assistance, and educational materials are available and must be pursued if sediment reduction goals are to be realized.

1.0 INTRODUCTION

The Lake Granger and San Gabriel River Watershed is located in central Texas within the Brazos River Basin (Figure 1). The watershed covers approximately 720 square miles within Williamson and Burnet Counties. Lake Georgetown and Lake Granger are the only two major water impoundments in the watershed. Approximately 34% of the watershed flows into Lake Georgetown with the remaining watershed draining into Lake Granger. Lake Georgetown impounds the North Fork of the San Gabriel River, upstream of Lake Granger. The San Gabriel River and Willis Creek drainages are impounded by Lake Granger.

Figure 1. The San Gabriel River Watershed



The objective of the Lake Granger and San Gabriel River WPP is to identify and implement strategies that reduce sediment loading into the watershed. The plan also identifies water quality concerns and suggests strategies to address them.

1.1 *Watershed Definition*

A watershed is an area of land that water flows across, through, or under on its way to a single common point in a stream, river, lake, or ocean. Watersheds include not only waterbodies such as streams and lakes, but also all the surrounding lands that contribute water to the system as runoff during and after rainfall events. Relationships between the quality and quantity of water affect the function and health of a watershed. Thus, significant water removals (such as irrigation) or water additions (such as wastewater discharges) are important. Watersheds can be extremely large, covering many thousands of acres, and often are separated into smaller subwatersheds for the purposes of study and management.

1.2 *Watersheds and Water Quality*

To effectively address water issues, it is important to examine all natural processes and human activities occurring in a watershed that may affect water quality and quantity. Runoff that eventually makes it to a waterbody begins as surface or subsurface water flow from rainfall on agricultural, residential, industrial, and undeveloped areas. This water can carry with it pollutants washed from the surrounding landscape. In addition, wastewater from various sources containing pollutants may be released directly into a waterbody. To better enable identification and management, potential pollutants are classified based on their origin as either point source or nonpoint source (NPS) pollution.

Point source pollution is discharged from a defined location or a single point, such as a pipe, drain, or wastewater treatment plant. Point source pollution is typically discharged directly into a waterway and often contributes flow across all conditions, including both droughts and floods. In Texas, dischargers holding a wastewater permit through the Texas Pollutant Discharge Elimination System are considered point sources, and their effluent is permitted with specific pollutant limits to reduce their impact on the receiving stream.

NPS pollution, on the other hand, comes from a source that does not have a single point of origin. The pollutants are generally carried off the land, roads, buildings, and other features of the landscape from rainfall or snowmelt. As the runoff moves over the land, it can pick up both natural and human-related pollutants, depositing them into water bodies such as lakes, rivers, and bays.

Ultimately, the types and amounts of pollutants entering a waterbody will determine the quality of water it contains and whether it is suitable for particular uses such as irrigation, fishing, swimming, or drinking.

1.3 *Benefits of a Watershed Approach*

Because watersheds are determined by the landscape and not political borders, watersheds often cross municipal, county, and state boundaries. By using a watershed perspective, all potential sources of pollution entering a waterway can be better identified and evaluated. Just as important, all stakeholders in the watershed can be involved in the process. A watershed stakeholder is anyone who lives, works, or engages in recreation in the watershed. They have a direct interest in the quality of the watershed and will be affected by planned efforts to address water quality issues. Individuals, groups, and organizations within a watershed can become involved as stakeholders in initiatives to protect and improve local water quality. Stakeholder involvement is critical for selecting, designing, and implementing management measures to successfully improve water quality.

1.4 *Watershed Protection Planning*

A WPP is typically developed according to EPA's Nine Elements of Successful Watershed Plan (listed below) by local stakeholders with the primary goal being to restore and/or protect water quality and designated uses of a water body through voluntary, non-regulatory water resource management.

a. Identification of cause and sources of concerns

An identification of the causes and sources or groups of similar sources that will need to be controlled to achieve the load reductions estimated in the watershed-based plan (and to achieve any other watershed goals identified in the watershed protection plan). Sources that need to be controlled should be identified at the significant subcategory level with estimates of the extent to which they are present in the watershed. Information can be based on a watershed inventory, extrapolated from a subwatershed inventory, aerial photos, GIS data, and other sources.

b. Expected load reductions

An estimate of the load reductions expected for the management measures proposed as part of the watershed plan. Percent reductions can be used in conjunction with a current or known load.

c. Proposed management measures

A description of the management measures that will need to be implemented to achieve the estimated load reductions, and an identification of the critical areas (using a map or description) in which those measures will be needed to implement the plan. These are defined as including best management practices (BMPs) and measures needed to institutionalize changes. A critical area should be determined for each combination of source and BMP.

d. Technical and financial assistance needs

An estimate of the amount of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan. Authorities include the specific state or local legislation which allows, prohibits, or requires an activity.

e. Information, education, and public participation component

An information/education component that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the appropriate NPS management measures.

f. Schedule of implementation

A schedule for implementing the NPS management measures identified in the plan that is reasonably expeditious. Specific dates are generally not required.

g. Milestones

A description of interim, measurable milestones for determining whether NPS management measures or other control actions are being implemented. Milestones should be tied to the progress of the plan to determine if it is moving in the right direction.

h. Load reduction evaluation criteria

A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made towards attaining water quality standards and, if not, the criteria for determining whether the watershed-based plan needs to be revised. The criteria for loading reductions do not have to be based on analytical water quality monitoring results. Rather, indicators of overall water quality from other programs can be used. The criteria for the plan needing revision should be based on the milestones and water quality changes.

i. Monitoring component

A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the evaluation criteria. The monitoring component should include required project-specific needs, the evaluation criteria, and local monitoring efforts. It should also be tied to the state water quality monitoring efforts.

Public participation is critical throughout plan development and implementation, as ultimate success of any WPP depends on stewardship of the land and water resources by landowners, businesses, elected officials, and residents of the watershed.

2.0 San Gabriel River Watershed Characteristics

The San Gabriel River Watershed is one of the most diverse watersheds in the Brazos River Basin. The headwaters of the San Gabriel River lie at the junction of the Cross Timbers and Edwards Plateau eco-regions where much of the land remains native prairie and brushy rangeland mixed with juniper growth. The soils in the western, upstream area are shallow, rocky and typical of the upland Edwards Plateau region. The downstream portion of the watershed is located within the Blackland Prairie eco-region and is dominated by deep and fertile soils typical to this region. The deep, fertile soils located in the downstream portion of the watershed are considered valuable farmland and agricultural land use predominates.

The geological variation of the watershed is most evident when characterizing difference in water quality between Lake Georgetown and Lake Granger. Lake Georgetown, located in the upper portion of the watershed, is a scenic lake known for its relatively clear water. Lake Granger, located at the bottom of the San Gabriel River watershed, exhibits high rates of sedimentation and elevated nutrient concentration. Both reservoirs provide a vital drinking water source to Williamson County and also provide flood control.

The San Gabriel River provides excellent habitat for fishing and is a scenic background for numerous parks and miles of hike and bike trails through the City of Georgetown, one of the most notable being Blue Hole Park (Figure 2) on the South San Gabriel River just a few blocks from downtown Georgetown. "Blue Hole" as it is referred to by local residents, is a natural lagoon formed in limestone and surrounded by cliffs on one side. The location gets its name from the blue-green tint of the water atypical to central Texas.

Figure 2. Blue Hole near downtown Georgetown

2.1 *Climate*

The climate is sub-humid. Average annual precipitation ranges from about 34.2 inches in Williamson County to 30.5 inches in Burnet County; however, historic totals have ranged from 7.4 inches to 60.5 inches. Due to geographical location and weather patterns, the region is subject to occasional, localized, high intensity rainfall events during the spring and summer months. As evidence, approximately 14 to 16 inches of rain fell across the watershed during one 24-hour storm event in July of 2007. In 1921 the community of Thrall, in eastern Williamson County, recorded over 38 inches of rain in a 24-hour period which remains the highest total ever reported in the United States. Typically, however, summers are hot and winters are mild with intervals of freezing temperatures as cold fronts pass through the region.

2.2 *Demographics*

Georgetown is the largest urban population within the San Gabriel River Basin with an estimated population of approximately 47,400 and is one of the fastest growing areas in the nation (Tables 1 and 2). The once rural areas to the west and east of Georgetown are quickly becoming more suburban as the populations continue to grow.

The City of Granger is the closest community to Lake Granger. Other small communities in the watershed include Bertram, Liberty Hill, and Weir. The populations of these small communities have remained stable or decreased in recent years. These communities are currently dependent on groundwater and do not utilize the surface water resources of Lake Georgetown or Lake Granger.

However, Lake Granger is the sole source of drinking water for the city of Taylor, which is located just south of watershed and has a population of approximately 15,000. Additionally, the City of Hutto supplements their water supply with treated water purchased from Taylor, which originates from Lake Granger.

Table 1. Population of select incorporated cities located in or near the San Gabriel River Watershed utilizing surface water. Source: Texas State Data Center and Office of the State Demographer.

City	2000 Census Population	2010 Census Population	Percent Change
Georgetown	28,339	47,400	67%
Hutto	1,250	14,698	1076%
Taylor	13,575	15,191	12%

Table 2. Population of counties partially within the San Gabriel River Watershed. Source: Texas State Data Center and Office of the State Demographer.

County	2000 Census Population	2010 Census Population	Percent Change
Burnet	34,147	42,750	25%
Williamson	249,967	422,679	69%

2.3 *Soils*

The watershed is located within portions of the Edwards Plateau and Texas Blackland Prairie land resources areas. The Edwards Plateau region is characterized by erosion resistant limestone mesas, canyons, hills, and valley floors with gentle slopes. Soils are calcareous and range from shallow, rocky soils that overlay the limestone bedrock to deep, loamy soils found in alluvial and valley-fill sediment deposits and are representative of the Brackett-Eckrant-Real Soil Association. The Texas Blackland Prairie is characterized by nearly level to gently rolling plains bordered on the west by the Austin Chalk formation of the Balcones Escarpment. The soils of the Blackland Prairie are made up of calcareous clay that is a product of the shale parent material indicative of the Houston Black-Heiden-Wilson Soil Association.

2.4 *Land Use Analysis*

While much of the area is experiencing rapid growth, only 2.59% of the watershed is considered "urban" land (Figures 3 and 4). Approximately 89% of the acreage in the watershed is classified as brushy/open rangeland or is utilized for agriculture (Table 3). The majority of agricultural land use is located in close proximity to Lake Granger with up-land forest and rangeland dominating the landscape adjacent to and upstream of Lake Georgetown. The land cover and related land-usage surrounding both reservoirs are sufficiently distinct to result in dramatic differences in water quality and clarity. The predominantly agricultural land and erodible nature of the soils surrounding Lake Granger result in surface water with high turbidity which sharply contrasts with Lake Georgetown.

Table 3. Land use in Lake Granger watershed

Description	Acres	Cover %
Brushy Rangeland	153,301	33.02
Open Rangeland	113,903	24.54
Cropland	95,410	20.55
Pastureland and/or Hayland	51,486	11.09
Other Populated Land	14,668	3.16
Urban	12,029	2.59
Recreation Land (Park Land)	10,388	2.24
Water	7,482	1.61
Highways	3,835	0.83
Farm Ponds	929	0.20
Active Strip Mines	593	0.13
Horticultural Land	208	0.04
TOTAL	**464,232**	**100**

Figure 3. Land use map of the San Gabriel River Watershed

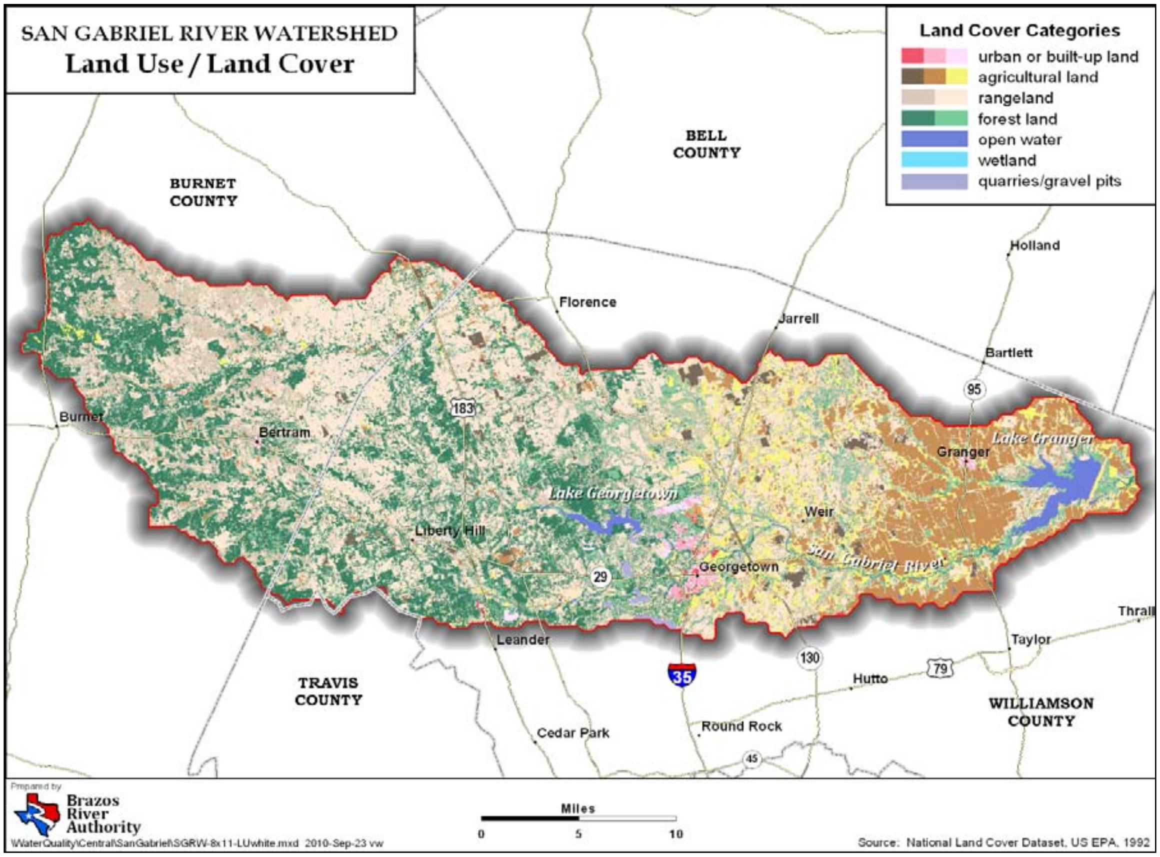
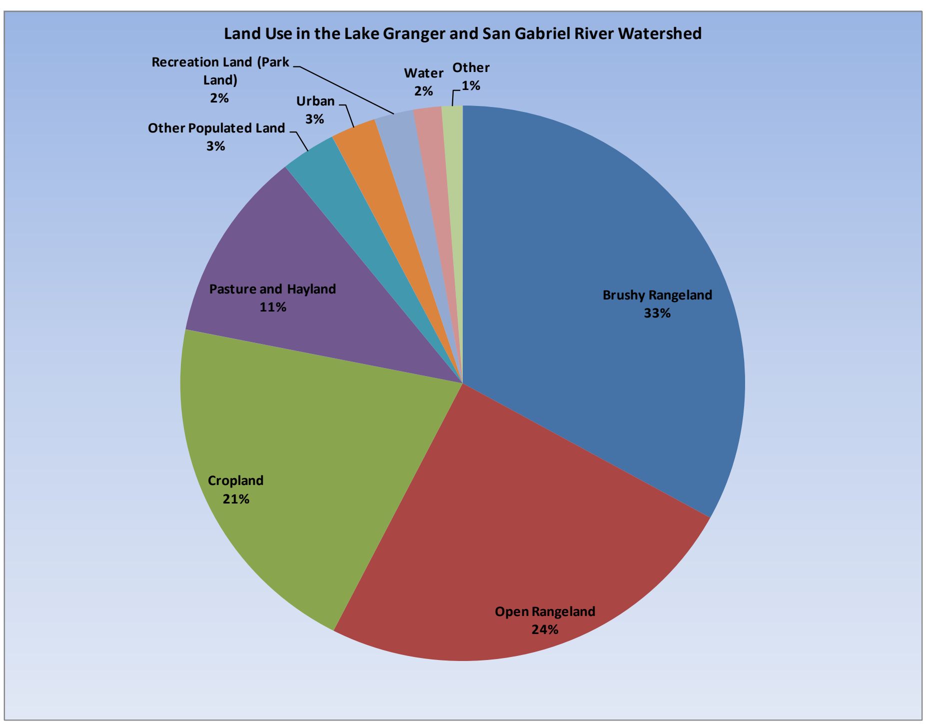


Figure 4. Land use percent coverage in Lake Granger and San Gabriel River Watershed



3.0 WATERSHED CONCERNS AND MANAGEMENT

3.1 *Stream Segment Descriptions*

Lake Granger, classified as segment 1247, receives inflows from Willis Creek and the North Fork/San Gabriel River respectively. The North Fork/San Gabriel receives inflows from Berry Creek, Mankins Branch and the South Fork of the San Gabriel River and stretches 23 miles from the North San Gabriel Dam at Lake Georgetown to 1.2 miles downstream of SH 95 in Williamson County. The North San Gabriel Dam at Lake Georgetown impounds the North Fork of the San Gabriel River upstream of Lake Granger.

3.2 *Concerns*

Currently, there are no numeric criteria for nutrients in the Texas water quality standards. However, waterbodies with nutrient concerns are evaluated using screening values based on the 85th percentile of nutrient concentrations in all streams monitored in the state during the assessment period. The draft 2010 Texas Integrated Report identifies several waterbodies for concerns related to nutrient enrichment and dissolved oxygen (Table 5).

Table 4. Draft 2010 Texas Integrated Report concerns for the Lake Granger watershed

Segment	Water body	Assessment Area	Use/Concern	Status	Parameter
1247	Granger Lake	Entire water body	Nutrient Enrichment	Concern	Nitrate
1247A	Willis Creek	Entire water body	Nutrient Enrichment	Concern	Nitrate
1248B	Huddleston Branch	Entire segment	Nutrient Enrichment	Concern	Nitrate
1248C	Mankins Branch	Entire water body	Nutrient Enrichment	Concern	Nitrate Orthophosphate Total Phosphorus
1250	South Fork San Gabriel	Confluence with unnamed tributary to headwaters of water body	Erosion/sedimentation	Concern	Dissolved Oxygen

3.2.1 *Nutrients*

Nutrient concerns are fairly widespread throughout the San Gabriel River Watershed with the majority of the concerns related to elevated levels of nitrate. The waterbodies with elevated nutrients comprise the primary drainages for Lake Granger and are located downstream of Lake Georgetown. Agricultural land-use predominates in this area of the watershed and runoff from agricultural interests is considered the potential source of nutrients. In addition, continued and increasing urbanization in the Georgetown and Granger area has likely contributed to increased nutrient loading via wastewater effluent and septic systems. However, there is a significant linkage between nutrient loading and sedimentation in agricultural dominated watersheds. Consequently, addressing sediment loading through implementation of BMPs may be beneficial in addressing partial concerns related to nutrient inputs.

3.2.2 *Dissolved Oxygen*

The South Fork of the San Gabriel River is listed as a concern for near non-attainment for low dissolved oxygen levels in the draft 2010 Texas Integrated Report. The Texas Commission on Environmental Quality (TCEQ) attributes the oxygen depletion to an increase in sedimentation from the rapid development that occurred along this segment in recent years from Leander to Georgetown. The Brazos River Authority conducted biological assessments in 2008 on the South Fork of the San Gabriel River at the “Weir Pit” located west of Georgetown. The results of the field work indicated that early to middle phases of construction of a major sewer line along the streambed did not significantly impact the biota but habitat was affected.

Effects included destruction of riparian vegetation, increased turbidity, deposition of large amounts of silt on the streambed, direct physical damage to the stream channel by trenching and heavy machinery traffic, and construction of low water crossings for heavy vehicle access. Continued observation revealed progressive levels of deterioration and evidence of severe habitat disruption during the latter phases of construction, with a high likelihood of significant aquatic life impacts. Additional assessments were conducted in 2010 to evaluate for comparison with assessments conducted in 2008. The results of the 2010 field work indicated that habitat and biological assemblage had not completely recovered from the effects of the sewer line construction; primarily as a result of residual and excessive amounts of siltation.

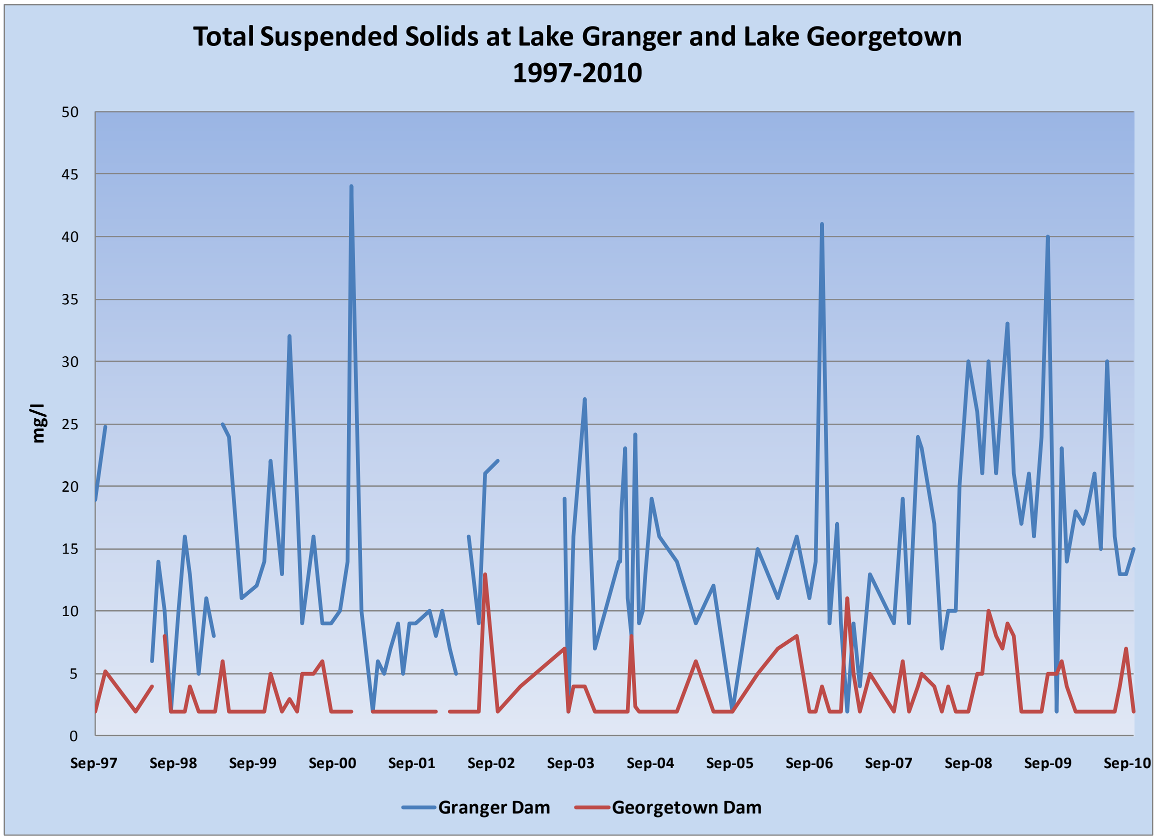
3.2.3 *Sedimentation*

Although bacteria impairments and concerns for non-attainment are present, the impacts from sedimentation and related nutrient concerns are the primary focus of this WPP. Water quality data indicates elevated concentrations of TSS in Lake Granger are typical. However Lake Georgetown, approximately 20 miles upstream of Lake Granger, exhibits much lower levels of TSS and a much higher degree of water clarity. This dramatic difference is likely attributable to significant differences in land use and associated soil types in the drainages surrounding either reservoir. Over the 13 year period between 1997 and 2010, the average TSS concentration was 3 mg/l at the Lake Georgetown dam and 15 mg/l at the Lake Granger Dam (Figure 6).

This section of the WPP focuses on these specific concerns and describes their significance. Material presented in this section regarding each concern includes:

- Causes and sources of sedimentation
- Location of critical areas
- An estimate of load reduction
- Management measures

Figure 5. TSS concentrations measured at Lake Granger and Georgetown Dam monitoring sites



3.3 *Explanation of Erosion and Sedimentation*

Soil erosion is a two-part process involving the detachment and transport of soil particles. The process of water erosion consists of discrete stages from rain drop impact to the formation of gullies. Each stage has its own processes and characteristics. Controlling or preventing soil erosion requires an understanding of each step in the erosion process. Soil erosion can be broken down into five basic stages: splash erosion, sheet erosion, rill erosion, gully erosion, and then stream bank erosion.

Splash Erosion is the displacement of soil as a result of rainfall. The impact of rain drops on exposed or bare soil causes the detachment of particles from larger soil aggregates, displacing the soil particles and destroying soil structure. Studies have shown that detached particles may rise as high as 0.6 meters above the ground and move up to 1.5 meters horizontally. Splash erosion results in the formation of surface crusts which can reduce infiltration contributing to an increase in surface water runoff.

Sheet Erosion is responsible for extensive soil loss in both cultivated and non-cultivated environments. Sheet erosion occurs as a shallow 'sheet' of water flowing over the ground surface, resulting in the removal of a uniform layer of soil from the soil surface without the development of conspicuous water channels. Sheet erosion occurs when rainfall intensity is greater than the infiltration rate.

Rill Erosion is the removal of soil through the cutting of numerous small but conspicuous water channels or tiny rivulets. Rill erosion results from the concentration of surface water (sheet erosion) into deeper, faster-flowing channels. As the flow becomes deeper the velocity increases detaching soil particles and scouring channels up to 30 cm deep. Rill erosion represents the intermediate process between sheet and gully erosion.

Gully Erosion is an advanced stage of rill erosion where surface channels have eroded to the point where they cannot be safely crossed in a vehicle. Gully erosion is responsible for removing vast amounts of soil, irreversibly destroying farmland, roads and bridges and reducing water quality by increasing the sediment and nutrient load in streams. A gully forms as rill erosion deepens and widens creating a characteristic nick point or headwall. Most gullies extend up slope as a result of headwall migration. However, it is the collapse and slumping of the sidewalls of the gully which usually contributes the greatest proportion of soil loss.

Stream Bank Erosion is the removal of soil on or near stream banks by water either flowing over the sides of a stream or scouring at the base. The majority of stream bank erosion in Texas occurs during high flow storm events.

3.4 *Sediment Loading to Lake Granger*

The USACE began construction of Lake Granger in 1972 as a water supply and flood control reservoir. In 1980 when Lake Granger first started impounding water, initial storage calculations estimated that the volume of the lake at conservation pool to be 65,510 ac ft. The estimated storage capacity was based on calculations from topographic maps of the area of impoundment.

In 1995, the Texas Water Development Board (TWDB) conducted the first volumetric survey of Lake Granger to directly quantify the volume of the reservoir and to establish a baseline for future surveys. This and subsequent surveys were essential to documenting sedimentation rates and temporal loss of storage capacity. The 1995 survey revealed that only 54,280 ac ft (Table 6) of storage remained; a staggering loss of approximately 18% of the total estimated design volume of the reservoir. Assuming that the original estimates on the volume of the lake were correct, sedimentation had accounted for average reduction in storage capacity of 749 ac ft/yr (1,343,095 tons of sediment/year).

Since then, BRA has partnered with the TWDB to conduct two subsequent surveys in April 2002 and August 2008. Texas AgriLife Research also conducted volumetric surveys of Lake Granger in 2007 and 2010 as part of a more detailed sediment loading and accumulation study to assess sedimentation rates as well as measure the success of WQMPs developed by the LR-SG SWCD) in cooperation with local landowners as part of this watershed protection planning effort.

The 2007 Texas AgriLife Research volumetric study utilized low frequency acoustics as a method to quantify post-impoundment sedimentation, which indicated a pre-impoundment lake volume of 56,189 ac ft; an approximate 10,000 ac ft difference from the original 1980 engineering design (Appendix A). Using the Texas AgriLife Research estimated value results in a much less dramatic average sedimentation rate of 127 ac ft/year. Additionally, there is a distinct difference in the annual loss of volume within the lake between the periods 1980-1995 and 1995-2002. These differences are likely caused by differences in annual rainfall and intensity of rainfall. The results of the 2002 TWDB survey indicated a loss of 1,319 ac ft of capacity in the 6 ½ years between surveys with an average annual sedimentation rate of 203 ac ft/year (Table 6).

Table 5. Summary of volumetric surveys conducted on Lake Granger

Source of Survey	Date of Survey	Surface Area (Acres)	Volume (ac ft)	Loss of Capacity (ac ft)	Annual Sedimentation Rate (ac ft per yr)
Engineering Design (Estimate)	Jan-80	4,400	65,510	-	-
Texas AgriLife Research (Estimate)	Feb-07	4,074	56,189	-	-
TWDB	Oct-95	3,913	54,280	1,909	*(Between 749 and 127)*
TWDB	Apr-02	4,064	52,961	1,319	**203**
Texas AgriLife Research	Feb-07	4,075	51,144	1,817	**286**
TWDB	Aug-08	4,203	50,779	365	**243**
Texas AgriLife Research	Jul-10	3,820	49,971	808	**421**
			Cumulative Since 1995	**3,873**	**263**

As a result of the conflicting conclusions as to the original capacity of Lake Granger, the WPP uses known volumetric data from 1995 as the baseline volume and draws no conclusions on estimated rates of sedimentation prior 1995. Based on the data collected since 1995, Lake Granger has lost an approximate total of 3,873 ac ft of capacity with an average sedimentation rate of 263 ac ft/yr.

In addition, the Texas AgriLife Research study concluded that Lake Granger lost an average of 328 ac ft/year of storage during between February 2007 and July 2010. Texas AgriLife Research also concluded that their results were in line with the findings from the TWDB surveys conducted in 1995 and 2002.

The TWDB approved 2011 Region G Water Plan projects water supply shortages for 10 municipal water user groups in Williamson County by 2010, 5 more by 2020, 3 more by 2030 and a projected total municipal water supply shortage for the county of 110,812 ac/ft by 2060. Additionally, the plan also projects water supply shortages for manufacturing and mining beginning in 2010. Even though recent studies indicate a reduced rate of storage capacity loss due to sedimentation, any further loss of storage capacity in Lake Granger, regardless of quantity of the loss, will have a significant impact on water supply availability in the region.

Sedimentation into the reservoir not only threatens to reduce the storage and flood control capacity of the reservoir but also causes significant problems with water treatment. Turbidity measurements above 200 nephelometric turbidity units (ntu) are common with spikes that exceed 5000 ntu. While there is no a water quality criterion in Texas for raw water, the drinking water standard for turbidity is only 0.1 ntu. Elevated turbidity can significantly impact the cost of water treatment. In addition, infrastructure such as water treatment plant intakes may require modifications or relocation to address decreasing water depths caused by sedimentation.

Impacts to water treatment caused by excessive turbidity are an important consideration. However, the rapidly growing population makes the issue of sedimentation into Lake Granger even more alarming as water cannot be treated for the public if it is not available.

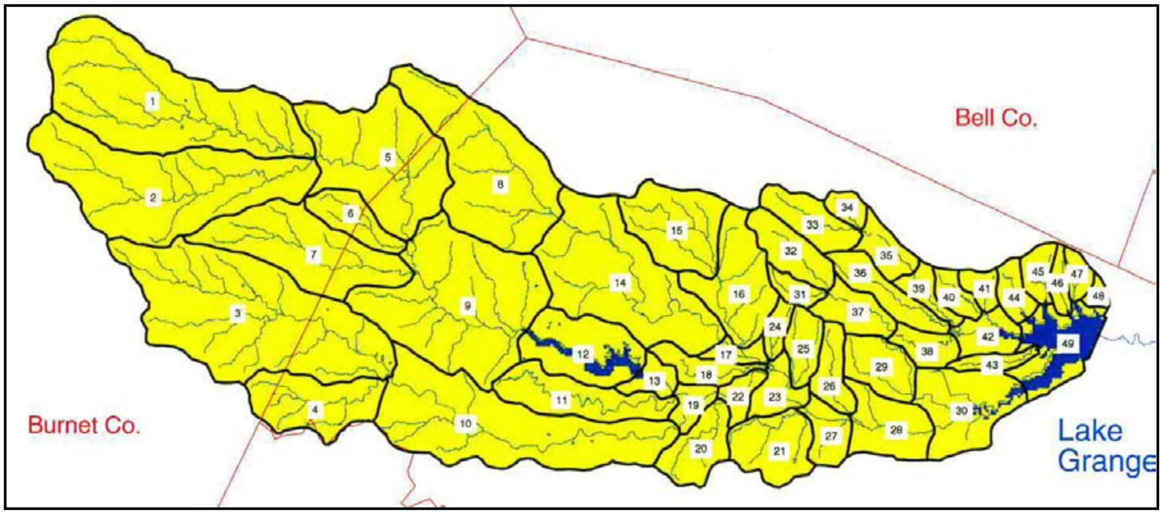
Nutrients are also transported with sediments through runoff. In 2010, the TCEQ assigned nutrient standards to all reservoirs in the state based on measured historic concentrations and their potential contribution to algal productivity (as chlorophyll a), with the premise of anti-degradation (meaning that nutrient concentrations and/or algal growth should not worsen from historic conditions). Although elevated levels of nitrate are present in Lake Granger, algal productivity is somewhat limited by high turbidity caused by suspended solids. It is essential that management strategies not only target sedimentation but also address nutrients. An increase in transparency from decreasing concentrations of suspended solids may inadvertently create an environment conducive to eutrophication in Lake Granger.

3.5 ***Identification of Source(s) of Sediment***

In 1999 the NRCS-Water Resource Assessment Team (WRAT), conducted the "*Lake Granger Sediment Study*" (Appendix B). The study utilized the SWAT basin model. The SWAT computer process model was developed by USDA-Agricultural Research Service to predict the effects of land management on water, sediment and nutrient yields on large river basins. SWAT was calibrated to U.S. Geological Survey stream flow gauge records within the watershed. Comparisons of predicted sediment loadings were made to estimate sediment accumulation in Lake Granger utilizing four basic scenarios. While this study was conducted based on data collected prior to the 1995 volumetric survey, the land use data for the critical areas has not changed substantially. As a result, the SWAT generated reduction values were utilized.

To more accurately identify sediment sources the watershed was divided into 49 sub-basins (Figure 7). These sub-basins were used to identify sediment sources and prioritize management implementation based on four scenarios.

Figure 6. San Gabriel River Watershed map depicting SWAT generated sub-basins. Source: 1999 NRCS Lake Granger Sediment Study



Scenario 1: Control

The calibration run best represents the "current" condition with appropriate inputs for typical crops and management techniques (conventional tillage, fertilizer, etc.). For this scenario it was assumed no conservation practices such as terraces or contour farming were utilized.

Scenario 2: Conversion of Cropland to Grass

To evaluate the effects of land use change, it was assumed that all cropland was converted to perennial grass pasture. The objective of this scenario was to reveal the maximum possible reductions of sediment as a result of crop treatment. It is recognized that this is not a practical or viable alternative for farmers; however, this scenario is useful in determining the effectiveness of cropland treatment with BMPs.

Scenario 3: Applying Terracing, Contour Farming, and Minimum Tillage practices

The same crop rotation used in Scenario 1 was used for Scenario 3. Additionally, it was assumed that all cropland was terraced and contoured with minimum tillage practices.

Scenario 4: Construction of Sediment Control Dams

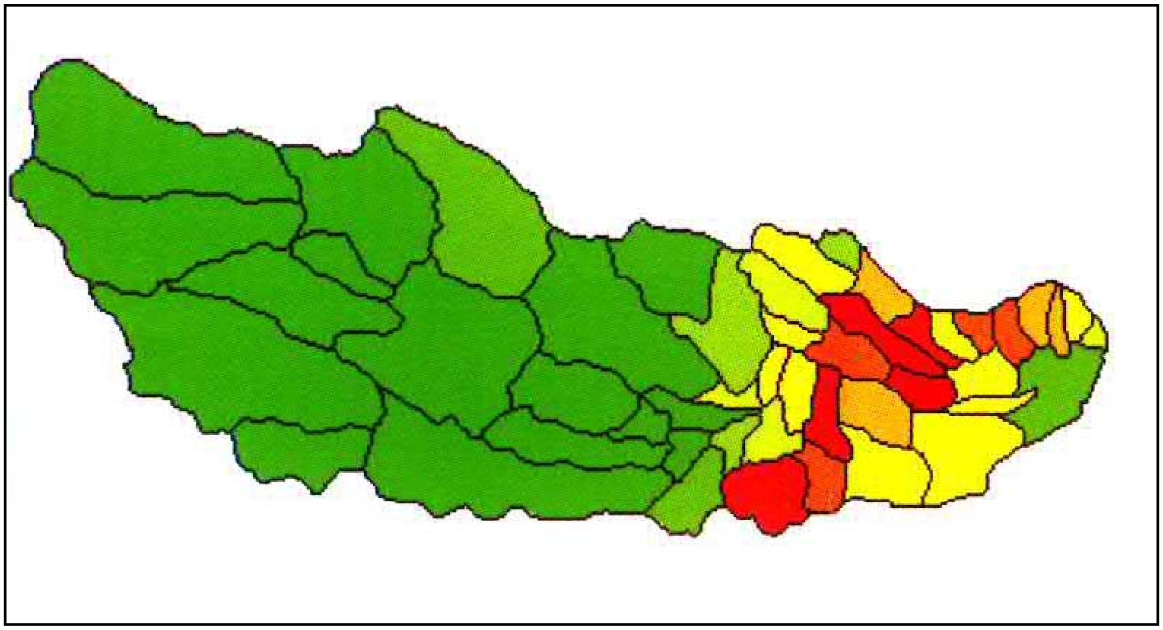
The fourth scenario modeled the construction of six sediment control impoundments with principal spillway storage capacities ranging from 65 ac ft to 1,215 ac ft. Four small private inventory sized dams are present within the watershed but were not utilized in the modeling process.

3.6 *Discussion of SWAT modeling results and conclusions*

Comparisons of scenarios 2, 3, and 4, with the "control" scenario, all demonstrate reductions in sediment load to Lake Granger. Conversion of all cropland to perennial grassland (scenario 2) resulted in a 24% reduction or about 122 ac ft/year. Treatment of cropland with BMPs as described in the third scenario reduced the sediment load by 16% or about 84 ac ft/year and installation of sediment retention ponds reduced sediment by 7% or approximately 37 ac ft/year.

The SWAT generated predictions of erosion during "wet" conditions predicted the sub-basins closest to Lake Granger have the highest sedimentation rates (Figure 8). The sub-basins shaded in yellow, orange and red represent the sub-basins with high rates of sedimentation, which also correlate with the predominant agricultural use and the deep clay loam soils.

Figure 7. Predicted Sediment Loading to Lake Granger. Source: 1999 NRCS Lake Granger Sediment Study



The modeling results indicate that a combination of conversion of highly eroded cropland to grassland and employment of terracing, minimum tillage, and contour farming has the potential to reduce sediment loads by 20%. Essentially, this is a combination of scenarios 2 and 3. Modeling results also indicated that soil control dams would only reduce soil loss by 7%, however this practice called for the construction of several impoundments and was not recommended for implementation. Other practices such as stream bank restoration and the creation of in-stream wetlands were not considered in the study.

3.7 *Management Strategies*

The Little River-San Gabriel Soil and Water Conservation District (LR-SG SWCD) in conjunction with the Texas State Soil and Water Conservation Board (TSSWCB) partnered with local landowners to provide technical assistance and financial incentives to

Table 6. Practices Utilized In WQMPs

Practices	
Pasture/Hayland Planting	**Terraces**
Grassland Waterways	**Contour Farming**
Livestock Pond	**Critical Area Planting**
Forage Harvest Management	**Conservation Crop Rotation**
Prescribed Grazing	**Nutrient Management**
Pest Management	**Conservation Tillage**
Residue Management	

agricultural producers in the Lake Granger and San Gabriel River Watershed for the development and implementation of WQMPs.

A WQMP is a site-specific plan developed through and approved by SWCDs for agricultural or silvicultural lands. The plan includes appropriate land treatment practices, production practices, management measures, technologies or combinations thereof. The purpose of WQMPs is to achieve a level of pollution prevention or abatement determined by the TSSWCB, in consultation with local SWCDs, to be consistent with state water quality standards.

A District Technician was hired by the LR-SG SWCD to coordinate activities between the SWCD, TSSWCB, NRCS, and local landowners. The District Technician, working in cooperation with the NRCS, developed WQMPs based on the criteria outlined in the Field Office Technical Guide (FOTG), a publication of the NRCS. The FOTG represents the best available technology and is already tailored to meet the needs of SWCDs all over the nation. A WQMP includes the following:

- Conservation plan map showing boundaries, fields, land use, acres and facilities
- Soils map
- Soils description
- Topography map
- Conservation Plan of Operation
- Soil test (required when nutrients are applied)

Once the WQMP was developed and approved by NRCS and the local district, it was then sent to the TSSWCB Dublin Regional Office for technical review and certification. Upon certification of the WQMP, the plan could be implemented.

The District Technician worked with landowners to implement BMPs laid out in the WQMP. The BMPs installed would assist with the reduction of sedimentation and nutrients in the watershed. Status Reviews were conducted annually on all WQMPs developed and certified through this project to ensure the BMPs were installed and maintained properly.

In all, 81 WQMPs were developed utilizing some or all of the 13 practices itemized in Table 7 and collectively treated a total of 12,407 acres. The main BMPs installed included pasture/hayland planting, terraces, grassed waterways, and critical area planting. A breakdown of practices implemented and total acreage treated per WQMP is included in Appendix C. The WQMPs were implemented entirely within Williamson County in those areas around Lake Granger with the highest erosion potential and highest agricultural use.

The BMPs installed in the 81 WQMPs consist of irrigated cropland, non-irrigated cropland, and grazing land practices as outlined in Tables 8, 9, and 10 respectively.

Table 7. Intended benefits of irrigated cropland BMPS utilized in project WQMPs

Intended Benefit	Irrigated Cropland Best Management Practices: Conservation Crop Rotation	Pest Management	Conservation Tillage	Residue Management - Seasonal
Reduce erosion	✓		✓	✓
Reduce sheet and rill soil erosion			✓	
Reduce irrigation-induced erosion	✓		✓	
Reduce wind erosion			✓	
Improve or maintain water quality	✓		✓	✓
Maintain or improve water infiltration	✓		✓	✓
Maintain or improve soil organic matter content and tilth	✓		✓	✓
Manage deficient or excess plant nutrients	✓			
Improve efficient use of available water	✓		✓	
Enhance quality and quantity of crops	✓	✓	✓	
Minimize negative impact of pest control on natural resources		✓		

Table 8. Intended benefits of non-irrigated cropland BMPS utilized in project WQMPs

Intended Benefit	Non-irrigated Cropland Best Management Practices					
	Conservation Crop Rotation	Conservation Tillage	Pest Management	Contour Farming	Grassed Waterway	Terrace
Reduce erosion	✓	✓				✓
Reduce sheet and rill erosion		✓		✓		
Reduce wind erosion		✓				
Reduce transport and content of sediment and/or contaminants in runoff				✓	✓	✓
Improve or maintain water quality	✓	✓			✓	✓
Improve or maintain water infiltration	✓	✓				
Maintain or improve soil organic matter	✓	✓				
Manage deficient or excess plant nutrients	✓					
Improve efficient use of available water	✓					
Convey runoff from diversions without contributing to erosion or flooding					✓	
Reduce or prevent gully erosion					✓	
Prevent gully development						✓
Reduce flooding					✓	✓
Enhance quality and quantity of crops			✓			
Minimize negative impact of pest control on natural resources			✓			

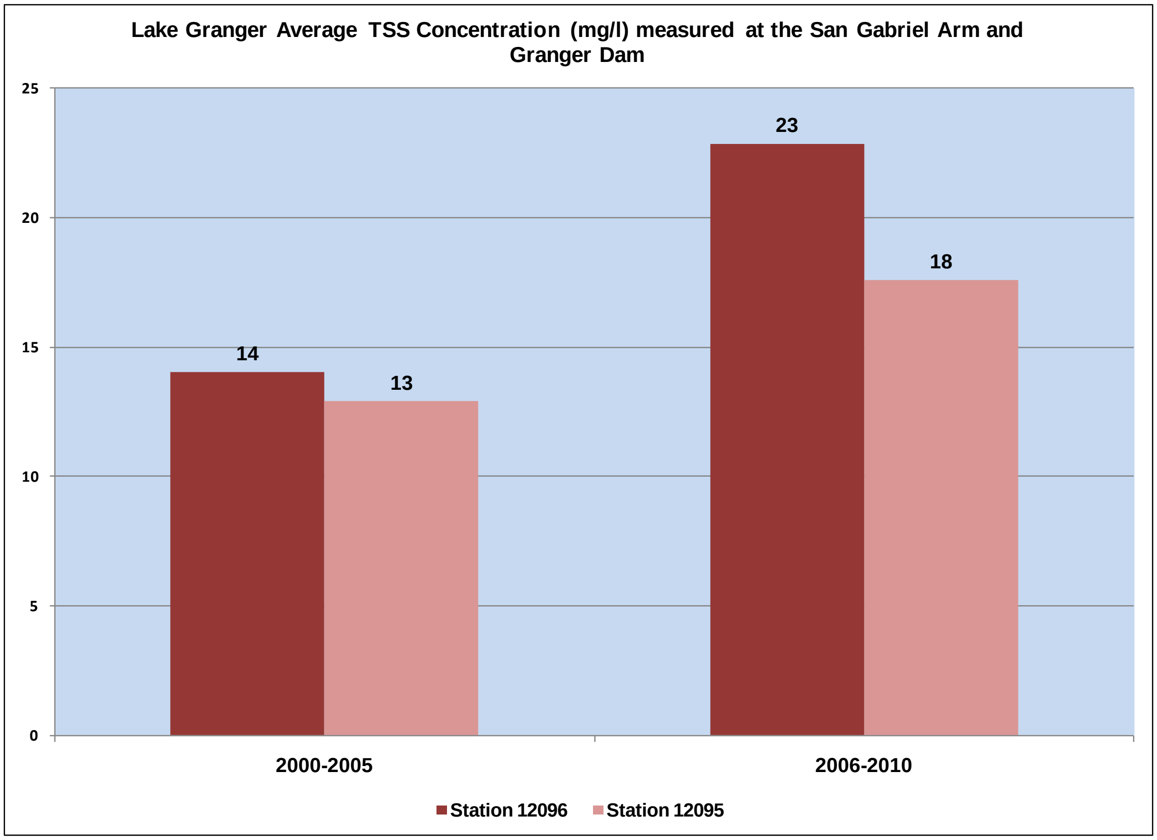
Table 9. Intended benefits of grazing BMPs utilized in project WQMPs

Intended Benefit	Grazing Best Management Practices					
	Pasture and Hay Planting	Critical Area Planting	Pest Management	Forage Harvest Management	Prescribed Grazing	Livestock Pond
Reduce soil erosion by wind and water	✓					
Reduce accelerated soil erosion and maintain or improve soil condition					✓	
Maintain forage quantity and quality	✓		✓	✓	✓	
Reduce transport and content of sediment and nutrients in runoff	✓					✓
Improve or maintain water quality	✓				✓	✓
Stabilize areas with existing or expected high rates of soil erosion by water and wind		✓				
Restore degraded sites that cannot be stabilized by normal methods		✓				
Optimize yield of and quality of forage	✓		✓	✓		
Use forage plant biomass as a nutrient uptake tool				✓		
Maintain or improve wildlife habitat				✓		✓
Control insects, diseases and weeds			✓	✓		
Minimize negative impact of pest control on natural resources			✓			

4.0 Measure of Success

Water quality monitoring and TSS analysis were conducted throughout the duration of the implementation (2006 – 2010) of the WQMPs and compared with data collected from 2000 – 2005. The monitoring stations selected for comparison were Granger Lake at San Gabriel Arm (Station 12096) and Granger Lake at Dam (12095). The data demonstrates that the 30% reduction goal for TSS was not met during the period when the WQMPs were implemented. The average TSS concentrations for both sites showed an increase during the implementation period of 2006-2010 (Figure 9).

Figure 8. TSS five year concentration comparison for two stations in Lake Granger



The relative success of the practices included in the implemented WQMPs in achieving the 20% reduction in soil erosion requires some assumptions. For the purpose of this WPP, only sub-basins located entirely within Williamson County, not including the Lake Georgetown or Lake Granger sub-basins (Figure 7) are considered. Thus, only the SWAT generated values for tons of sediment and tons per acre for those sub-basins are utilized for calculating the estimated percent soil reduction (Table 11). Urban and water land-use classifications were excluded from total acres per sub-basin.

A total of 12,407 acres of land are currently included in the 81 WQMPs, out of approximately 225,307 acres of agricultural and rangeland within the described sub-basins. The SWAT model predicted a total sediment value of 13,657,515 tons and a total sediment load of approximately 61 tons/acre within these sub-basins. Multiplying the predicted sediment load of 61 tons/acre by the 12,407 acres included in the WQMPs resulted in an approximate total sediment value of 745,115 tons, which translates to a reduction of 5.5%. Based on these assumptions, future WQMPs that take in a much more substantial area will be required if the targeted sediment reduction of 20% is to be realized.

In addition, the Texas AgriLife Research Lake Granger sediment study results demonstrated an approximate loss of 328 ac ft/year during the duration of the three year study. This loss of capacity indicates that the current implementation practices may not have had the desired effect and that significant expansion of additional acreage in BMPs incorporated into local WQMPs will be necessary if sediment loading into Lake Granger is to be managed effectively.

Table 10. Selected sub-basin land-use and predicted sediment load yield. Source: 1999 NRCS Lake Granger Sediment Study

	Subbasin land use acres					subbasin sediment (tons)	tons/acre
Sbasin	AGRL	PAST	RNGE	RNGB	TOTAL acres		
9	959	3262	5011	20213	29445	**298,903**	**10**
10	1127	2491	840	22802	27260	**200,483**	**7**
11	672	761	138	6939	8510	**47,913**	**6**
13	0	445	0	336	781	**274,846**	**352**
14	1789	1977	2965	15834	22565	**110,243**	**5**
15	1552	642	119	9429	11742	**49,221**	**4**
16	5357	3924	217	1661	11159	**446,926**	**40**
17	633	593	0	484	1710	**726,834**	**425**
18	425	781	0	494	1700	**27,629**	**16**
19	89	208	0	316	613	**2,983,858**	**4868**
20	741	1749	168	968	3626	**52,242**	**14**
21	3123	3875	405	109	7512	**166,293**	**22**
22	712	583	10	682	1987	**2,356,831**	**1186**
23	1374	1611	0	336	3321	**2,418,861**	**728**
24	1443	356	0	109	1908	**55,991**	**29**
25	2392	1236	0	20	3648	**90,071**	**25**
26	2560	1137	0	385	4082	**93,880**	**23**
27	2145	1690	0	0	3835	**617,099**	**161**
28	6336	1364	0	69	7769	**-149,060***	**-19***
29	4329	1156	0	544	6029	**124,189**	**21**
30	7769	3202	30	0	11001	**1,003,525**	**91**
31	1166	633	0	128	1927	**57,571**	**30**
32	2145	2590	0	850	5585	**89,128**	**16**
33	2629	1443	40	1591	5703	**114,643**	**20**
34	642	474	208	544	1868	**24,549**	**13**
35	2906	682	0	99	3687	**141,661**	**38**
36	4260	1492	0	40	5792	**170,213**	**29**
37	1749	1067	0	1927	4743	**164,995**	**35**
38	2698	544	0	89	3331	**156,120**	**47**
39	2026	543	0	0	2569	**114,173**	**44**
40	1848	178	0	0	2026	**38,526**	**19**
41	1829	119	0	0	1948	**43,228**	**22**
42	2550	1502	0	0	4052	**354,122**	**87**
43	1651	395	0	0	2046	**33,568**	**16**
44	1908	880	0	0	2788	**54,585**	**20**
45	2204	405	0	0	2609	**44,073**	**17**
46	1423	359	0	0	1782	**21,977**	**12**
47	1611	148	0	0	1759	**26,325**	**15**
48	633	256	0	0	889	**11,280**	**13**
Total	81405	46753	10151	86998	225307	**13,657,515**	**61**

*Represents net deposition in sub-basin

5.0 Technical Assistance and Financial Incentives

Continued technical assistance and financial incentives will be necessary if currently implemented BMPs are to be maintained or if additional BMPs are to be put in place to expand soil loss prevention practices in the watershed. Assistance will also be required to replace or restore existing BMPs as they approach the end of their intended lifespan. The costs associated with sustaining many of the agricultural management strategies listed in this WPP will be significant and continued cooperation between landowners, technical professionals, and potential funding agencies is essential. Potential key sources of funding and supporting programs that will be explored include:

5.1 *Environmental Quality Incentives Program (EQIP)*

The Environmental Quality Incentives Program in administered by the NRCS. EQIP is a voluntary conservation program that promotes the compatibility of agricultural production and environmental quality. Through cost-sharing, EQIP offers financial and technical assistance to eligible participants for the installation or implementation of structural controls and management practices on eligible agricultural land. This program represents one of the most essential options for successfully continuing and expanding implementation of agricultural management measures in the San Gabriel River and Lake Granger watershed.

5.2 *Water Quality Management Plan Program*

The WQMP Program is another essential resource that is administered by the TSSWCB. Also known as the 503 program, the WQMP program is a voluntary mechanism that assists in the development of site-specific plans that are developed and implemented on agricultural and silvicultural lands to prevent or reduce NPS pollution from those operations. WQMPs include specific or combinations of appropriate treatment practices, production practices, management measures, and technologies. These plans are coordinated with local SWCDs, include entire operations, and utilize financial incentives to encourage local participation. Additional funding from the 503 program will be essential to meeting future soil reduction and erosion goals. Approximately $600,000 was spent establishing the existing WQMPs however, a more substantial amount will be necessary to meet reduction goals.

5.3 *Federal Clean Water Act Section 319(h) Nonpoint Source Grants*

The U.S. Environmental Protection Agency provides funding to states to support projects and activities that meet federal requirements of reducing and eliminating NPS pollution. In Texas, both the TSSWCB and the TCEQ receive §319(h) funds to support the NPS projects, with the TSSWCB funds allocated to agricultural and silvicultural projects and TCEQ funds allocated to urban and other non-agricultural related projects. Funding from both TSSWCB and TCEQ represent significant resources for addressing NPS issues identified in this WPP.

5.4 *Supplemental Environmental Project Program (SEP)*

The Supplemental Environmental Projects program is administered by the TCEQ and is designed to direct fines, fees, and penalties for environmental violations toward environmentally beneficial uses. Through this program, a respondent in an environmental enforcement matter may choose to forego paying into the Texas General Revenue Fund and, instead, pay those funds towards environmental improvements. The SEP program may be of use in improving infrastructure of treatment facilities or septic system repair.

5.5 *Texas Clean Rivers Program (CRP)*

The CRP is a statewide water quality monitoring, assessment, and public outreach program funded by state fees. The TCEQ coordinates CRP activities with all 15 regional river authorities in Texas to achieve the goal of improving water quality throughout the state. Funds from CRP are utilized to collect quality-assured surface water quality data to assess water quality standards in support of the Clean Water Act. The CRP will continue to be an important resource to support water quality monitoring.

5.6 *Regional Water Supply and Wastewater Facility Planning Program*

The TWDB offers grants for assessments to determine feasible, cost effective options to meet regional water supply and wastewater facility needs, estimate costs to implement wastewater facility options, and to identify institutional arrangements to provide wastewater services to areas across the state. This program will be an important resource as infrastructure is developed to meet the increasing demands of the rapidly growing populations in and around the Leander and Georgetown area. The expansion of wastewater services into these areas is a necessity and proper planning to ensure treated effluent is of sufficient quality and does not contribute significantly to TSS and nutrient loading is of great importance.

6.0 Education and Outreach

A continued commitment to local stakeholders and the general public is an essential component of the WPP's implementation. Continued cooperation between TSSWCB, LR-SG SWCD, TCEQ, will be vital to successful engagement of local stakeholders. Educational materials and programs already exist to address NPS pollution from both nutrients and sedimentation. Effectively disseminating this material and providing access to educational programs to local stakeholders and the public will be essential to increasing the effectiveness of this plan. Outreach programs may include broad-based programs that address water quality and conservation to programs that target agriculture or construction activities (Table 12). Note that CWA funding may be necessary to fund some of the listed activities but many of the programs are also provided free of charge by the Texas AgriLife Extension Service.

Table 11. Potential outreach and education programs

Outreach Activities

Broad-Based Programs	**Agricultural Programs**	**Urban Programs**
Texas Watershed Steward Training	Soil and Water Testing	Nutrient Education
Watershed Road Signage	Nutrient Management Education	Construction Stormwater Seminars
Displays at Local Events	Crop Management Seminars	Sports and Athletic Field Education
Rainwater Harvesting Education	Lone Star Healthy Streams	Pet Waste Programs
Community Stream Cleanup Events	Livestock Grazing Management	

7.0 Measuring Progress and Adaptive Management Strategy

As needed, stakeholder meetings will be scheduled to provide opportunity for input and evaluation of ongoing management measures and to discuss the potential for additional measures necessary to meet the stated goals of this WPP. In conjunction with TSSWCB, LR-SG SWCD, and the BRA, stakeholders may use these opportunities to prioritize areas that would benefit from the establishment of additional WQMPs.

Based on landowner participation and available funding, additional WQMPs will be pursued to meet sediment reduction goals.

Additional volumetric surveys and SWAT assessments of flow and sediment loading into Lake Granger will further quantify loss of storage capacity and sedimentation.

Continued monitoring of the San Gabriel River and Lake Granger Watershed will be necessary so that data will be in place to adjust management strategies as needed based on documented changes in water quality, quantity, and land-use.

7.1 *Water Quality Monitoring*

The BRA will continue to conduct routine water quality monitoring at 12 stations in the Lake Granger watershed including three in-lake stations on Lake Granger and two on Lake Georgetown (Figure 5). The remaining monitoring stations are located on the tributaries that feed the two reservoirs (Table 4). All water quality stations are monitored monthly or quarterly by BRA. Parameters will be monitored to support continued assessment of sediment loading will include total suspended solids, nutrients, and transparency. Flow measurements will be collected at tributary stations when possible.

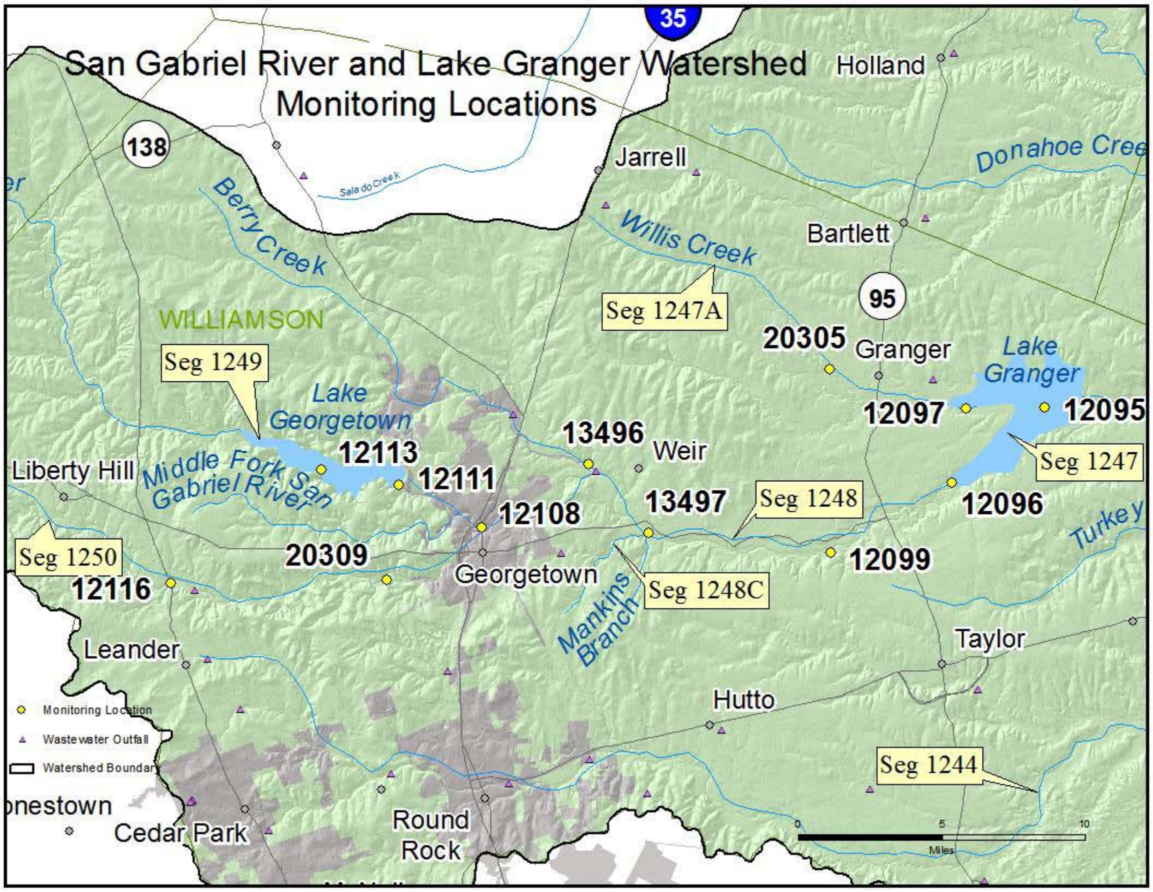
Table 12. Monitoring Stations in Granger Lake Watershed

Segment	Station	Site Description	Monitoring Frequency
1247	12095	Granger Lake at Dam	Monthly
1247	12096	Granger Lake at San Gabriel Arm	Monthly
1247	12097	Granger Lake at Willis Creek Arm	Monthly
1247A	20305	Willis Creek at CR 326	Quarterly
1248	12099	San Gabriel River at CR 366, 2.8 miles upstream of SH 95	Quarterly
1248	12108	North Fork of San Gabriel River in Georgetown	Quarterly
1248A	13496	Berry Creek at FM 971	Quarterly
1248C	13497	Mankins Branch at CR 100	Quarterly
1249	12111	Lake Georgetown at Dam	Monthly
1249	12113	Lake Georgetown at San Gabriel River Arm	Monthly
1250	20309*	South Fork San Gabriel	Quarterly

		River at Weir Pit West of Georgetown	
1250	12116	South Fork San Gabriel River at US 183	Quarterly

* Biological assessment scheduled for FY2012

Figure 9. San Gabriel River and Lake Granger monitoring locations



Data will be compiled and assessed for trends that may indicate spatial and/or temporal changes in water quality that may be attributed to either benefits from management measures, changes in land-use, or acceleration of NPS pollution.

7.2 *Volumetric Surveys*

The TWDB conducted the first volumetric survey of Lake Granger in 1995 to serve as a baseline for future surveys. Four additional surveys were conducted between 2002 and 2010 by TWDB and Texas AgriLife Research to document loss of storage capacity and temporal changes in sedimentation into Lake Granger. Further volumetric studies of Lake Granger will be a necessary tool for judging success of WQMPs and BMPs employed as part of this WPP. The importance of Lake Granger as a source of drinking water to the rapidly growing communities in Williamson County adds additional significance to maintaining partnerships with the TWDB and Texas AgriLife Research for future studies of Lake Granger. At a minimum, it is recommended that surveys be conducted at five year intervals to track changes in sedimentation and storage capacity.

8.0 References

NRCS (1999). Assessment of Flow & Sediment Loadings and BMP Analysis for Lake Granger.

TWDB (2003). Volumetric Survey of Granger Lake, April 2002 Survey

TWDB (2003). Volumetric Survey of Granger Lake, October 1995 Survey

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McAlister, J., (2011). Granger Lake Sedimentation and Watershed Conservation Implementation Assessment.

Appendix A

GRANGER LAKE SEDIMENTATION AND WATERSHED CONSERVATION IMPLEMENTATION ASSESSMENT

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A Thesis

by

JASON ROSS MCALISTER

Submitted to the Office of Graduate Studies of
Texas A&M University
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MASTER OF SCIENCE

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Approved by:

Chair of Committee,	Bradford Wilcox
Committee Members,	William Fox, III
	Raghavan Srinivasan
Head of Department,	Steven Whisenant

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ABSTRACT

Granger Lake Sedimentation and Watershed Conservation Implementation Assessment.

(December 2011)

Jason Ross McAlister, B.S., Texas State University

Chair of Advisory Committee: Dr. Bradford Wilcox

Sedimentation rates for many Texas reservoirs may be skewed by overstated estimates of design capacity and assumptions perpetuated through subsequent volumetric surveys. Multi-frequency reservoir surveys offer the means by which we may improve existing reservoir data and validate historic sedimentation rate estimates. To demonstrate application of this technology and value of its data derivatives, a multi-year, multi-frequency acoustic survey of Granger Lake, located in Williamson County, Texas was undertaken. Objectives of the study were to use hydro-acoustic survey techniques to verify assumptions of original reservoir capacity, examine the general accuracy of previously derived sedimentation rate, and document conservation implementation effectiveness. The intended benefit of these pre and post-watershed conservation implementation project surveys was to provide a temporal snapshot of sediment flux. Specifically, these data would be used as a tool to quantitatively estimate project success or non-success in annual sediment delivery reduction to the reservoir.

During the course of the Granger Lake Watershed Implementation project, Granger Lake lost on average 343 acre feet of water storage annually to watershed sediment contribution. Sediment profiling results indicate pre-impoundment design estimates were overstated, thus skewing subsequent sediment deliver estimates.   Since the mid-1990's, an accelerating sedimentation trend is apparent. Conservation implementation is not plainly responsible for the decrease in sediment delivery, and in fact may be undetectable for the foreseeable future.

The study illustrates the value of examining previously established reservoir sedimentation estimates and assumptions of reservoir life based on design capacity estimates and routine volumetric surveys. Insights from this research highlight the importance of validating historic reservoir survey data and significance regarding its use in quantifying historic and future conservation effects, or other reservoir sustaining strategies.

ACKNOWLEDGEMENTS

The Texas Water Development Board provided documentation for initial reservoir volume and post-impoundment bathymetry data for comparison. The original manuscript was significantly improved as a result of suggestions from committee members as well as Dr. June Wolf. Funding was provided through a Clean Water Act §319(h) Nonpoint Source Grant from the Brazos River Authority, Texas State Soil and Water Conservation Board, and the U.S. Environmental Protection Agency.

NOMENCLATURE

BREC	Blackland Research and Extension Center
CPE	Conservation Pool Elevation
DGPS	Differential Global Positioning System
DOQQs	Digital Ortho Quarter-Quadrangle
kHz	Kilohertz
NAD 83	North American Datum 1983
NGVD29	National Geodetic Vertical Datum 1929
NOAA	National Oceanic and Atmospheric Administration
RWPA	Regional Water Planning Area
TIN	Triangular Irregular Network
TWDB	Texas Water Development Board
USACE	United States Army Corps of Engineers
USDA-FSA-APFO	United States Department of Agriculture-Farm Service Agency-Aerial Photography Field Office
USGS	United States Geological Survey

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Reservoirs around the world lose about 1% of their storage capacity annually (WCD 2000), and historically, U.S. reservoirs lose an average of 0.22% per year as a result of sedimentation (Dendy and Champion 1978). However, rates at which individual reservoirs lose volume vary widely and are functions of the relative size of the reservoir, supplying watershed, soil type, climate, land use, and conservation practices (Allen et al. 1999).

Reservoir sedimentation is a process function heavily influenced by catchment and reservoir management. Reservoir sedimentation involves both soil losses from the surrounding watershed and deposition within the reservoir which leads to a reduction in storage capacity (Chanson and James 1998). These processes have large economic and environmental implications including accelerated coastal erosion, decrease in habitat, and downstream scouring of channels (WCD 2000; Crowder 1987; Syvitski 2003) .

Assessment of watershed contribution poses many challenges because colluvial and alluvial deposits can buffer changes in sediment supply at the catchment scale. They can serve as a sink for sediments, eroded upstream, but can become a sediment source when the upstream sediment supplies decline.

This thesis follows the style of Journal of Soil and Water Conservation.

Improvements in land use management or the implementation of soil and water conservation measures does not necessarily result immediately in lower sediment yields. As an example, erosion in many agricultural areas has been declining in recent decades as indicated by the National Resource Inventory, and at least in some regions erosion has been dropping since the 1930s (Renwick 2005).

Unfortunately, even today, the effectiveness of many watershed conservation programs is not realized short term. Conservation programs historically have equal eligibility criteria throughout an area to encourage broad participation – often based on political subdivisions rather than watershed and target specific location criteria. They often do not place enough emphasis on placement or targeted conservation measures relative to areas of high erosion potential (Cox 2008). Furthermore, Garbrecht and Starks (2009) point out "funding for conservation programs is administered on an annual basis and spread over several years, leading to a gradual enrollment and corresponding incremental implementation of conservation practices, all adding to the lag time to full realization of conservation goals. These realities of on-the-ground program implementation suggest that it may take several years, even decades, before the extent of treated cropland is large enough for downstream sediment reduction and associated benefits to become noticeable or measurable at the watershed outlet."

Taking in consideration the temporal and spatial variability in conservation program participation, soil erosion and sediment transport, and watershed storage and flushing effects, Renwick (2005) suggests "…it is not clear whether reservoir sedimentation rates have responded to this reduction in erosion, or whether they should have responded. Lags in the sediment transport system may cause downstream sediment yields associated with a pulse of erosion to remain high well after upstream erosion rates decline. For this reason, and perhaps because of continued accelerated upland erosion, reservoir sedimentation rates in many areas may be steady or increasing" (Renwick 2005).

Hydrologic watershed models do offer advantage to demonstrating pre and post-conservation practice implementation by holding all other conditions constant and climatic drivers can also be introduced. These capabilities make watershed simulations/modeling a sensible approach (Santhi et al. 2005). However, as Garbrecht and Starks (2009) state, "…watershed-scale sediment storage effects, conditions for and recurrence of sediment mobilization, the dynamics of shifting sediment sources, and the spatial and temporal propagation of perturbations in the sediment budget within the watershed system are very difficult to quantify," yet they are valuable to understanding conservation implementation effectiveness" (Garbrecht and Starks 2009). Simply put, watershed-scale sediment simulations require data. More often than not, pre and post-implementation monitoring data is not always readily available.

With the above complexities of watershed sediment yield assessment in mind, reservoir surveys are seen as more accurate than some alternative assessments of sediment export at the basin scale, since they provide direct measurements instead of indirect estimates (Strand and Pemberton 1982). They often provide information over long time spans and represent the effect of frequent and rare events. Reservoir surveys are often required to establish or update stage – volume curves for reservoir operation, to calculate the sediment yield of the upstream hydrological basin, to assist reservoir designers with design of other reservoirs in the region, to predict the spatial distribution of sediment within the reservoir which may affect hydraulic structures such as intakes, and to evaluate methods of prevention or sediment removal.

Water storage volumes for many reservoirs were originally estimated by analyzing available topographic maps, pre-impoundment surveys, and range-line bathymetry surveys. Follow-up sediment survey results show a considerable underestimation of the sediment volume for all range line sets. The underestimation is more evident when range lines are sparse, and beyond a certain number of range lines there is no improvement of the overall estimation (Zarris and Lykoudi 2002). Because the original reservoir volume estimates were limited by the accuracy of existing topographic maps and land surveys, estimates of the current capacities for reservoirs not re-surveyed since their construction are subject to error (Morris and Fan 1997; Dunbar et al. 1999) .

As related to reservoir sedimentation projections, this error may be unknowingly perpetuated. Current assumptions of watershed contribution and hence, reservoir sedimentation rates, may be in error and simply the consequence of over-reliance on the universal soil loss equation (Odhiambo and Boss 2004) or overstated reservoir capacity (Dunbar et al. 1999). Successive volumetric surveys and assessments of conservation implementation effectiveness - no matter the integrity and intended good of the assessment – could be flawed from the offset. Failure to correctly reassess and/or revise design capacity estimates may lead to ill-perceived valuation of historic and future conservation efforts (Davis et al. 1999).

Largely, rates of sediment accumulation are determined by directly measuring the volume of deposits or by acoustically determining a reservoir's current capacity and subtracting this from its original stated capacity or capacities derived from previous volumetric surveys. Acoustic surveying techniques remain a superior methodology for the accurate calculation of reservoir volume. A chief result of the improved spatial sampling and automation of reservoir surveys has been the realization that some older volumetric surveys had significant error. Some reservoirs, for example, appear to have increased in storage capacity since impoundment, despite several decades of sedimentation. Other reservoirs appear to have lost 12-17% of their initial capacity in little over a decade (Dunbar et al. 1999).

Modern technology allows the simultaneous operation of multiple transducers, i.e., collection of multiple transducer data separated by acoustic wave-length making possible spatially and temporally correlated collection of acoustically independent data. Independence of frequency means surveyors may utilize higher wavelengths to calculate water depth, while simultaneously utilizing the sediment penetrating capability offered by lower acoustic wavelengths (Dunbar et al. 1999). When calibrated by sparse coring or spud bar determinations of sediment thickness, multi-frequency acoustic surveys can produce accurate estimates of current reservoir capacity and long-term volume loss in one survey. This methodology offers a distinct advantage because of its non-reliance on historic reservoir survey data. Accurate long-term sedimentation rates can be determined for older reservoirs for which only sparse-profile initial surveys were performed as well as reservoirs for which have no initial volumetric surveys (Allen et al. 1999).

Implementation this contemporary survey technology offers validation of initial reservoir design capacity while assessing current reservoir water capacity - allowing accurate and repeatable means by which reservoir sedimentation rates may be assessed. The much broader implication/benefit provides resource planners and researchers reliable reservoir data on which to base projections, and measure outcomes.

Further, reservoir survey data offers opportunity to understand watershed dynamics. Sedimentation data contained therein is an unexploited archive useful in answering important conservation and watershed resource management questions. For example, there is an increasing need to assess conservation implementation and its effects with drainage catchments. As often the case, little baseline water quality monitoring data is available for stream courses within these basins, therefore calculating the before and after effects of implementation is theoretical at best. Few models are available that focus on sediment export at the basin scale, incorporating both erosion and sediment delivery accurately. A reservoir, metaphorically, may be viewed as a large scale experiment – described as the outlet of a very large watershed plot (Ambers 2001; Verstraeten et al. 2003). As such, reservoir sedimentation studies offer a surrogate methodology for directly monitoring sediment delivery. It can serve as supplemental data resource for model validation, and snapshot of watershed sediment flux.

1.1 Purpose and Objectives

In January, 2007 the Blackland Research & Extension Center (BREC) began a multi-year acoustic survey of Granger Lake, located in Williamson County, Texas. The purpose was to determine the effect of conservation practices being implemented through Granger Lake Watershed Conservation Implementation Project. High-resolution lake bathymetry and sediment distribution coverage for the reservoir was collected to serve as a pre-conservation implementation baseline -- a surrogate to historic water quality monitoring data, as none existed.

Reservoir capacity at conservation pool elevation (CPE) was identified using high frequency acoustics. Simultaneously, low frequency acoustics provided a sediment profiling ability used to identify the reservoir's pre-impoundment topography, penetrate and map spatial distribution of unconsolidated sediments, and quantify cumulative post-impoundment sediment to date. A second hydro-acoustic survey provided for temporal comparison of sedimentation.

Objectives of the study were to use hydro-acoustic survey techniques to verify assumptions of original reservoir capacity, examine the general accuracy of previously derived sedimentation rate, and document conservation implementation effectiveness.

Research Objective 1. Conduct a sediment profiling survey to identify Granger Lake's as-built pre-impoundment capacity.

Ho: Granger Lake USACE design capacity of 65,000 acre-feet is accurate.

Research Objective 2. Plot historic bathymetric datasets including pre-impoundment (year 1) surface determined by low frequency acoustics, identifying any changes in annualized sediment delivery curve to date.

Ho: Annualized sediment delivery rate is not changed.

Research Objective 3. Identify annualized sedimentation rates prior to Granger Lake Watershed Assessment and Implementation Project and compare post-implementation reservoir capacity to quantify changes in watershed sediment delivery.

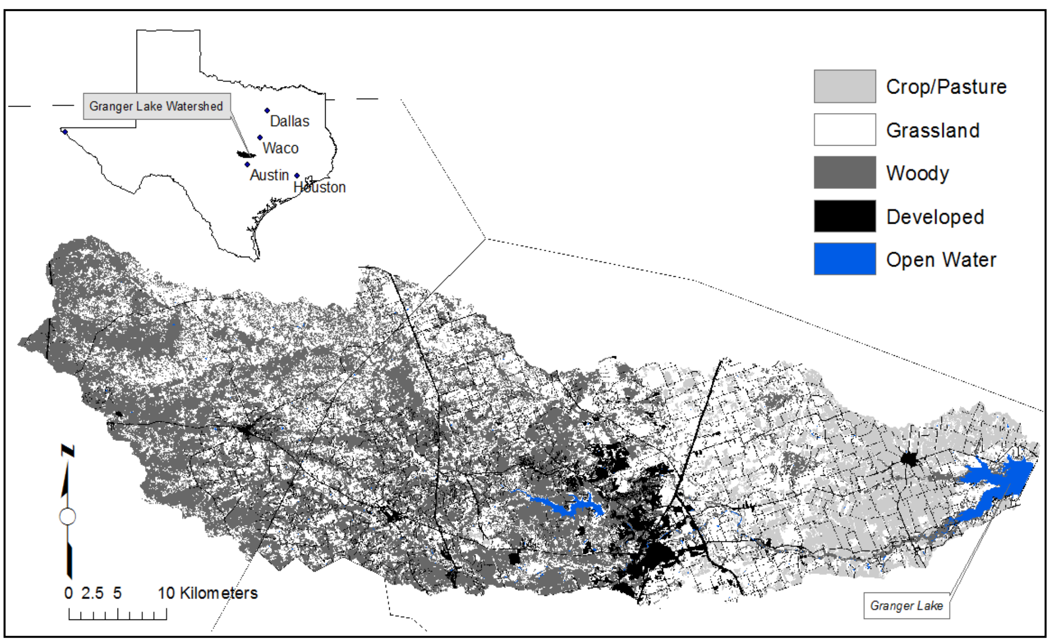
Ho: There is no change in watershed sediment delivery as a result of conservation practice implementation.

2. STUDY AREA

2.1 Granger Lake

Granger Lake is located approximately seven miles east of the City of Granger (Figure 1). Construction of Granger Dam began in October of 1972, with deliberate impoundment of the Brazos River Basin's San Gabriel River beginning on January 21, 1980 (USACE 2011). This 4000 acre lake is owned by the U.S. Government and operated by the U.S. Army Corps of Engineers, Fort Worth District (TWDB 1973), and functions as a flood control, water conservation, fish and wildlife habitat, and general recreation reservoir (USACE 2011). Over the last two decades, Granger Lake sedimentation has been a major concern to state and regional water planners.

Figure 1: Granger Lake Watershed and land use/land cover.



2.2 History

In 1980 when Granger Lake first started impounding water, initial storage calculations estimated that the volume of the lake at the conservation pool to be 65,510 acre/feet. In 1995, a volumetric survey determined capacity to be 54,280 acre/feet, a loss of 11,230 acre/feet (748.67 acre/feet per year) – a 17% storage capacity loss over 15 years (TWDB 1995).

In 2002 a similar survey was conducted to determine reservoir capacity changes since the last survey. Results indicated a loss of 1,319 acre/feet (202.92 acre/feet per year) over 6.5 years (TWDB 2002). There is a distinct difference in the annual loss of volume in the lake between 1980-1995 and 1995-2002. This difference is thought to be rainfall and storm intensity related.

In 1999 the Natural Resources Conservation Service Water Resource Assessment Team, at the request of the Brazos River Authority conducted a separate study of the Granger Lake Watershed using the Soil and Water Assessment Tool (SWAT). Flow and sediment loads were assessed as well as effectiveness of various erosion mitigating conservation practices. Modeling results indicated that conventional conservation practices, used in combination, had the potential to reduce sediment loads by 20-30% (NRCS 1999).

Sediment accumulation rates based on original design estimates and volumetric surveys have demonstrated capacity loss at an alarming rate, while prior modeling assessment has simulated conservation practice effectiveness. Addressing the perceived sedimentation problem continues to be a focus of natural resource and water availability planners.

2.3 Granger Lake Watershed

The Lake Granger Watershed is located in Central Texas. This 188,856 hectare watershed is located in Williamson County, extending slightly into Burnet County. Lying within the IH-35 corridor with Highway 183 in the southwestern part of the Williamson County, with its close proximity to Austin Texas, the watershed's urban component is rapidly expanding (Table 1).

Table 1: Changes in land use/land cover extracted from 2001 & 2006 NLCD raster datasets.

Land Use / Land Cover	**2001**	**2006**
Crop/Pasture	11.3%	11.1%
Grassland/Herbaceous	40.9%	38.1%
Woody	41.4%	39.7%
Developed/Developing	5.1%	9.7%
Open Water	1.4%	1.4%

Agricultural land uses are dominant in the drainage area. Without adequate treatment and management, soils are subject to accelerated erosion with subsequent increased reservoir sedimentation. Soil conservation practices such as grass planting, alteration of tillage practices, and installation of impoundment structures for preventing reservoir sedimentation are currently being implemented (Table 2).

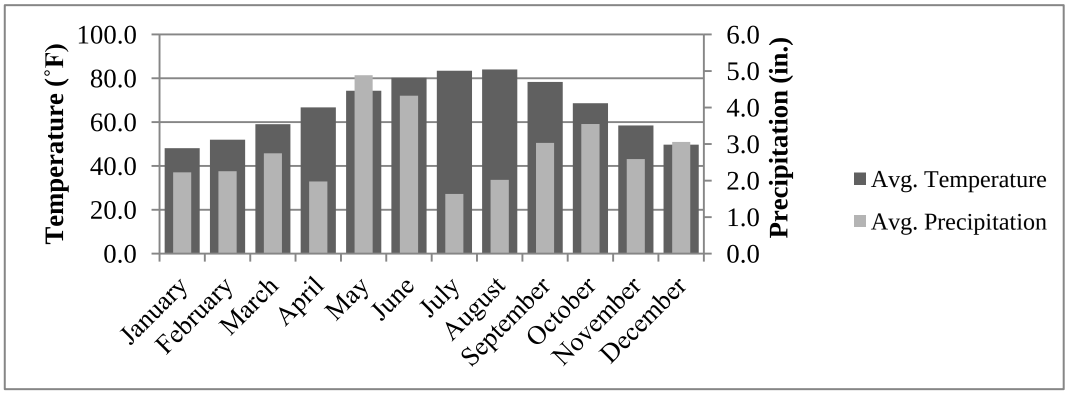
Table 2: Granger Lake Watershed conservation practices cost-shared 2007-2010.

Practice	Quantity	Unit
512 - Pasture/Hayland Planting *	1022.6	ac.
600 - Terraces Installed *	270247.0	linear ft.
412 - Grassed Waterways *	87.0	ac.
378 - Livestock Pond *	10.0	ac.
342 - Critical Area Planting *	17.3	ac.
330 - Contour Farming	6636.4	ac.
511 - Forage Harvest Management	659.0	ac.
328 - Conservation Crop Rotation	6890.4	ac.
528A - Prescribed Grazing	3484.0	ac.
590 - Nutrient Management	10622.1	ac.
595 - Pest Management	10540.0	ac.
329 - Conservation Tillage	4656.0	ac.
344 - Residue Management-Seasonal	6890.4	ac.
* Practices installed to date (2007-2010)		

2.4 Climatic History

The climate is sub-humid. Granger Lake Watershed is characterized by hot summers and cool winters; average temperature range from 49˚F in winter to 83˚F in summer (Figure 2). Typically, summers are hot and winters are mild with intervals of freezing temperatures as cold fronts pass through the region. Average annual precipitation ranges from about 34.2 inches in Williamson County to 30.5 inches in Burnet County. Sixty percent of annual precipitation usually falls between April and September (Werchan and Coker 1983).

Figure 2: Historical monthly average temperature (°F) and monthly average precipitation recorded by NOAA at Granger Dam weather station from 1980 – 2010.



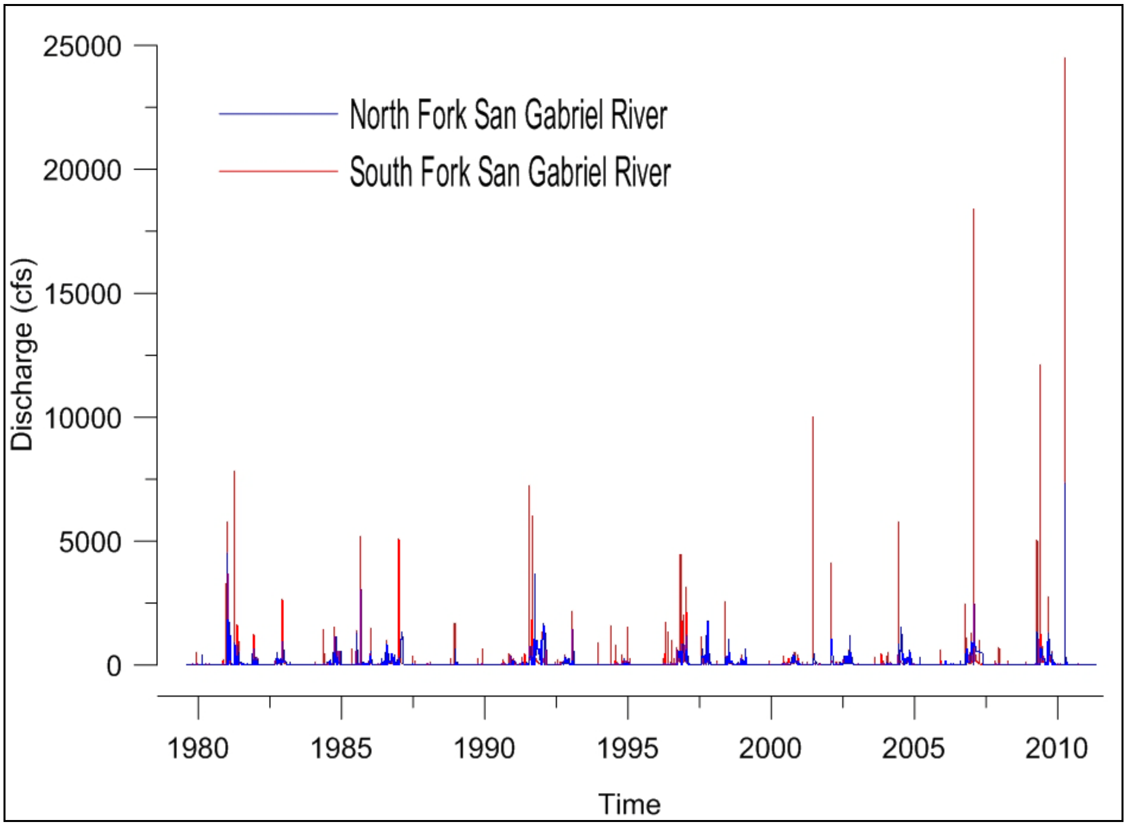
2.5 Soils

The watershed is within portions of the Edwards Plateau, Grand Prairie, and Texas Blackland Prairie Major Land Resource Areas. Soils range from shallow loamy or clay, stony and cobbly soils in the Edwards Plateau region to deep fine textured montmorillonitic clays in the Blackland Prairie. Soil depths vary from very shallow to deep. Upland topography ranges from nearly level to steeply sloping.

2.6 Watershed Hydrology

The San Gabriel River and Brushy Creek are the main watercourses within the county. They flow in a west-east direction, and all drainage is in the Brazos River Watershed and TWDB Regional Planning Area G. Daily discharge data for North and South San Gabriel Rivers are provided (Figure 3). Georgetown and Granger Lakes account for approximately 5,710 surface acres of water. Lake Georgetown controls about 34% (63,795 hectares) of the Granger Lake Watershed in the upstream portion of the basin. There are seven NRCS flood control structures and numerous surface water components including 45 Brushy Creek watershed structures, hundreds of farm ponds and several streams - adding approximately 7,052 surface acres of water resources within Williamson County (Werchan and Coker 1983).

Figure 3: North and South Forks of San Gabriel River – Daily Discharge (1980-2010)



3. METHODOLOGY

Digital echo sounder profiles were obtained on overlapping grids in order to provide high resolution sediment distribution coverage. Precision geo-referenced depth measurements were acquired with Knudsen Engineering 320 B/P dual-frequency sonar and Trimble DGPS. Using frequencies of 200 kHz and 28 kHz, high-resolution lake bathymetry and sediment distribution coverage was obtained running predetermined survey lines perpendicular to the shoreline. Sediment probing implemented to confirm system calibration and verify sediment thickness. The resulting data set was used to create digital terrain models of the pre- and post-impoundment lakebed morphology - the basis for quantifying spatial mapping of post-impoundment sediment deposition.

3.1 Pre-Survey Setup

The digitized reservoir boundary was created from aerial photographs or digital ortho quarter-quadrangle images (DOQQs) at an approximate scale of 1:1,500 (Table 3). The quarter-quadrangles that cover Granger Lake are Granger NE, Granger SE, Granger Lake NW, and Granger Lake SW. Each quarter quadrangle image was photographed on January 23, 1995. The water surface elevation for this day averaged 504.18 feet. These photographs have 1-meter resolution; therefore, the physical lake boundary is within +/- 1 meter of the location derived from the manual delineation. Additionally, island boundaries were verified and/or correctly digitized based on a more current 2005 United States Department of Agriculture-Farm Service Agency-Aerial Photography Field Office

(USDA-FSA-APFO) natural color county mosaic. Verification of island boundaries was necessary because of the dynamic morphology of these landforms, especially in close proximity to stream/lake confluence. Although the more recent (2005) imagery has a more coarse resolution (2m), there are strong biophysical cues that indicate terrestrial boundaries and were digitized with a reasonably high level of accuracy. Lake elevation at the time of the 2005 imagery was at 503.83. Boundary sets were digitized at the land water interface visible in the photos; given resolution of imagery and closeness to conservation pool elevation at the time of photography, resulting contours were assigned elevations of 504.0 feet (conservation pool elevation) accordingly.

Table 3: Aerial photography utilized for pre-survey setup.

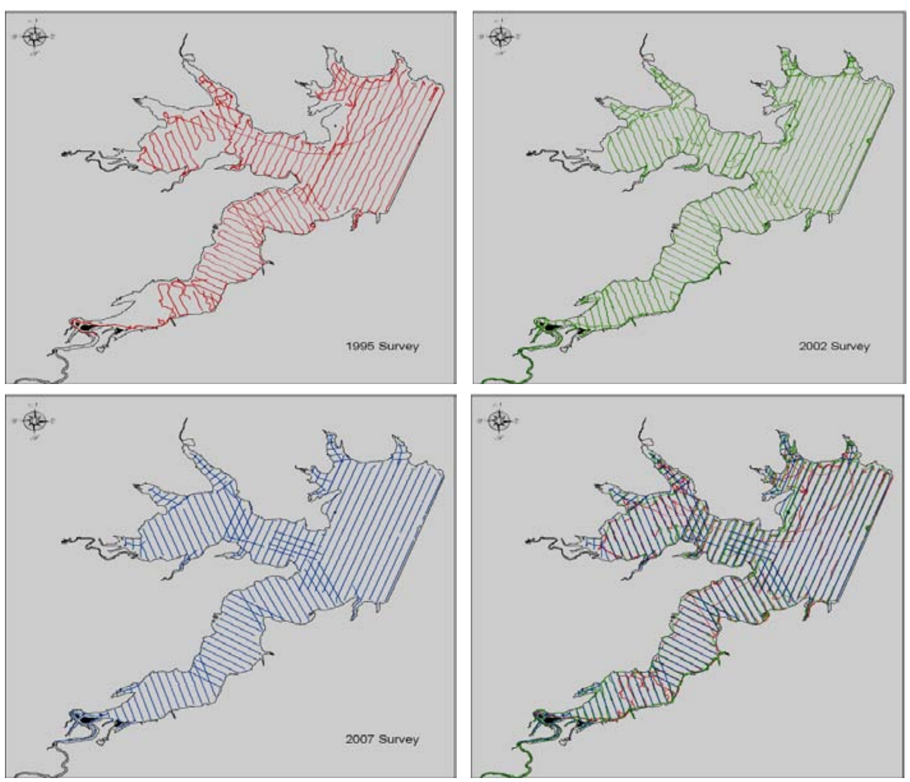
Aerial Imagery	Resolution	Date of Acquisition	Lake Elevation (ft)
Texas Orthoimagery Program Granger NE	1m	23-Jan-1995	504.18
Texas Orthoimagery Program Granger SE	1m	23-Jan-1995	504.18
Texas Orthoimagery Program Granger Lake NW	1m	23-Jan-1995	504.18
Texas Orthoimagery Program Granger Lake SW	1m	23-Jan-1995	504.18
USDA-FSA-APFO Williamson County, Texas (Mosaic)	2m	21-Oct-2005	503.83

3.2 Positioning

Coastal Oceanographic's HyPack Max software was used to assign geodetic parameters, import background files, and create planned survey lines or transects.

Horizontal positions were acquired with a Trimble® differential global positioning system (DGPS). This system integrates a Trimble® GPS receiver with a Trimble GeoBeacon® radio beacon receiver. With this system, Coast Guard radio signals were input from an array of base stations to improve horizontal positioning accuracy to better than 0.5 m (1.6 ft) (Trimble Navigation 2004). TX. The datum for this gage is reported as National Geodetic Vertical Datum 1929 (NGVD29) or mean sea level. The horizontal datum for this research is the North American Datum of 1983 (NAD83) and the horizontal coordinate system is State Plane Texas Central FIPS 4203 (feet). Pre-planned survey transects spaced 500 feet apart were created as close as possible to transects used by previous Texas Water Development Board surveys in 1995 and 2002

Figure 4: Replicated survey track-lines illustrating agreement between surveys.



(Figure 4). Reasoning behind replicating the established routes was to enable comparative analysis with previous volumetric surveys. Additionally, although not in the scope of analysis, utilization of previous data collected under similar methods provide the opportunity to identify “active” sediment transport zones within Granger Lake – allowing targeted sediment mitigation in future watershed conservation efforts.

3.3 Equipment Calibration and Operation

A bar check was performed, incorporating the survey vessel’s static draft and the sound velocity throughout the water column, ensuring accuracy of depth measurements. An iron plate measuring 12” in circumference was lowered 5’ below the static water line and draft corrections were applied to the echosounder until the depth reads 5’. Next, the bar (or plate in our case) was lowered to the maximum expected survey depth. Once lowered and identified on the echogram, sound velocity was adjusted until the echosounder displays the correct value. The bar was raised again to 5’ where a slight adjustment to draft can be made, then return to the maximum intended survey depth to correct (as necessary) the sound velocity. This was an iterative process until physically and acoustically measured depths agree throughout the range with no adjustment. Additionally, direct sediment depth measurement (probing) was implemented to confirm low frequency acoustic profiling data.

For verification of positional accuracy, a geodetic control survey was conducted by static GPS techniques from a known monument with published positions. At the beginning of each survey, a position verification of the GPS was performed using monument BZ0824, X, Y coordinate 31 04 04.18773 (N), 097 27 53.90621 (W), North American Datum 1983 (NAD 83). The GPS unit was positioned directly on the monument while collecting X, Y coordinates. A series of observations were made with redundant comparisons to document accuracy of the survey. When the points were averaged, they were within 3 ft of the monument.

3.4 Field Survey

The survey vessel used in this research was an eighteen-foot pontoon boat. This vessel was equipped with an integrated navigation and data acquisition system and a custom through-deck mount for the Knudsen Engineering dual-frequency transducer.

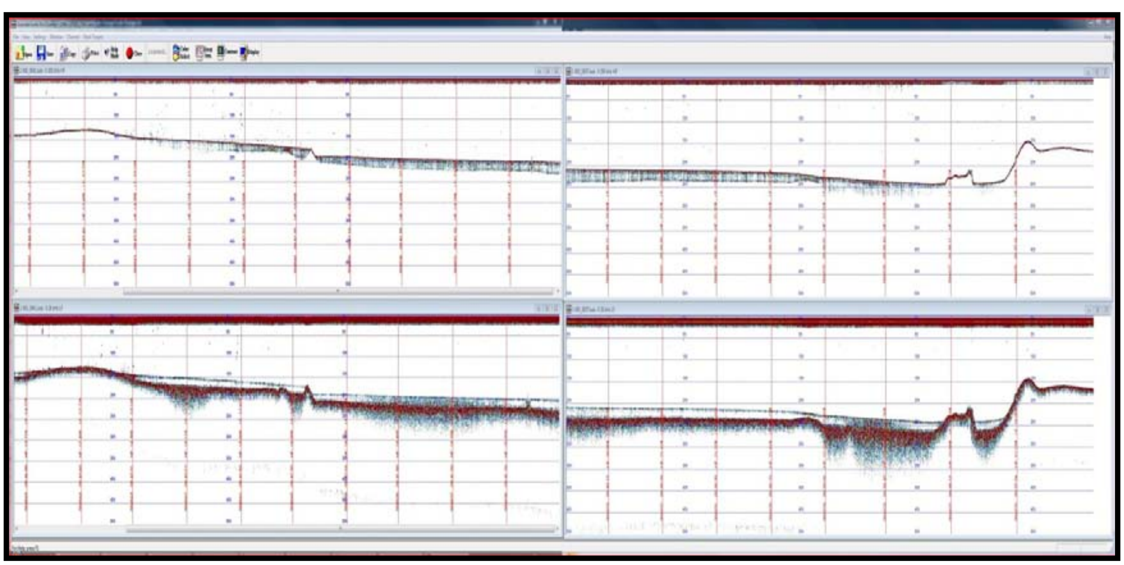
The hydro-acoustic sediment profiling system used in the survey was developed by Knudsen Engineering, Ltd. Knudsen echosounders are used for precision measurement of water depths for hydrographic survey, dredging, ship navigation, defense, and scientific applications. The system used consists of a Knudsen Engineering 329 BP echosounder, and a dual frequency (200/28 kHz) acoustic source. The 200 kHz acoustic impulse provides approximately 1 cm vertical resolution and is used primarily to acquire detailed hydrographic data. The 28 kHz acoustic impulse penetrates fine-grained lacustrine sediment to provide an indication of sediment thickness (Knudsen Engineering 1998). Power for the system is provided by 12-volt marine batteries.

Data acquisition was controlled via Knudsen Engineering Ltd. Sounder Suite® and Coastal Oceanographic's HYPACK MAX software. Using frequencies of 200 kHz and 28 kHz, sonar data was collected by running slow, uniform lines in a systematic pattern and perpendicular to the shoreline.   Adjustments were made to scale and gain settings, as required, to maximize data resolution. During the survey, preliminary hydrographic data was displayed in real-time. Direct sediment depth measurement (probing) was implemented, confirming low-frequency acoustic profiling data.

3.5 Analytical Methodology

Post-processing of sonar data was carried out utilizing HyPack® Single Beam Max. The HyPack® Single Beam Max software allows for simultaneous viewing of the dual-frequency sonar data (Figure 5) to analyze anomalies on the lake bottom during post-processing. Water-level data was applied to adjust all depth measurements to conservation pool elevation. Daily gage observations, at 30 minute increments were applied to all survey measurements on their respective day and time of acquisition.

Figure 5: Digital echogram of Granger Lake illustrating 200kHz (top) and 28kHz (bottom) acoustic profiles of lake-bottom morphology.

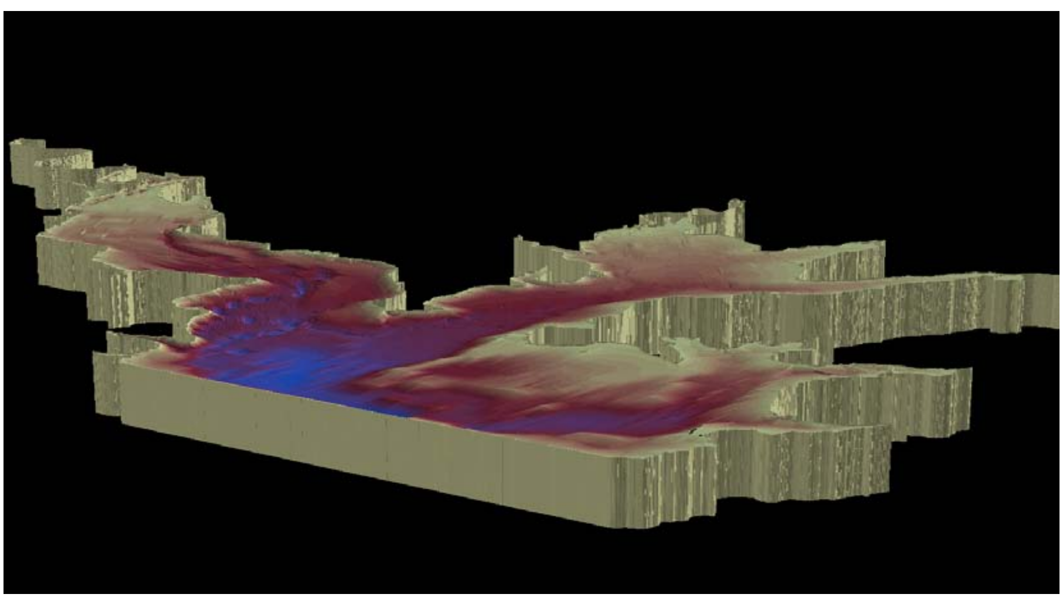


Volume and area calculations were referenced to water levels provided by the Granger Lake USGS gage.

Processing of acoustic data began with review of each survey line using HyPack's Single Beam Max. Position and sensor data was reviewed and accepted if no outliers were present, or rejected if erroneous data was observed. Sounding data was reviewed and edited for anomalies such as bottom multiples, and returns from submerged debris. These data points were flagged as rejected and not used as part of the final data set.

Volumetric and area calculations were derived using a triangular irregular network (TIN) surface model (Figure 6). The TIN model was created within ArcGIS, and uses Delaunay's criteria for triangulation placing a triangle between three non-uniformly spaced points which includes field survey data points and the lake boundary

Figure 6: Digital terrain model created from acoustic data collection.



vertices. Granger Lake pre-impoundment capacity and current capacity was calculated by dividing the TIN into tenth of a foot reference planes between lowest and shallowest recorded depth.

Contours, depth ranges, and the shaded relief map were derived from the TIN. Bathymetric maps were created using ArcGIS spatial analyst “Topo to Raster” tool. Specifically, reservoir boundary files and collected data points were used for interpolation of a digital raster grid and hillshade model illustrating depth ranges (appendix C). Contours were generated and lightly smoothed using polynomial approximation algorithm to improve cartographic quality.

Sediment range lines previously established by Brazos River Authority were used as a comparison of Granger Lake bathymetry since its deliberate impoundment in 1980. These range lines were collected for documentation purposes only. Representative cross- sections were extracted from TIN surfaces. The bathymetric surfaces used for comparison were a pre-impoundment datum, derived from 2007 28kHz acoustic profiling data, and pre-conservation implementation (2007) and post-conservation implementation (2010) 200kHz volumetric datasets. Cross-sectional views of Granger Lake bathymetry offers a discrete and coarse approximation of lake-bottom morphology in time, therefore should be viewed as just that – a rough approximation. Although the TIN is useful for assessing volumetric change and its ability to interpolate landforms while preserving “real” data, differences in spatial coverage of survey data can reveal large elevation differences locally; such differences were apparent in discrete cross sectional profiles where data points were available for one survey, but not for another

(Figures 7 & 8). However, volumetric differences due to incomplete survey data are minimized in the final digital terrain model due to overall breadth of survey coverage - unlike what might be observed using range lines alone. The majority of range lines observed closely match in coverage (Figure 9).

Figure 7: Range line location and aerial photos depicting temporal survey accessibility.

Figure 8: Example of range-line extracted from TIN where pre and post-implementation survey location is accessible.

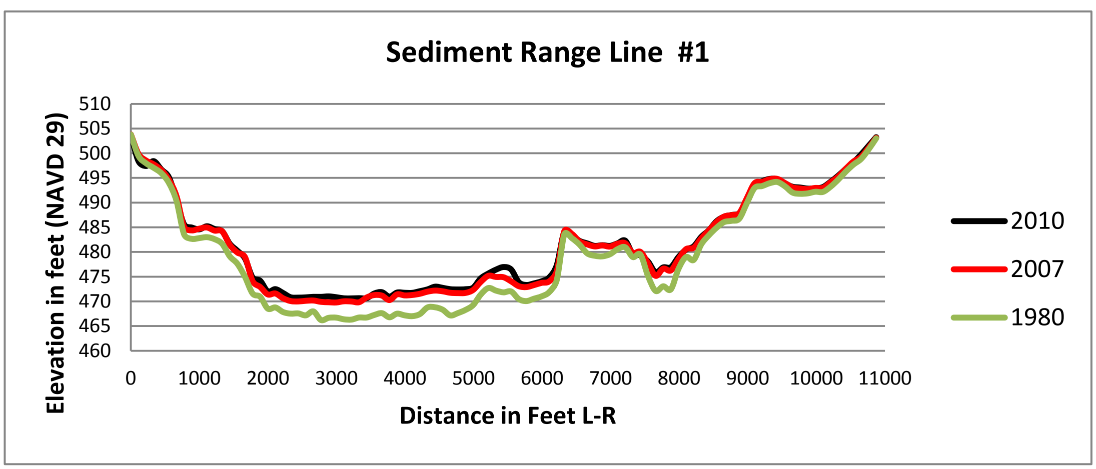
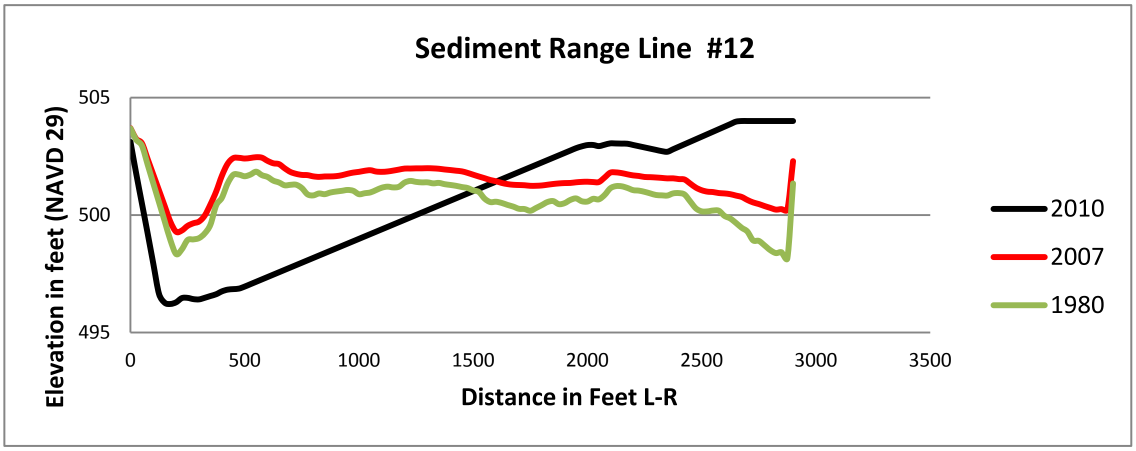


Figure 9: Example of range-line extracted from TIN illustrating change in channel morphology and inaccessibility of survey area.



4. RESULTS

The conservation implementation survey period took place between January 11th -12th, and 24th-26th 2007. During this time, bathymetric (volumetric capacity) reservoir data, as well as acoustic profiling data was collected. The post-conservation implementation bathymetric survey took place June 23-25th 2010. Once filtered, over 900,000 data points were used during the course of this research.

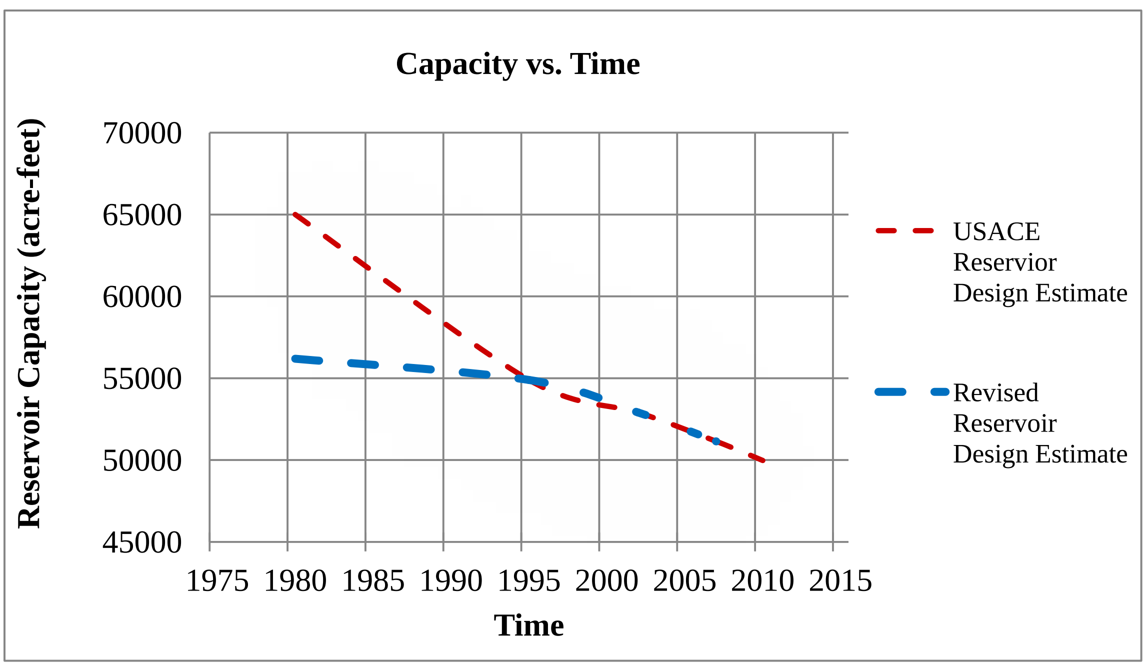
4.1 Assessment of Pre-impoundment Capacity

A baseline estimate for pre-impoundment (pre-1980) water storage capacity was assessed using low frequency sediment profiling data to create a pre-impoundment digital terrain model using ArcGIS. Analysis of low-frequency acoustic profiling data provided a cumulative post-impoundment (1980-2010), and 2010 volumetric data provided a total sediment deposition value of 6,218 acre-feet. Granger Lake reservoir was assessed to have originally impounded 56,189 acre-feet of water. As confirmed by sediment profiling data, initial reservoir capacity estimate of 65,510 acre feet provided by the U.S. Army Corps of Engineers, appears to have been overstated. This equates to 9,321 acre-feet of water storage previously thought available to water resource planners. From a watershed perspective, the previously assumed 19.2% loss in storage (1980-2002) due to erosion and soil loss has been overstated by 13.4%. Our assessment reveals an 11.1% capacity reduction over 30 years (1980-2010).

A mean sediment thickness of .78 feet was observed with heavier deposits (approaching 5.5 feet) primarily in the area of western and southwestern fork convergence. Sediment accumulation appears to be concentrated in the reservoir's western fork (appendix D). Baring significant in-lake currents or re-circulation/re-suspension of sediments, this concentration of deposits may indicate long term deposition and sediment origin within the Willis Creek drainage. Although the notion of an active depositional zone driven by Willis Creek and its supplying watershed is evidenced by chronological comparison of bathymetric surfaces, this idea is speculative and identifying areas of "active" deposition was not within the scope of this research.

4.2 Revised Post-Impoundment Sedimentation Trend

Figure 10: Revised trend in post-impoundment reservoir sedimentation.



In August 2008 TWDB conducted a routine volumetric survey to assess reservoir capacity at CPE. Supplemental to their standard volumetric survey techniques, and included at the request of the Brazos River Authority, was a separate sedimentation study for assessing water intake relocation feasibility. Pre-impoundment capacity, cumulative post-impoundment sediment volume, and volumetric capacity were reported. TWDB's 2008 volumetric survey was useful in validating revisions to pre-impoundment capacity and re-evaluate annual reservoir capacity loss (Figure 10). Adjustment in pre-impoundment (year-1) capacity, existing data provided by TWDB surveys in 1995 and 2002, and our supplemental data provided by survey years 2007 and 2010 result in and adjusted annual sedimentation average of 208 acre-feet per year.

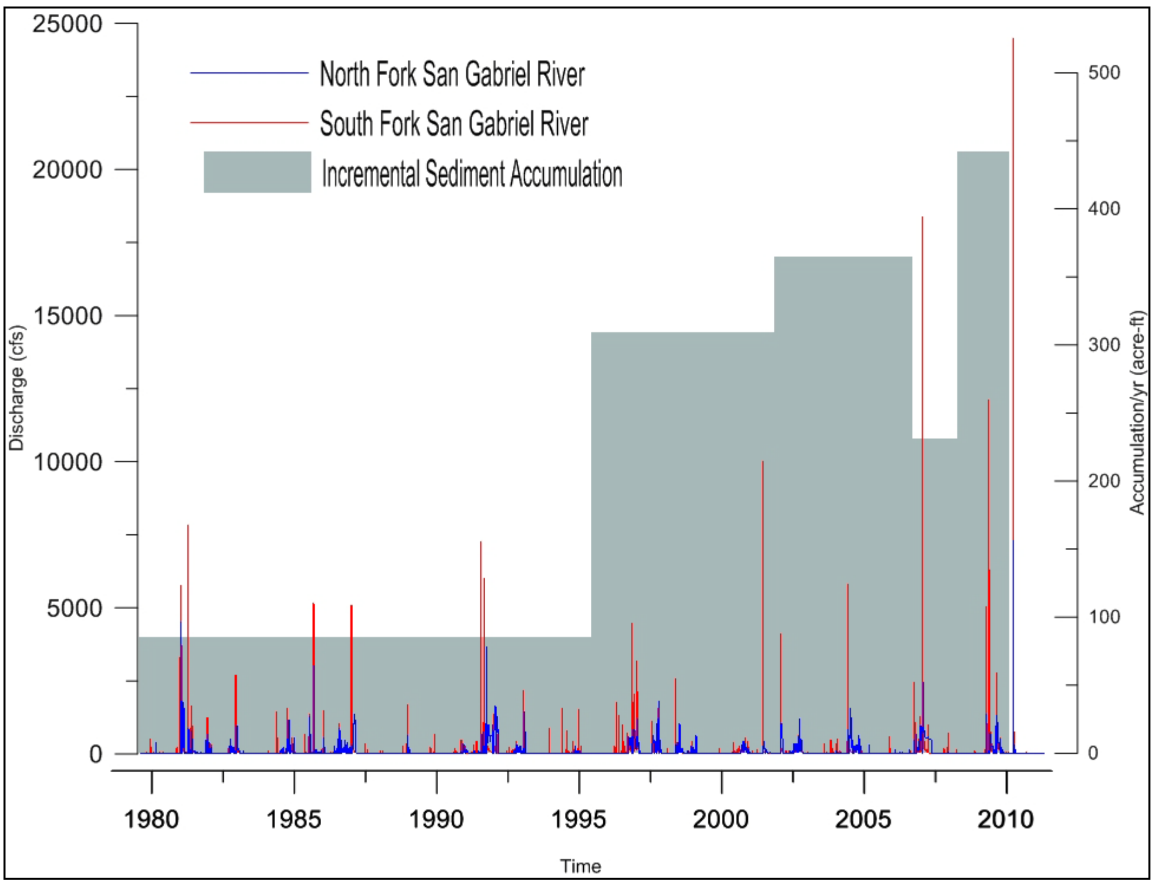
4.3 Watershed Conservation Effect on Reservoir Sedimentation

Analysis indicated pre-implementation (2007) conservation pool storage of 51,144 acre-feet. In 2010, in anticipation Granger Lake Watershed Implementation Project's end, a final hydro-acoustic survey provided a post-project benchmark for comparison. Granger Lake's 2010 conservation pool water storage capacity was 49,971 acre-feet.

During the course of the Granger Lake Watershed Implementation project, as represented by hydro-acoustic data, Granger Lake lost 1173 acre-feet in capacity or 2.3% of its available capacity at CPE. Between February 2007 and July 2010, Granger Lake lost an average of 343 acre feet of water storage per year.

By supplementing the pre and post-conservation implementation period surveys with intermediate TWDB (2008) volumetric data, we further resolve the flux in sediment delivery (Figure 11). However, occasionally high discharge from the contributing watershed may dilute any measureable effect of conservation implementation over the short term.

Figure 11: Incremental changes in conservation implementation period sediment accumulation (refined) with TWDB 2008 survey data.



5. SUMMARY AND CONCLUSIONS

5.1 Summary

Granger Lake's USACE estimated capacity appears to be overstated. This error in year-one capacity has been perpetuated in subsequent reservoir capacity loss estimates, thus misleading water and watershed resource managers to assume an accelerated reservoir sedimentation rate since the reservoir's impoundment.

After adjusting Granger Lake's pre-impoundment capacity, trajectory of sedimentation appears less acute. Without this adjustment, resource managers and policy-makers would falsely conclude a 23.7% reduction in reservoir capacity over thirty years when in reality, Granger Lake has experienced 11.1% capacity loss. With this single adjustment (correction of pre-impoundment capacity), a mid-1990's acceleration of reservoir sedimentation becomes evident. Albeit unsubstantiated, this acceleration in capacity loss may coincide with the mid-1990s development boom occurring in Round Rock and Georgetown, Texas - in the IH-35 corridor/San Gabriel Watershed; certainly this hydrologic change is evidenced by South Fork San Gabriel River daily discharge data.

Granger Lake lost approximately 2.3% of its available capacity during the conservation implementation period (2007 – 2010). Results indicate a slight reservoir sedimentation decrease compared to 1995-2007 estimates. It is reasonable to suggest this is a consequence of climate variability, specifically the frequency of high intensity rainfall events. Conservation implementation is not plainly responsible for the decrease in sediment delivery, and in fact may be undetectable for the foreseeable future, given the brevity of response time prior to assessment and limited scope of conservation program participation (i.e., watershed area enrolled vs. total watershed acreage). The spatially and temporally dynamic nature of this watershed system and “noise” of system variables may require a longer assessment period or perhaps a more insolated assessment area.

5.2 Conclusions

This research illustrates the value of examining previously established reservoir sedimentation estimates and assumptions of reservoir life based on design capacity estimates and routine volumetric surveys. Pre-impoundment capacity was found to be significantly less than that stated by U.S. Army Corps of Engineers. Revised pre-impoundment capacity (1980-2008) assessed in 2007 differ by only 36 acre feet (0.6%) from a separate study conducted by Texas Water Development Board engineers (TWDB 2009). These comparable findings illustrate the high degree of repeatability using similar methodology.

Overall, the study provided a highly resolute and comparable snapshot of reservoir sedimentation, augmenting historic datasets with current volumetric and sediment profiling data. The data may be used as a tool to further direct watershed and resource conservation strategies.

Key to conserving this water resource and mitigating increased sedimentation lies in further assessment and mining of existing data. For example:

Overlay of available discharge data from the North and South Forks of the San Gabriel River may suggest some correlation between accelerated reservoir sedimentation associated and high intensity rainfall events. Source of these high-flow events may be strongly linked to land use / land cover change occurring around the mid-watershed IH-35 corridor. This area is rapidly growing and may be impacting the hydrological regime. An area of particular interest is that contributing to the South San Gabriel River, as the North San Gabriel River Watershed contribution is regulated by Lake Georgetown discharge.

Digital terrain models representing temporally discrete volumetric survey periods may hold the key to identifying areas of active sedimentation within Granger Lake, and their hydraulically linked and erosion prone upland counterparts. Time-lapse comparison of Granger Lake 2002, 2007, and 2010 bathymetry reveals active deposition zones. Zonal isolation and assessment of active deposition areas and their contributing sub-catchments may help researchers more accurately quantify targeted conservation effects.

Insights from this research highlight the importance of validating historic reservoir survey data and significance regarding its use as a direct measurement technique - for quantifying historic and future conservation effects, or other reservoir sustaining strategies. It can be a useful indicator of watershed erosion or other perturbation within the surrounding landscape. With population and statewide water use increasing, water shortages are a real possibility in places where storage capacities are significantly less than what is assumed from the original or previous surveys (Furnans and Austin 2008). Proper management of existing surface-water storage capacity as well as prediction of future water supplies requires knowledge of the rates of reservoir volume loss. Current and best available sediment/storage information for reservoirs is crucial for their continued operation and management.

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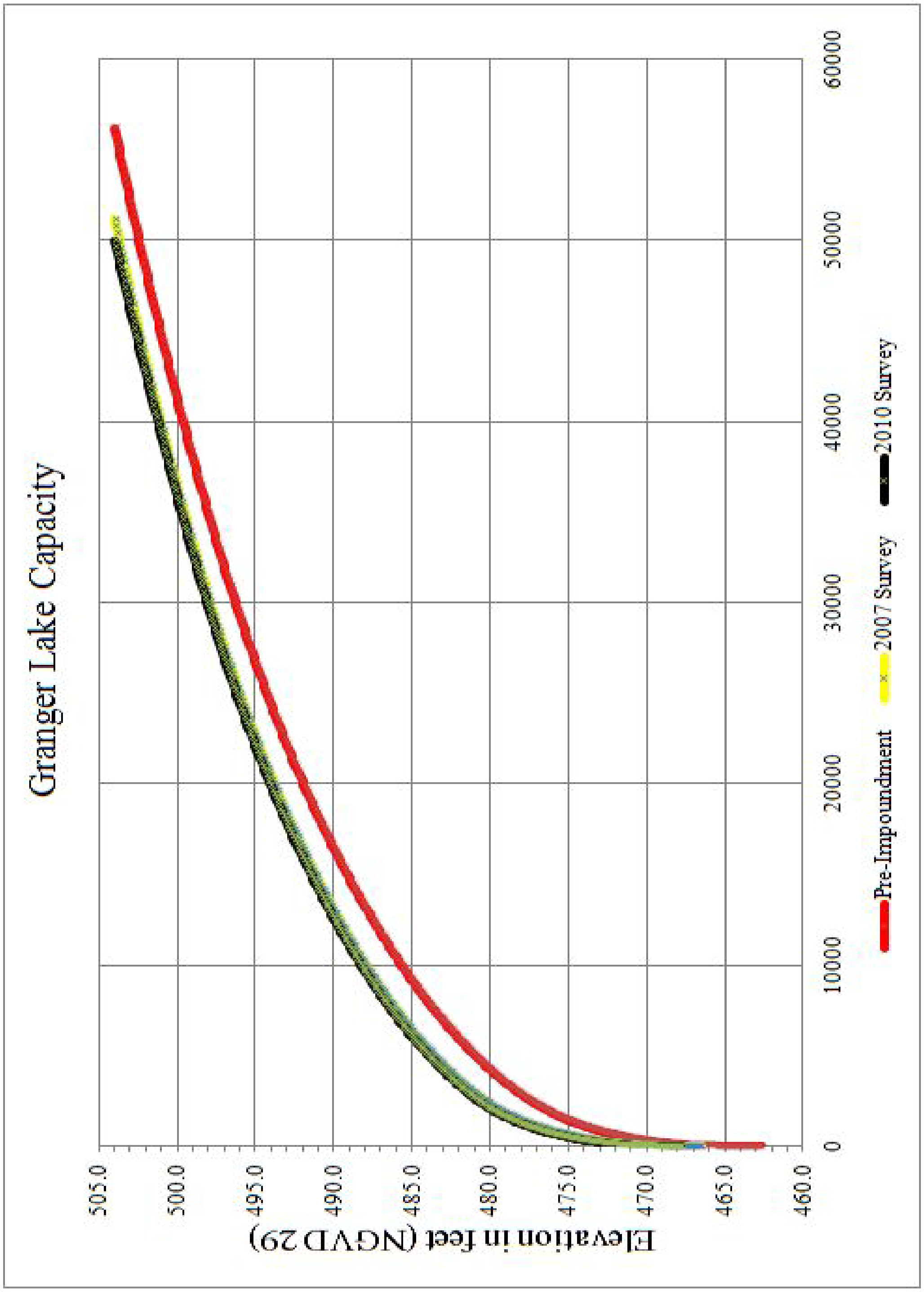
APPENDIX A


Granger Lake Capacity
Elevation in feet (NGVD 29)
505.0
500.0
495.0
490.0
485.0
480.0
475.0
470.0
465.0
460.0
0
10000
20000
30000
40000
50000
60000
Pre-Impoundment
2007 Survey
2010 Survey

Granger Lake
PRE-IMPOUNDMENT RESERVOIR AREA TABLE
Area in acres by tenth foot elevation increments
Determined by Low-Frequency Acoustic Profiling

Elevation	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
504										4074.4
503	4058.0	4042.9	4028.1	4013.5	3998.9	3984.2	3969.6	3955.0	3940.2	3925.1
502	3910.0	3894.5	3878.5	3862.2	3845.8	3829.6	3813.3	3796.3	3779.0	3762.3
501	3745.3	3727.4	3708.5	3688.6	3667.7	3645.9	3622.9	3600.9	3579.8	3557.0
500	3534.5	3512.6	3491.6	3470.5	3449.3	3429.0	3408.8	3389.6	3370.2	3351.3
499	3332.6	3313.9	3295.0	3276.2	3257.6	3239.2	3221.7	3204.9	3187.7	3170.2
498	3152.3	3133.7	3116.1	3098.1	3080.5	3063.2	3046.3	3028.5	3011.0	2993.5
497	2976.4	2959.9	2942.8	2925.7	2909.0	2892.5	2876.0	2859.4	2842.6	2825.9
496	2808.9	2791.7	2774.2	2756.2	2737.9	2719.0	2700.4	2681.7	2662.6	2643.2
495	2623.7	2603.7	2583.5	2563.9	2545.2	2526.5	2507.8	2488.9	2469.6	2449.5
494	2430.2	2411.5	2393.4	2375.5	2358.0	2340.8	2323.8	2306.7	2290.3	2274.3
493	2257.9	2241.2	2225.4	2210.3	2195.1	2179.8	2164.8	2150.1	2135.7	2121.3
492	2106.9	2092.4	2077.8	2062.8	2047.8	2032.8	2018.3	2004.1	1989.9	1975.6
491	1961.2	1946.7	1932.4	1918.2	1903.9	1889.3	1874.8	1860.1	1845.8	1832.1
490	1818.6	1805.7	1793.0	1780.6	1768.6	1756.8	1744.7	1733.5	1722.7	1712.0
489	1701.7	1691.6	1681.6	1671.5	1661.3	1650.7	1640.1	1629.5	1619.0	1608.6
488	1598.2	1587.6	1576.5	1565.3	1554.3	1542.9	1531.6	1520.9	1510.1	1499.5
487	1489.2	1478.7	1468.4	1458.5	1448.6	1438.8	1428.9	1419.0	1409.2	1399.7
486	1390.0	1380.5	1371.2	1362.0	1352.6	1343.3	1334.0	1324.4	1314.8	1305.5
485	1296.3	1286.7	1277.4	1268.2	1259.2	1250.1	1241.1	1231.5	1221.7	1212.0
484	1202.6	1193.3	1184.2	1175.3	1166.1	1156.6	1147.6	1138.5	1129.4	1120.1
483	1110.5	1100.3	1090.1	1080.2	1071.0	1061.9	1052.2	1042.9	1033.7	1024.4
482	1015.0	1005.8	996.9	988.3	980.0	971.7	963.4	955.4	947.5	939.6
481	931.4	922.9	914.7	906.6	898.4	890.2	882.0	873.7	865.5	857.3
480	849.1	841.1	833.2	825.3	817.5	809.6	801.7	793.5	784.8	775.9
479	767.0	758.3	749.7	741.3	732.7	723.6	714.4	705.3	696.3	687.5
478	678.8	670.3	661.4	652.3	643.7	635.3	627.0	618.9	610.9	602.6
477	593.7	584.6	575.6	567.2	558.5	549.3	540.3	531.3	522.1	513.2
476	504.5	495.7	486.8	477.6	467.5	457.5	447.6	438.8	430.4	422.5
475	414.7	407.1	399.6	392.2	385.1	378.4	372.0	366.0	360.0	354.0
474	347.8	341.4	335.0	328.7	322.4	316.1	309.3	302.5	296.5	290.7
473	285.2	279.9	274.7	269.9	265.1	260.2	255.5	250.8	246.1	241.4
472	236.8	232.1	227.6	223.1	218.6	214.2	209.6	205.2	201.1	196.9
471	192.7	188.0	183.3	179.5	176.0	172.6	169.1	165.7	162.3	158.9
470	155.7	152.6	149.7	146.9	144.1	141.4	138.6	135.8	133.0	130.1
469	127.1	124.2	121.6	119.1	116.5	113.8	111.1	108.4	105.9	103.3
468	100.8	98.2	95.7	93.1	90.0	86.6	83.5	80.7	77.9	75.3
467	72.5	69.2	65.7	62.3	58.8	55.3	52.2	48.9	45.4	41.8
466	38.2	34.4	30.6	27.5	24.4	21.5	18.9	16.3	13.9	12.0
465	10.1	8.2	6.2	4.5	3.1	2.4	1.9	1.6	1.4	1.3
464	1.2	1.1	1.0	0.9	0.8	0.8	0.7	0.6	0.5	0.4
463	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
462	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
461	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Granger Lake
PRE-IMPOUNDMENT RESERVOIR CAPACITY TABLE
Capacity in acre-feet by tenth foot elevation increments
Determined by Low-Frequency Acoustic Profiling

Elevation	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
504										56,189
503	55,782	55,377	54,973	54,571	54,171	53,772	53,374	52,978	52,583	52,190
502	51,798	51,408	51,019	50,632	50,247	49,863	49,481	49,100	48,721	48,344
501	47,969	47,595	47,224	46,854	46,486	46,120	45,757	45,396	45,036	44,680
500	44,325	43,973	43,623	43,274	42,928	42,585	42,243	41,903	41,565	41,229
499	40,894	40,562	40,232	39,903	39,576	39,252	38,929	38,607	38,288	37,970
498	37,654	37,339	37,027	36,716	36,407	36,100	35,795	35,491	35,189	34,889
497	34,590	34,293	33,998	33,705	33,413	33,123	32,834	32,548	32,263	31,979
496	31,697	31,417	31,139	30,863	30,588	30,315	30,044	29,775	29,508	29,242
495	28,979	28,718	28,458	28,201	27,946	27,692	27,440	27,190	26,943	26,697
494	26,453	26,211	25,970	25,732	25,495	25,260	25,027	24,795	24,566	24,337
493	24,111	23,886	23,662	23,441	23,220	23,002	22,784	22,569	22,354	22,142
492	21,930	21,720	21,512	21,305	21,099	20,895	20,693	20,491	20,292	20,093
491	19,897	19,701	19,507	19,315	19,124	18,934	18,746	18,559	18,374	18,190
490	18,007	17,826	17,646	17,467	17,290	17,114	16,939	16,765	16,592	16,420
489	16,250	16,080	15,911	15,744	15,577	15,411	15,247	15,083	14,921	14,760
488	14,599	14,440	14,282	14,125	13,969	13,814	13,660	13,507	13,356	13,205
487	13,056	12,908	12,760	12,614	12,469	12,324	12,181	12,038	11,897	11,757
486	11,617	11,479	11,341	11,204	11,069	10,934	10,800	10,667	10,535	10,404
485	10,274	10,145	10,017	9,889	9,763	9,637	9,513	9,389	9,267	9,145
484	9,024	8,904	8,785	8,668	8,550	8,434	8,319	8,205	8,091	7,979
483	7,867	7,757	7,647	7,539	7,431	7,325	7,219	7,114	7,010	6,907
482	6,805	6,704	6,604	6,505	6,407	6,309	6,212	6,116	6,021	5,927
481	5,833	5,741	5,649	5,558	5,467	5,378	5,289	5,202	5,115	5,028
480	4,943	4,859	4,775	4,692	4,610	4,528	4,448	4,368	4,289	4,211
479	4,134	4,058	3,982	3,908	3,834	3,761	3,689	3,618	3,548	3,479
478	3,411	3,343	3,277	3,211	3,146	3,082	3,019	2,957	2,895	2,835
477	2,775	2,716	2,658	2,601	2,545	2,489	2,435	2,381	2,328	2,277
476	2,226	2,176	2,127	2,078	2,031	1,985	1,940	1,895	1,852	1,809
475	1,767	1,726	1,686	1,646	1,608	1,569	1,532	1,495	1,459	1,423
474	1,388	1,353	1,320	1,286	1,254	1,222	1,191	1,160	1,130	1,101
473	1,072	1,044	1,016	989	962	936	910	885	860	835
472	812	788	765	743	721	699	678	657	637	617
471	597	578	560	542	524	506	489	472	456	440
470	424	409	394	379	364	350	336	322	309	296
469	283	270	258	246	234	223	212	201	190	179
468	169	159	150	140	131	122	114	105	97	90
467	82	75	69	62	56	50	45	40	35	31
466	27	23	20	17	15	12	10	8	7	6
465	5	4	3	2	2	2	2	1	1	1
464	1	1	1	1	1	0	0	0	0	0
463	0	0	0	0	0	0	0	0	0	0
462	0	0	0	0	0	0	0	0	0	0
461	0	0	0	0	0	0	0	0	0	0

Granger Lake
2007 RESERVOIR AREA TABLE
Area in acres by tenth foot elevation increments
Determined by High-frequency Acoustics

Elevation	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
504										4074.78
503	4056.24	4039.03	4021.87	4004.75	3987.65	3970.46	3953.06	3935.55	3917.87	3899.56
502	3881.15	3862.36	3843.40	3823.90	3803.87	3783.36	3762.39	3740.48	3715.32	3689.97
501	3664.89	3639.65	3615.42	3592.06	3569.05	3545.51	3522.44	3500.55	3479.30	3457.33
500	3435.26	3414.35	3393.50	3372.43	3351.26	3330.22	3309.00	3287.97	3266.90	3247.29
499	3227.72	3208.35	3188.58	3168.76	3148.48	3127.09	3106.19	3086.30	3066.66	3047.49
498	3028.68	3010.28	2992.22	2974.16	2955.92	2936.76	2918.34	2899.76	2881.33	2863.26
497	2845.41	2827.62	2809.48	2790.85	2771.86	2751.65	2732.41	2713.95	2694.94	2675.54
496	2655.43	2633.25	2608.77	2587.19	2565.77	2544.09	2522.71	2501.97	2481.83	2461.98
495	2442.58	2423.49	2403.97	2383.90	2364.97	2346.09	2328.86	2311.97	2295.50	2279.41
494	2263.91	2248.77	2233.50	2216.94	2200.34	2183.25	2166.08	2149.03	2132.50	2116.63
493	2100.91	2086.21	2071.97	2058.33	2044.86	2031.45	2017.99	2004.38	1990.57	1976.61
492	1963.03	1949.45	1935.62	1921.38	1906.93	1892.42	1878.12	1864.28	1850.87	1837.49
491	1824.09	1810.82	1797.59	1784.61	1771.81	1759.35	1747.50	1735.80	1724.09	1712.57
490	1701.02	1689.30	1677.77	1666.24	1654.74	1643.50	1632.27	1620.87	1609.29	1598.03
489	1587.21	1576.25	1565.09	1553.68	1542.79	1532.29	1522.13	1511.83	1501.43	1490.59
488	1479.54	1468.83	1458.64	1448.38	1438.20	1428.13	1418.05	1407.74	1397.83	1388.15
487	1378.38	1368.37	1358.64	1348.93	1338.75	1328.02	1317.04	1305.98	1294.66	1283.31
486	1271.45	1259.57	1247.76	1235.81	1223.91	1211.90	1200.24	1188.82	1177.62	1166.49
485	1155.32	1144.25	1133.04	1121.38	1109.97	1099.01	1088.05	1076.48	1065.20	1053.77
484	1043.83	1034.37	1024.40	1014.16	1003.89	994.31	983.54	973.85	965.05	956.84
483	948.82	940.64	932.20	923.57	915.31	907.14	898.99	890.71	881.94	872.92
482	863.52	854.03	843.51	832.65	823.19	813.66	804.78	796.12	787.57	778.82
481	769.38	759.65	750.02	739.83	729.30	718.20	707.63	697.65	687.61	676.86
480	665.27	651.54	636.85	622.87	610.00	597.34	585.09	573.70	562.41	551.43
479	539.08	526.33	514.28	502.94	492.27	481.87	471.47	460.96	451.42	442.50
478	433.80	425.10	416.66	408.30	400.32	392.46	384.50	376.74	369.10	361.41
477	353.76	346.44	339.38	332.41	325.31	318.11	311.53	305.14	299.17	293.23
476	287.59	281.81	275.78	269.84	264.02	258.25	252.71	247.36	242.45	237.64
475	232.69	227.90	223.32	218.91	214.60	210.24	205.49	200.30	196.59	193.04
474	189.86	186.74	183.63	180.49	177.41	174.39	171.37	168.32	165.25	162.16
473	159.05	155.91	152.82	149.69	146.58	143.44	140.23	136.94	133.62	130.39
472	127.27	124.25	121.25	118.14	115.04	111.89	108.71	105.50	102.30	99.12
471	95.79	92.46	89.07	86.36	83.81	81.27	78.64	75.94	73.13	70.07
470	66.70	62.98	60.07	57.39	54.48	51.30	48.24	44.82	41.29	37.53
469	34.38	31.79	29.64	27.57	25.59	23.64	21.63	19.53	16.99	14.34
468	11.74	9.57	7.58	5.33	3.12	1.61	1.24	0.99	0.78	0.62
467	0.53	0.44	0.36	0.29	0.24	0.20	0.17	0.14	0.11	0.08
466	0.06	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
465	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Granger Lake
2007 RESERVOIR CAPACITY TABLE
Capacity in acre-feet by tenth foot elevation increments
Determined by High-frequency Acoustics

Elevation	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
504										51,144
503	50,737	50,332	49,929	49,528	49,128	48,731	48,334	47,940	47,547	47,156
502	46,767	46,380	45,995	45,611	45,230	44,851	44,473	44,098	43,725	43,355
501	42,987	42,622	42,260	41,899	41,541	41,185	40,832	40,481	40,132	39,785
500	39,440	39,098	38,757	38,419	38,083	37,749	37,417	37,087	36,759	36,434
499	36,110	35,788	35,468	35,150	34,835	34,521	34,209	33,899	33,592	33,286
498	32,982	32,680	32,380	32,082	31,785	31,491	31,198	30,907	30,618	30,331
497	30,045	29,762	29,480	29,200	28,922	28,646	28,371	28,099	27,829	27,560
496	27,294	27,029	26,767	26,507	26,250	25,994	25,741	25,490	25,240	24,993
495	24,748	24,505	24,263	24,024	23,786	23,551	23,317	23,085	22,855	22,626
494	22,399	22,173	21,949	21,727	21,506	21,286	21,069	20,853	20,639	20,427
493	20,216	20,006	19,799	19,592	19,387	19,183	18,981	18,780	18,580	18,381
492	18,184	17,989	17,795	17,602	17,410	17,220	17,032	16,845	16,659	16,474
491	16,291	16,110	15,929	15,750	15,572	15,396	15,220	15,046	14,873	14,701
490	14,531	14,361	14,193	14,026	13,860	13,695	13,531	13,368	13,207	13,046
489	12,887	12,729	12,572	12,416	12,261	12,107	11,955	11,803	11,652	11,503
488	11,354	11,207	11,060	10,915	10,771	10,627	10,485	10,344	10,204	10,064
487	9,926	9,789	9,652	9,517	9,382	9,249	9,117	8,986	8,856	8,727
486	8,599	8,473	8,347	8,223	8,100	7,978	7,858	7,738	7,620	7,503
485	7,386	7,272	7,158	7,045	6,933	6,823	6,714	6,605	6,498	6,392
484	6,287	6,184	6,081	5,979	5,878	5,778	5,679	5,581	5,484	5,388
483	5,293	5,198	5,105	5,012	4,920	4,829	4,738	4,649	4,560	4,473
482	4,386	4,300	4,215	4,131	4,048	3,967	3,886	3,806	3,726	3,648
481	3,571	3,494	3,419	3,344	3,271	3,198	3,127	3,057	2,988	2,919
480	2,852	2,786	2,722	2,659	2,597	2,537	2,478	2,420	2,363	2,307
479	2,253	2,200	2,148	2,097	2,047	1,998	1,951	1,904	1,858	1,814
478	1,770	1,727	1,685	1,644	1,603	1,564	1,525	1,487	1,449	1,413
477	1,377	1,342	1,308	1,274	1,241	1,209	1,178	1,147	1,117	1,087
476	1,058	1,029	1,002	974	948	922	896	871	846	822
475	799	776	753	731	710	688	668	647	627	608
474	589	570	551	533	515	498	480	464	447	430
473	414	399	383	368	353	339	325	311	297	284
472	271	259	246	234	223	211	200	190	179	169
471	159	150	141	132	124	115	107	100	92	85
470	78	72	66	60	54	49	44	39	35	31
469	27	24	21	18	15	13	11	9	7	5
468	4	3	2	1	1	1	1	0	0	0
467	0	0	0	0	0	0	0	0	0	0
466	0	0	0	0	0	0	0	0	0	0
465	0	0	0	0	0	0	0	0	0	0

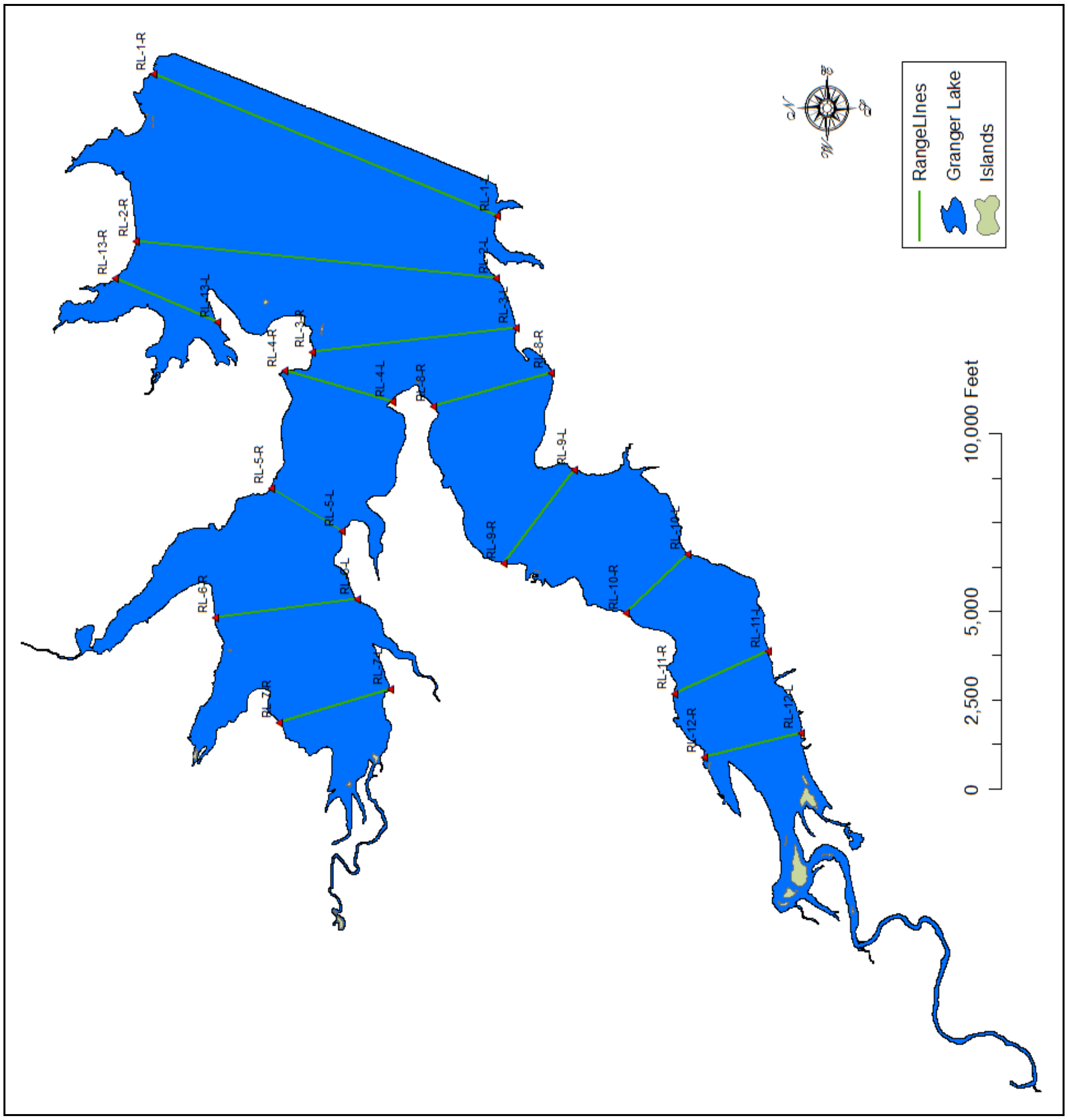
Granger Lake
2010 RESERVOIR AREA TABLE
Area in acres by tenth foot elevation increments
Determined by High-frequency Acoustics

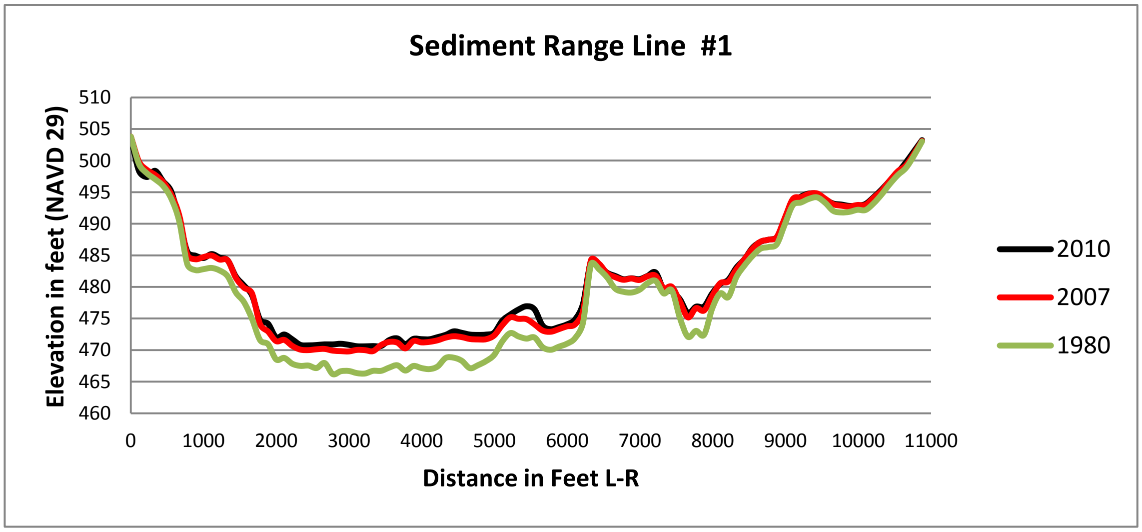
Elevation	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
504										3,820
503	3,805	3,791	3,777	3,763	3,748	3,734	3,720	3,706	3,691	3,677
502	3,663	3,649	3,635	3,621	3,607	3,592	3,578	3,564	3,550	3,536
501	3,522	3,508	3,494	3,480	3,466	3,452	3,438	3,425	3,411	3,397
500	3,383	3,369	3,355	3,341	3,328	3,314	3,300	3,282	3,266	3,249
499	3,232	3,214	3,197	3,180	3,163	3,146	3,128	3,106	3,084	3,064
498	3,044	3,024	3,003	2,982	2,962	2,942	2,923	2,904	2,884	2,865
497	2,845	2,825	2,806	2,785	2,762	2,739	2,718	2,697	2,676	2,654
496	2,633	2,613	2,593	2,574	2,554	2,533	2,512	2,491	2,469	2,449
495	2,429	2,409	2,389	2,369	2,350	2,331	2,312	2,294	2,277	2,260
494	2,243	2,226	2,209	2,191	2,174	2,157	2,141	2,126	2,110	2,096
493	2,082	2,068	2,054	2,040	2,026	2,012	1,998	1,984	1,969	1,955
492	1,941	1,927	1,914	1,900	1,886	1,873	1,860	1,847	1,834	1,821
491	1,808	1,795	1,781	1,768	1,755	1,742	1,730	1,718	1,706	1,694
490	1,682	1,670	1,658	1,647	1,635	1,624	1,613	1,603	1,592	1,580
489	1,568	1,556	1,543	1,531	1,519	1,508	1,497	1,487	1,477	1,467
488	1,457	1,446	1,436	1,426	1,416	1,406	1,396	1,386	1,376	1,366
487	1,356	1,344	1,333	1,321	1,310	1,298	1,287	1,275	1,263	1,251
486	1,240	1,228	1,217	1,206	1,195	1,183	1,172	1,160	1,149	1,138
485	1,127	1,116	1,105	1,095	1,084	1,073	1,062	1,050	1,039	1,029
484	1,019	1,009	1,000	992	983	973	963	955	947	940
483	932	924	917	909	901	893	883	873	863	853
482	844	834	825	816	807	798	789	780	770	761
481	751	740	728	716	704	692	681	669	656	643
480	631	617	603	591	579	567	555	543	530	517
479	504	492	481	471	461	451	441	432	424	415
478	407	398	391	383	375	368	360	353	346	339
477	331	324	315	307	300	293	286	280	273	267
476	261	255	249	243	238	232	227	221	216	211
475	207	202	198	194	191	188	185	182	178	175
474	172	169	166	163	159	156	153	150	146	143
473	140	136	133	130	126	123	120	116	113	110
472	107	104	101	98	95	92	88	85	82	80
471	77	74	71	68	65	62	59	56	53	49
470	46	42	38	35	33	31	29	26	25	23
469	20	17	14	12	9	7	4	2	1	1
468	1	1	0	0	0	0	0	0	0	0
467	0	0	0	0	0	0	0	0	0	0
466	0	0	0	0	0	0	0	0	0	0

Granger Lake
2010 RESERVOIR CAPACITY TABLE
Capacity in acre-feet by tenth foot elevation increments
Determined by High-frequency Acoustics

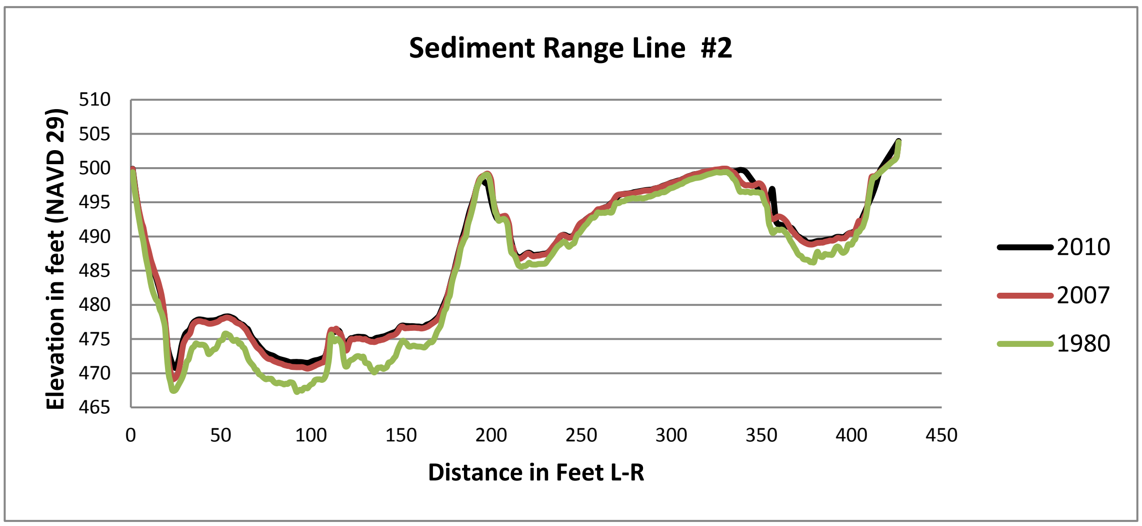
Elevation	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
504										49,971
503	49,590	49,210	48,832	48,455	48,079	47,705	47,332	46,961	46,591	46,223
502	45,856	45,490	45,126	44,763	44,402	44,042	43,683	43,326	42,970	42,616
501	42,263	41,912	41,562	41,213	40,866	40,520	40,175	39,832	39,490	39,150
500	38,811	38,473	38,137	37,802	37,469	37,137	36,806	36,477	36,149	35,824
499	35,500	35,177	34,857	34,538	34,221	33,905	33,592	33,280	32,970	32,663
498	32,358	32,054	31,753	31,454	31,156	30,861	30,568	30,277	29,987	29,700
497	29,414	29,131	28,849	28,570	28,292	28,017	27,744	27,474	27,205	26,939
496	26,674	26,412	26,152	25,893	25,637	25,382	25,130	24,880	24,632	24,386
495	24,142	23,900	23,661	23,423	23,187	22,953	22,720	22,490	22,262	22,035
494	21,810	21,586	21,364	21,144	20,926	20,710	20,495	20,281	20,070	19,859
493	19,650	19,443	19,237	19,032	18,829	18,627	18,426	18,227	18,030	17,833
492	17,639	17,445	17,253	17,062	16,873	16,685	16,498	16,313	16,129	15,946
491	15,765	15,585	15,406	15,229	15,052	14,878	14,704	14,532	14,361	14,191
490	14,022	13,854	13,688	13,523	13,358	13,195	13,034	12,873	12,713	12,554
489	12,397	12,241	12,086	11,932	11,780	11,628	11,478	11,329	11,181	11,033
488	10,887	10,742	10,598	10,455	10,313	10,172	10,032	9,893	9,754	9,617
487	9,481	9,346	9,212	9,080	8,948	8,818	8,688	8,560	8,434	8,308
486	8,183	8,060	7,938	7,816	7,696	7,578	7,460	7,343	7,228	7,113
485	7,000	6,888	6,777	6,667	6,558	6,450	6,343	6,238	6,133	6,030
484	5,927	5,826	5,726	5,626	5,527	5,430	5,333	5,237	5,142	5,047
483	4,954	4,861	4,769	4,678	4,587	4,498	4,409	4,321	4,234	4,148
482	4,064	3,980	3,897	3,815	3,734	3,653	3,574	3,496	3,418	3,342
481	3,266	3,191	3,118	3,046	2,975	2,905	2,836	2,769	2,703	2,638
480	2,574	2,511	2,450	2,391	2,332	2,275	2,219	2,164	2,110	2,058
479	2,007	1,957	1,909	1,861	1,814	1,769	1,724	1,681	1,638	1,596
478	1,555	1,514	1,475	1,436	1,398	1,361	1,325	1,289	1,254	1,220
477	1,186	1,154	1,122	1,091	1,060	1,031	1,002	974	946	919
476	892	867	842	817	793	769	746	724	702	681
475	660	639	619	600	581	562	543	525	507	489
474	472	455	438	422	405	390	374	359	344	330
473	316	302	289	275	263	250	238	226	215	204
472	193	182	172	162	152	143	134	125	117	109
471	101	93	86	79	73	66	60	54	49	44
470	39	35	31	27	24	21	18	15	12	10
469	8	6	4	3	2	1	1	1	0	0
468	0	0	0	0	0	0	0	0	0	0
467	0	0	0	0	0	0	0	0	0	0

APPENDIX B

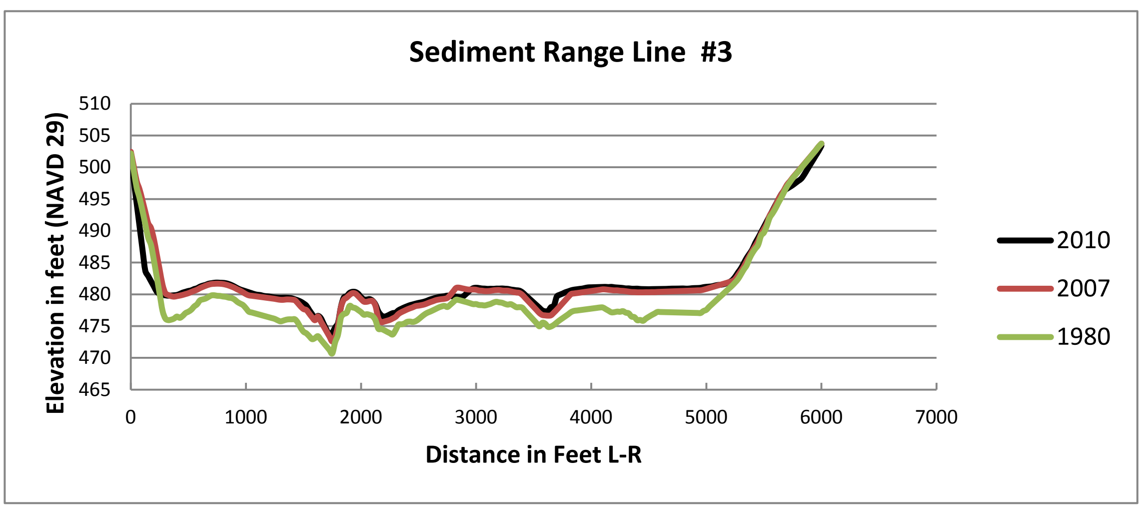

RL-1-R
RL-2-R
RL-13-R
RL-4-R
RL-4-L
RL-5-R
RL-5-L
RL-6-R
RL-9-R
RL-9-L
RL-10-R
RL-11-R
RL-11-L
RangeLines
Granger Lake
Islands
10,000 Feet
5,000
2,500
0



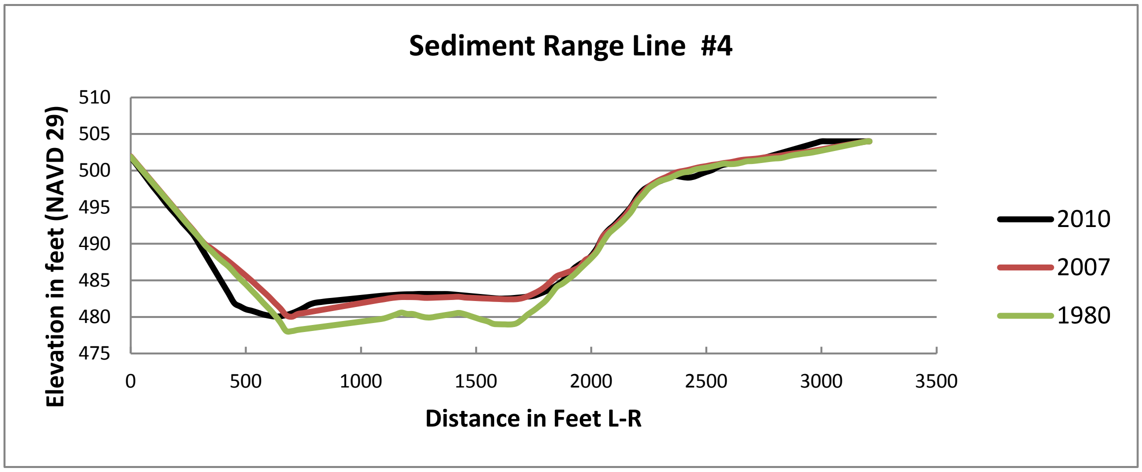
Sediment Range Line #1
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
470
465
460
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
Distance in Feet L-R
2010
2007
1980

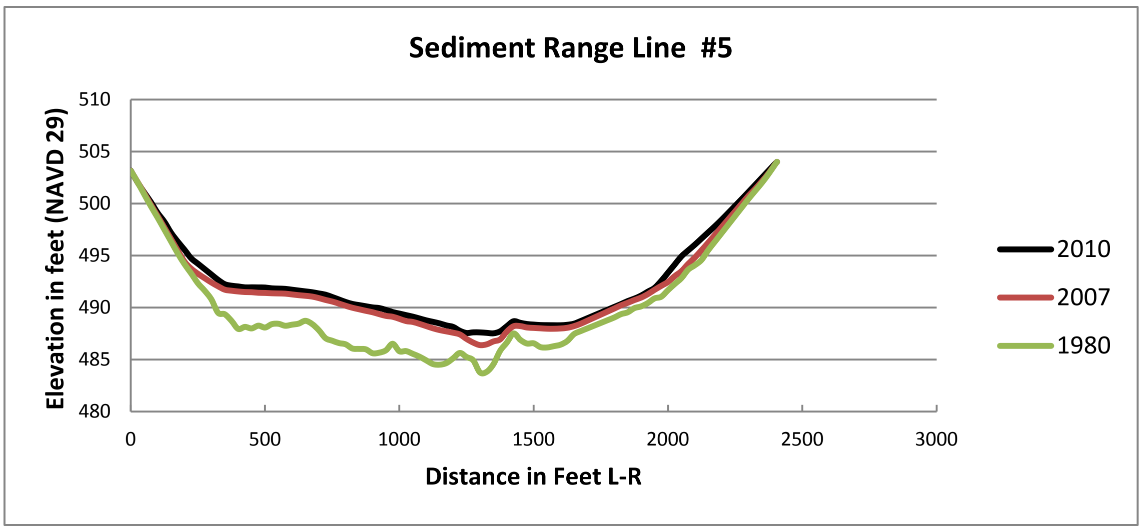


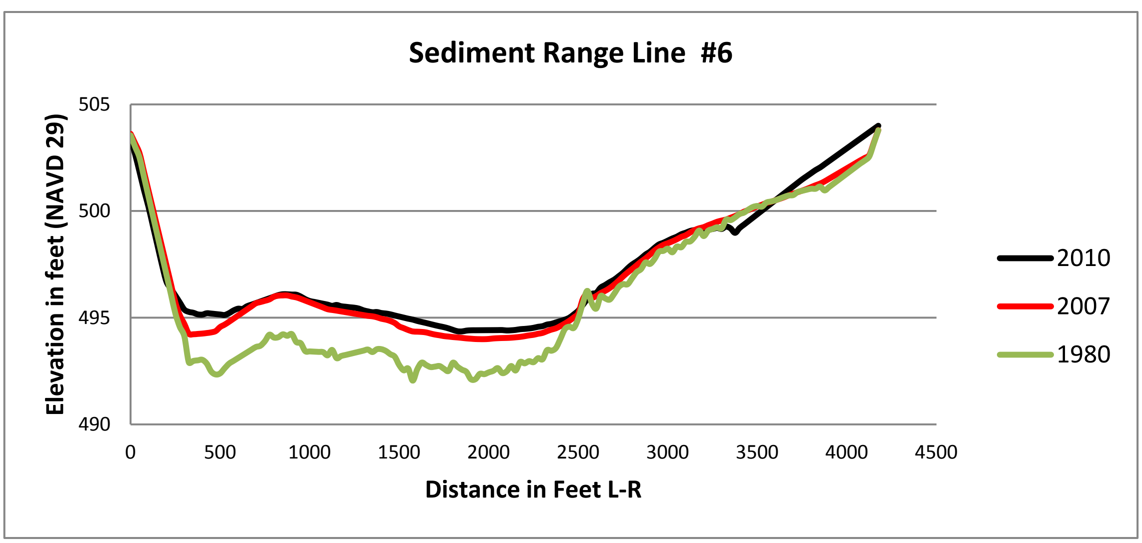
Sediment Range Line #2
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
470
465
0
50
100
150
200
250
300
350
400
450
Distance in Feet L-R
2010
2007
1980

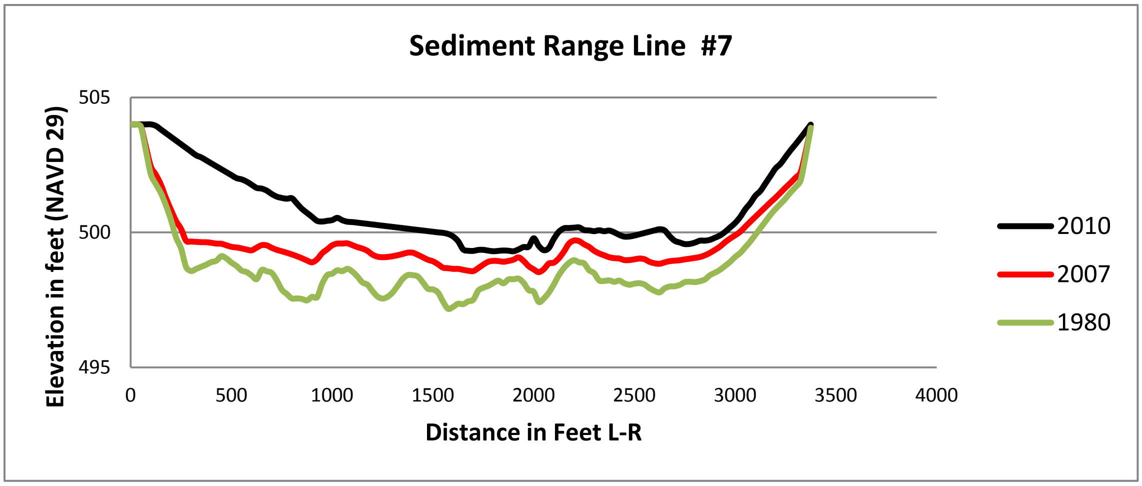


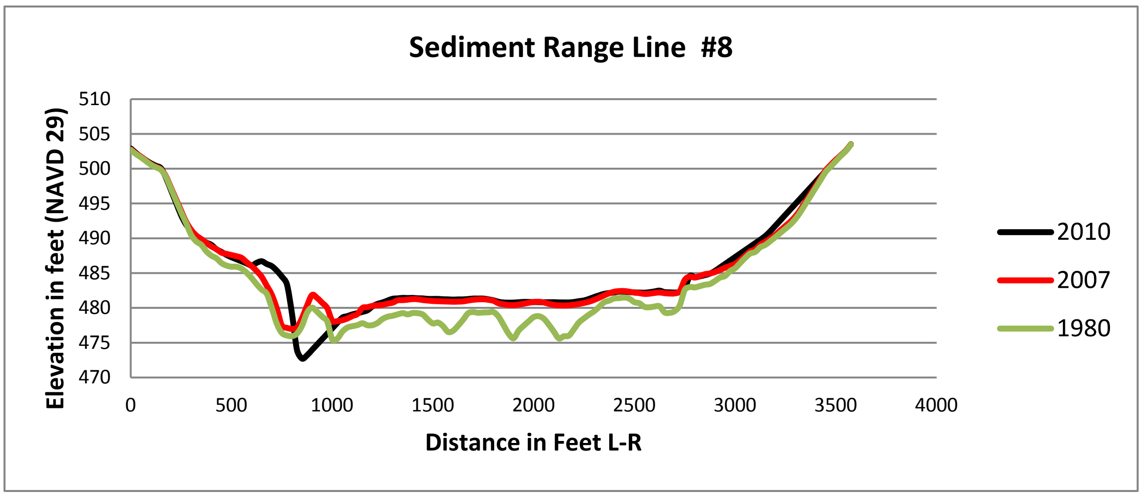
Sediment Range Line #3
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
470
465
0
1000
2000
3000
4000
5000
6000
7000
Distance in Feet L-R
2010
2007
1980

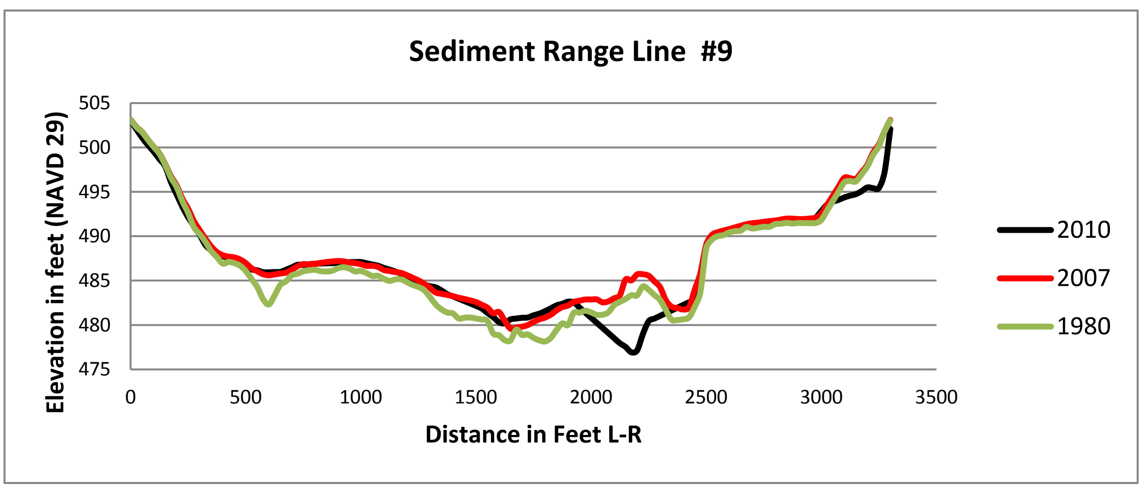

Sediment Range Line #4
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980

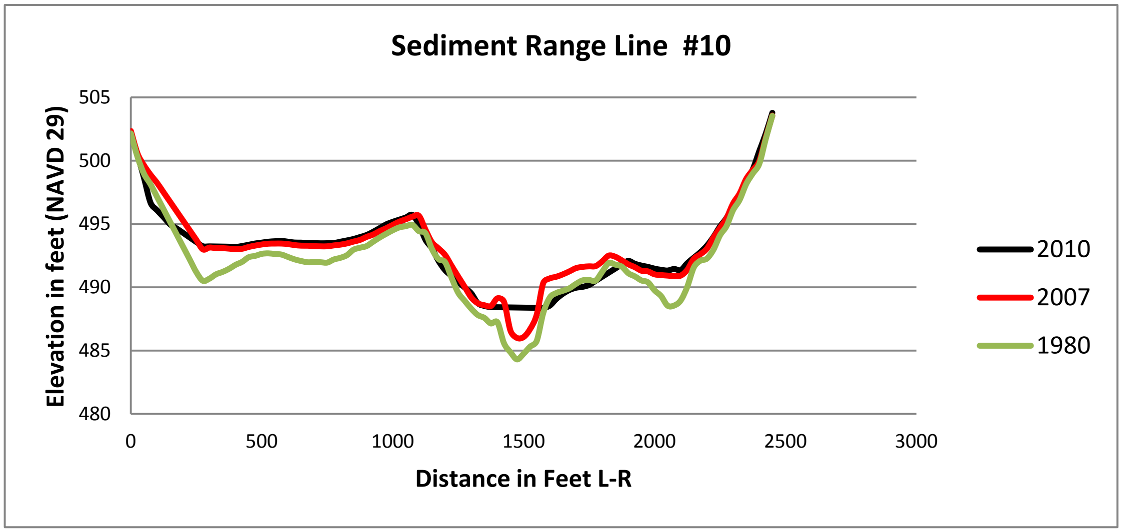

Sediment Range Line #5
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
0
500
1000
1500
2000
2500
3000
Distance in Feet L-R
2010
2007
1980

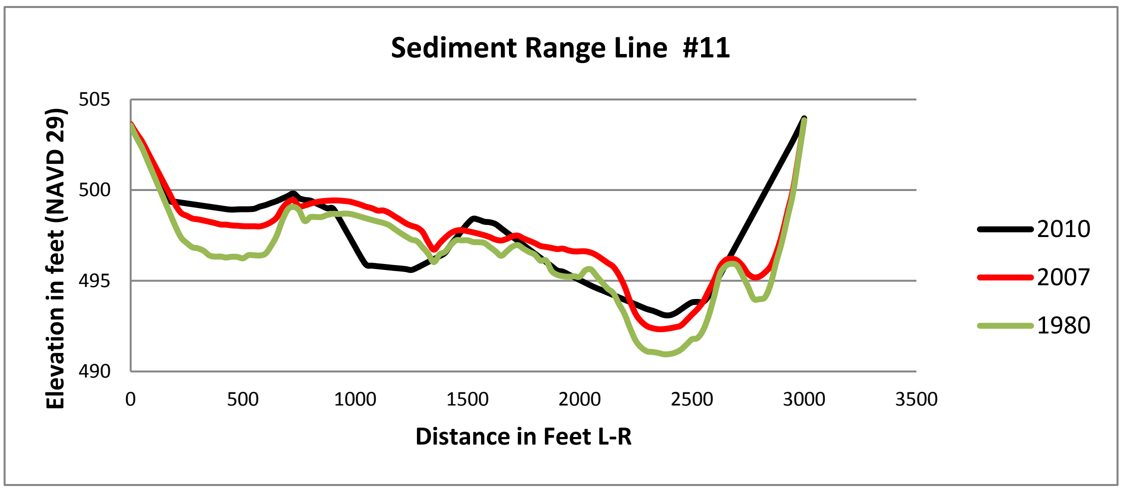

Sediment Range Line #6
Elevation in feet (NAVD 29)
505
500
495
490
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance in Feet L-R
2010
2007
1980

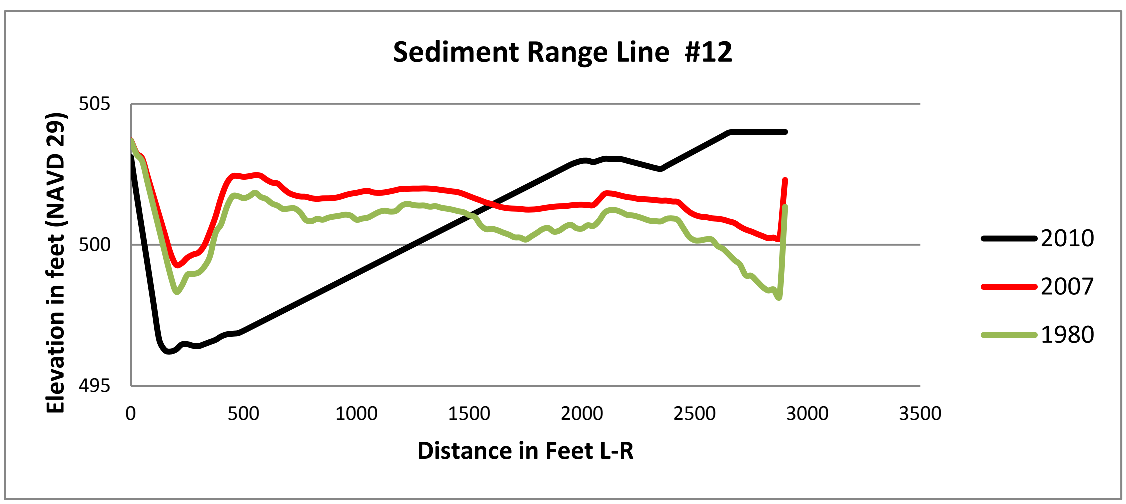

Sediment Range Line #7
Elevation in feet (NAVD 29)
505
500
495
0
500
1000
1500
2000
2500
3000
3500
4000
Distance in Feet L-R
2010
2007
1980

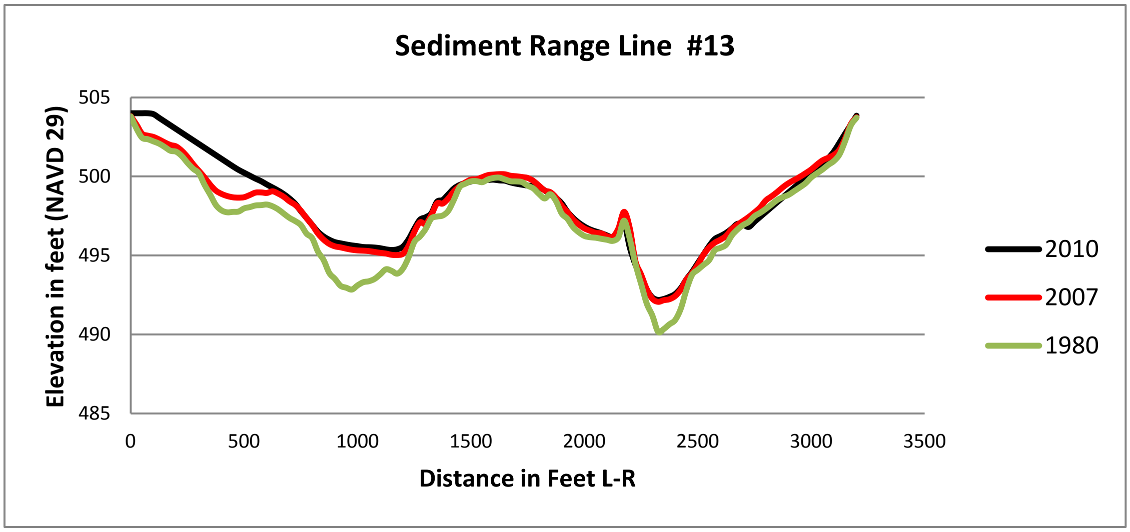

Sediment Range Line #8
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
470
0
500
1000
1500
2000
2500
3000
3500
4000
Distance in Feet L-R
2010
2007
1980


Sediment Range Line #9
Elevation in feet (NAVD 29)
505
500
495
490
485
480
475
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980

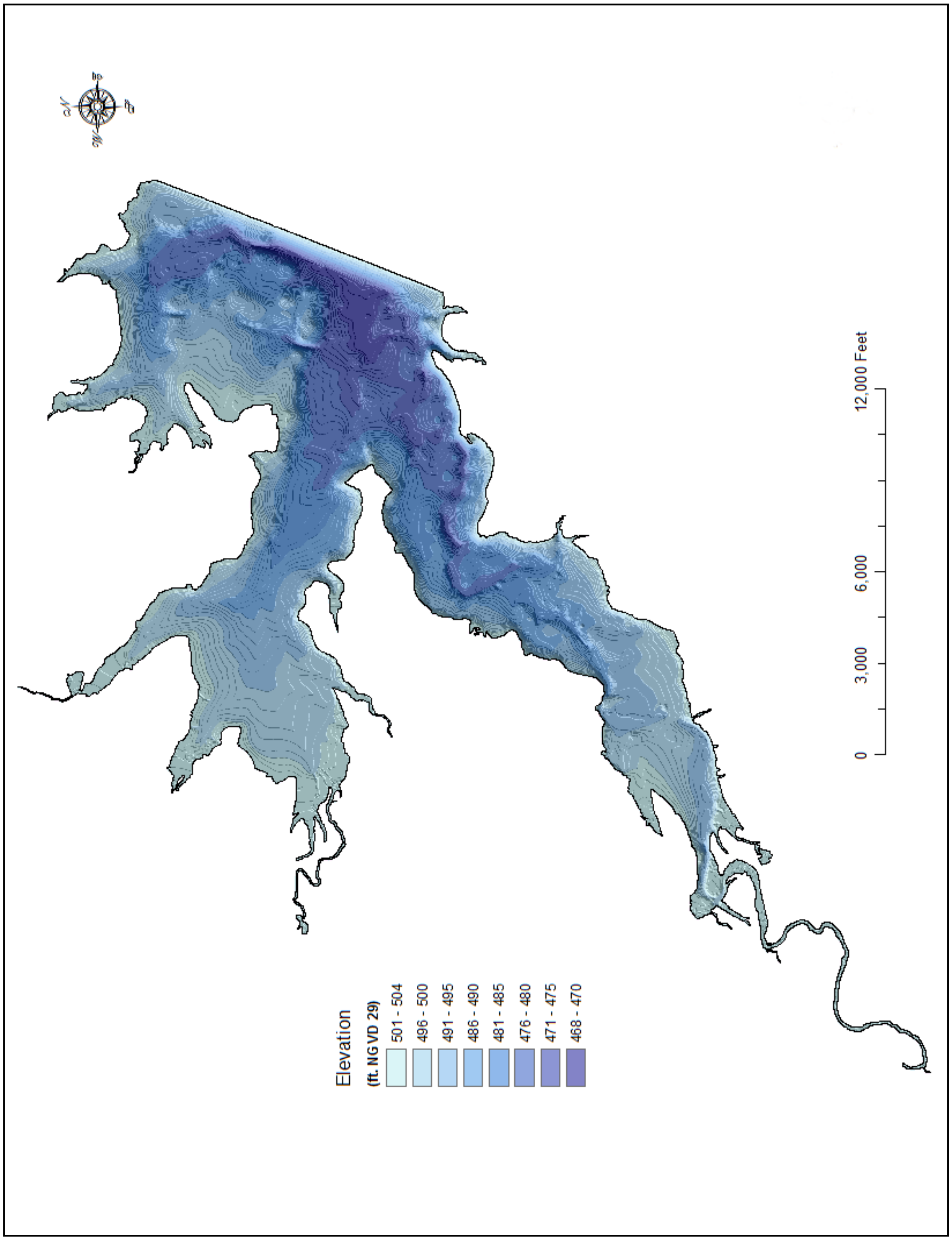

Sediment Range Line #10
Elevation in feet (NAVD 29)
505
500
495
490
485
480
0
500
1000
1500
2000
2500
3000
Distance in Feet L-R
2010
2007
1980


Sediment Range Line #11
Elevation in feet (NAVD 29)
505
500
495
490
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980

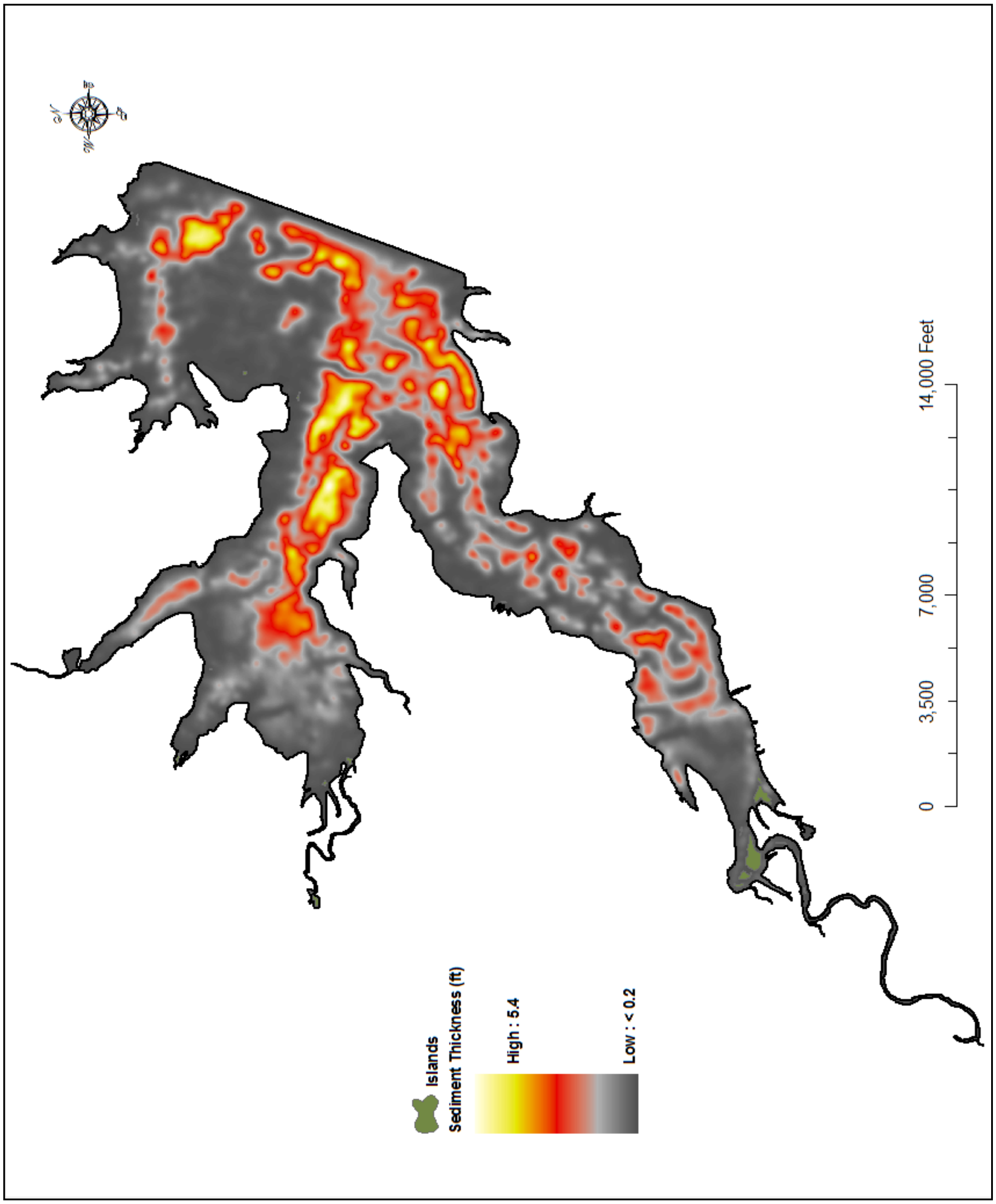

Sediment Range Line #12
Elevation in feet (NAVD 29)
505
500
495
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980


Sediment Range Line #13
Elevation in feet (NAVD 29)
505
500
495
490
485
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980

APPENDIX C


Elevation
(ft. NGVD 29)
501 - 504
496 - 500
491 - 495
486 - 490
481 - 485
476 - 480
471 - 475
468 - 470
0
3,000
6,000
12,000 Feet

APPENDIX D


Islands
Sediment Thickness (ft)
High : 5.4
Low : < 0.2
0
3,500
7,000
14,000 Feet

VITA

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Email Address:	jmcalister@brc.tamus.edu

Education:	B.S., Resource and Environmental Studies, Texas State University, 2001 M.S., Rangeland Ecology and Management, Texas A&M University, December 2011
Professional:	Research Assistant, Blackland Research and Extension Center – Texas AgriLife Research, Temple, Texas 2003 – Present Planner II, Texas State Soil and Water Conservation Board 2001--2003

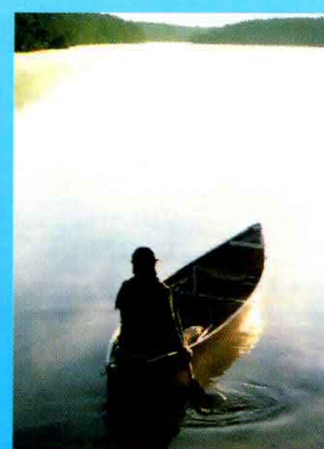
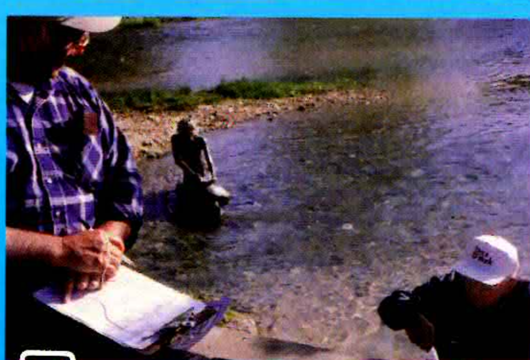
Appendix B

1999 NRCS Lake Granger Sediment Study

LAKE GRANGER

SEDIMENT STUDY



Brazos River Authority

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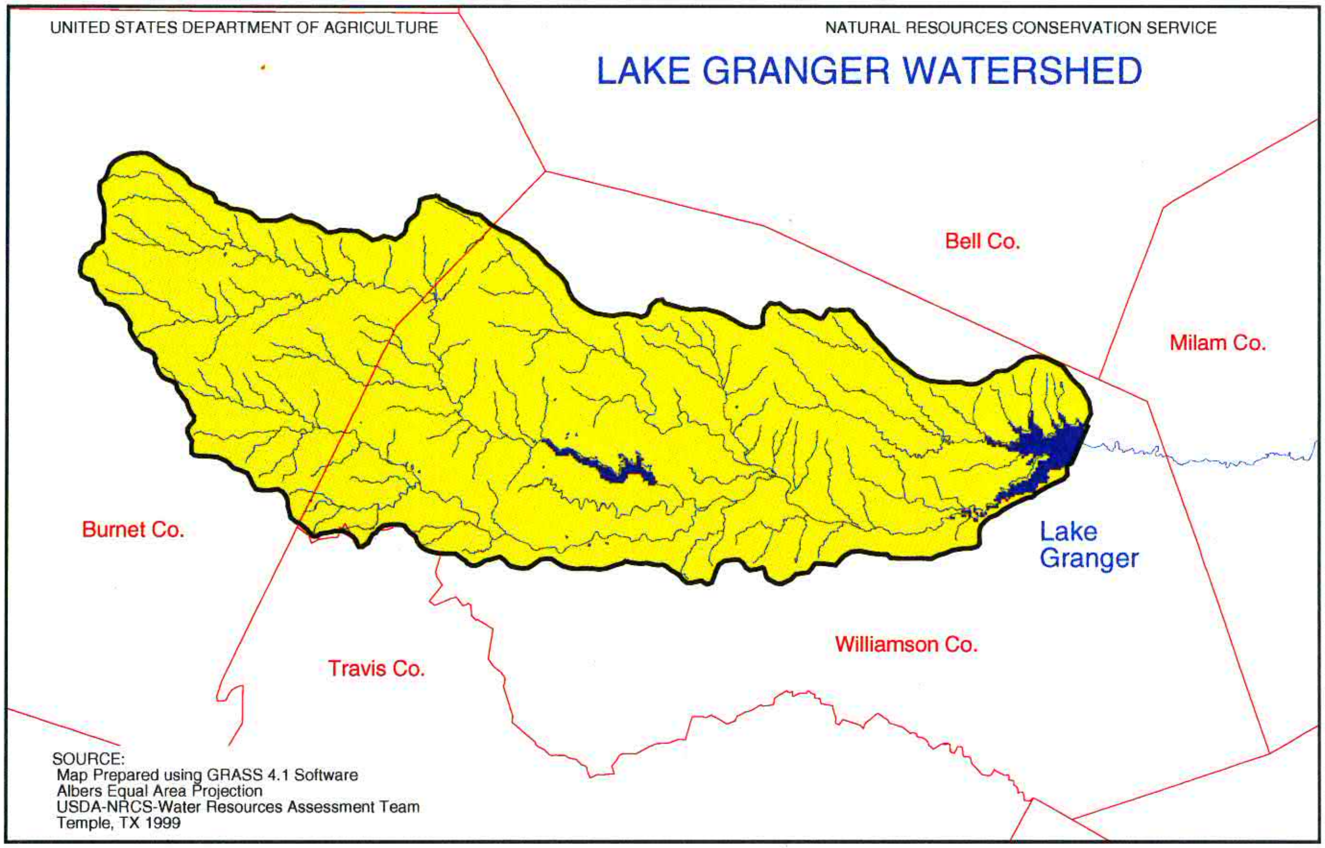


LAKE GRANGER SEDIMENT STUDY

USDA-Natural Resources Conservation Service
Water Resources Assessment Team
808 E. Blackland Road
Temple, TX 76502

May 13, 1999

ASSESSMENT OF FLOW & SEDIMENT LOADINGS AND BMP ANALYSES FOR LAKE GRANGER

USDA - Natural Resources Conservation Service

May 13, 1999

Prepared in Cooperation with the
Brazos River Authority

WATER RESOURCES ASSESSMENT TEAM
BLACKLAND RESEARCH CENTER
808 EAST BLACKLAND ROAD
TEMPLE, TEXAS 76502

EXECUTIVE SUMMARY

A Plan of Work was developed in September 1998 for the use of the Soil and Water Assessment Tool (SWAT) basin model to assess flow and sediment loads to Lake Granger Watershed and effects of various best management practices to those sediment loads. Water storage in this reservoir is experiencing a drastic decline due to sediment accumulation according to data collected by the Texas Water Development Board. This coupled with the rapid population growth of Williamson County is a cause of concern for Brazos River Authority (BRA). The Texas Natural Resources Conservation Service (NRCS) Water Resources Assessment Team developed a cooperative agreement between NRCS and BRA to carry out the work. GIS (Geographic Information System) data layers needed to drive the model were available with minimal processing. Cooperative agreements between NRCS, USDA-Agricultural Research Service (ARS), and Texas Agricultural Experiment Station (TAES) already existed to allow consultation and cooperation of a team comprised of individuals from the three agencies along with BRA staff to carry out the Plan of Work developed for the project.

The SWAT computer process model was developed by USDA-ARS to predict the effect of management on water, sediment, and nutrient yields on large river basins. TAES has interfaced SWAT with a GIS to provide general model input values. SWAT operates in the UNIX operating system and with the U.S. Army Corps of Engineers GRASS (Geographical Resources Analysis Support System) GIS.

SWAT was calibrated to USGS (Unites States Geological Survey) stream flow gauge records within the watershed. Comparisons of predicted sediment loadings were made to measured sediment accumulation in the reservoir.

Several scenarios or best management practices were included in SWAT alternative runs to determine what, if anything, can reduce sediment loads into the reservoir. One alternative, while maybe not practical, was used to determine sediment loads from cropland areas as compared to vegetating all those areas into permanent grass cover. Other scenarios included installation of floodwater retarding type structures with 100-year sediment storage included that will result in reduced sediment loads to the larger reservoir. Results of the alternative runs are detailed in the report.

Modeling results indicate good potential for reducing sediment load to Lake Granger. The combination of conversion of highly eroded cropland to grassland and installation of conservation practices such as terraces has potential to reduce sediment loads around 20%. A major obstacle to implementation of these BMPs is the fact that the watershed is not currently included in a priority area of the 1999 EQIP (Environmental Quality Incentives Program) funding program. Support to include this watershed in an EQIP priority area is essential to reduction of sediment loads to Lake Granger. Only about 7% reduction is projected from installation of sediment retention dams so it is unlikely they would have a favorable benefit/cost ratio in this watershed.

Modeling the different time periods does reveal that any long-term projections of sediment accumulation in the Granger reservoir based on its present lifespan may be quite high. The average annual sediment load based on the 16-year historical period is 38% higher than if the same conditions are based on a 48-year period.

INTRODUCTION

Sediment is being deposited in the Lake Granger reservoir at a rate significantly in excess of that initially estimated in studies for the Brazos River Authority (BRA) based on volumetric storage capacity measurements taken by the Texas Water Development Board (TWDB) recently. The main purpose of the study is to define flow quantity and sediment loadings into the reservoir from the watershed (Figure 1) using the Soil and Water Assessment Tool (SWAT) and existing Geographic Information System (GIS) data and make a preliminary determination of whether best management practices can significantly decrease sediment rates.

The model had been calibrated to approximate conditions and historical climatological data for the period that the reservoir has been in existence. A cursory examination will then assess effects of implementing best management practices (BMPs) such as floodwater retarding structures or sediment control structures along with changing some land use practices and management.

A Memorandum of Understanding between BRA and USDA-NRCS (Natural Resources Conservation Service) was executed in September 1993 to establish a framework to increase cooperation and coordination between the two entities on mutual water quality objectives.

DESCRIPTION OF STUDY AREA

Physical Characteristics

The Lake Granger Watershed is located in central Texas (Figure 1). It is predominantly located in Williamson County extending slightly into Burnet County. The reservoir controls runoff from about 720 square miles with deliberate impoundment begun in January 1980. A search of USGS website records indicated storage extremes: maximum contents, 266,600 acre-ft, Mar. 4, 1992; minimum observed (since initial filling), 45,120 acre-ft Oct. 6, 1984. Normal storage is 54,280 acre-ft based on the 1995 TWDB survey.

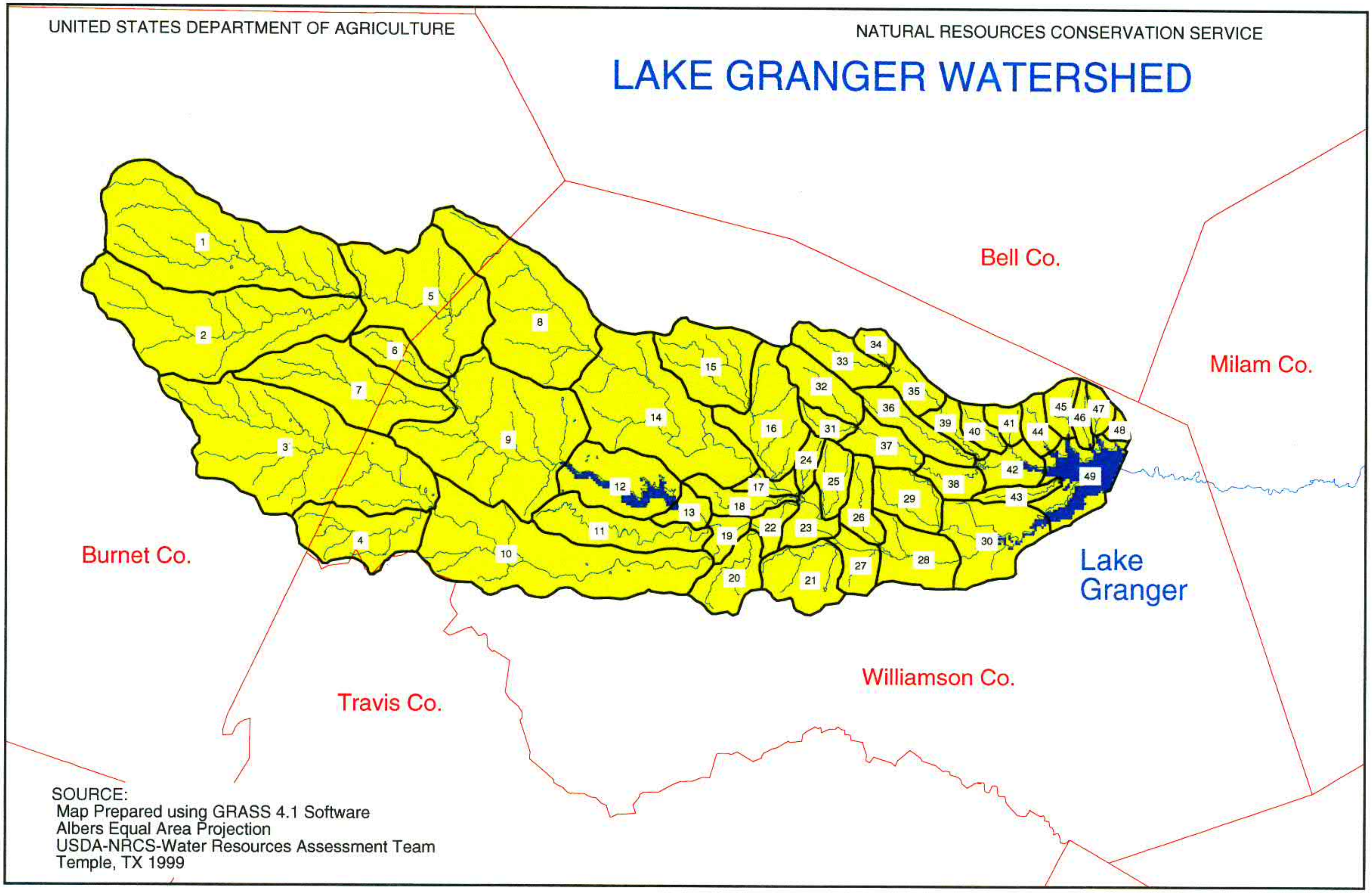
Climate

The climate is subhumid. Average annual precipitation ranges from about 34.2 inches in Williamson County to 30.5 inches in Burnet County. The entire area is subject to high intensity, short duration thunderstorms during the spring and summer months. Typically, summers are hot and winters are mild with intervals of freezing temperatures as cold fronts pass though the region.

Population

Georgetown is the largest urban population area within the Lake Granger basin with an estimated population of over 24,000 and one of the fastest growing areas within the state. What originally were rural areas west of Georgetown are now being developed into suburban communities such as Del Webb's Sun City.

Granger with a population of about 1,300 is the only other urban center and is located in the downstream portion of the watershed immediately above the reservoir.



UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
Bell Co.
Milam Co.
Burnet Co.
Travis Co.
Williamson Co.
Lake Granger
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SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999

FIGURE 1

Soils

The watersheds are within portions of the Edwards Plateau, Grand Prairie and Texas Blackland Prairie Major Land Resource Areas. Soils range from shallow loamy or clay, stony and cobbly soils in the Edwards Plateau region to deep fine textured montmorillonitic clays in the Blackland Prairie. Soil depths vary from very shallow to deep. Upland topography ranges from nearly level to steeply sloping. Spatial distribution of soils is indicated in Figure 2.

Land Use

Agricultural land uses are dominant in the drainage area comprising the project area. Without adequate treatment and management, soils are subject to accelerated erosion with subsequent increased reservoir sedimentation and related water quantity and quality degradation. BMPs such as planting permanent grass, altering tillage practices, and installing impoundment structures for alleviating or preventing these problems are unique to each soil, its location, and the circumstances under which the soil is used. Table 1 indicates the percentages of each landuse in the watershed based on NRCS's CBMS (Computer Based Mapping System) database. Spatial distribution of landuse is shown in Figure 3.

TABLE 1 - LAND USE IN GRANGER LAKE WATERSHED

No.	Description	Acres	Cover
32	Brushy Rangeland	153,301	33.02
31	Open Rangeland	113,903	24.54
21	Cropland	95,410	20.55
23	Pasture and Hayland	51,486	11.09
12	Other Populated Land	14,668	3.16
11	Urban	12,029	2.59
81	Recreation Land	10,388	2.24
51	Water	7,482	1.61
13	Highways	3,835	.83
52	Farm Ponds	929	.20
73	Strip Mines	593	.13
25	Horticultural Land	208	.04
	TOTAL	464,232	100.00

Source: USDA-NRCS - CBMS Land Use GIS database

Dams and Reservoirs

Lake Georgetown controls about 34% of the Granger Lake watershed in the upstream portion of the basin. Only 4% of the Lake Georgetown watershed is cropland, so there is neglibible effect of any modeling scenario of this watershed on the larger Granger Lake watershed. There are a few other ponds and reservoirs within the watersheds ranging from small livestock watering facilities to small reservoirs. All structures included in state or federal inventories are contained in the GIS database with much of the physical data for each reservoir, which is needed for input to the computer model. The location and size of the ponds was such that it was not anticipated that they would have significant effect on the flow and sediment results of the model runs. The location of these reservoirs within the watershed is shown in Figure 9.

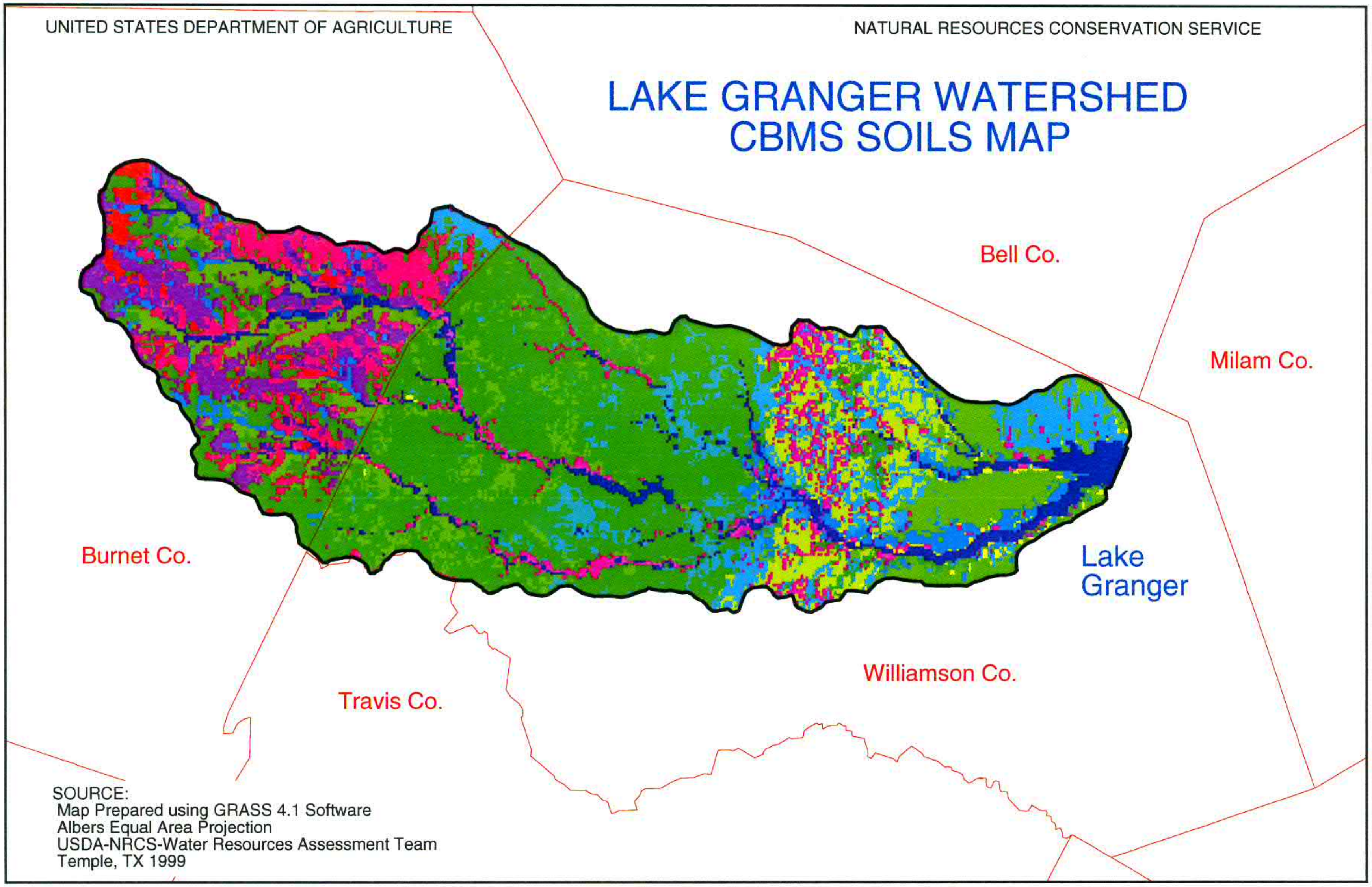

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
CBMS SOILS MAP
Bell Co.
Milam Co.
Burnet Co.
Lake
Granger
Williamson Co.
Travis Co.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999

FIGURE 2

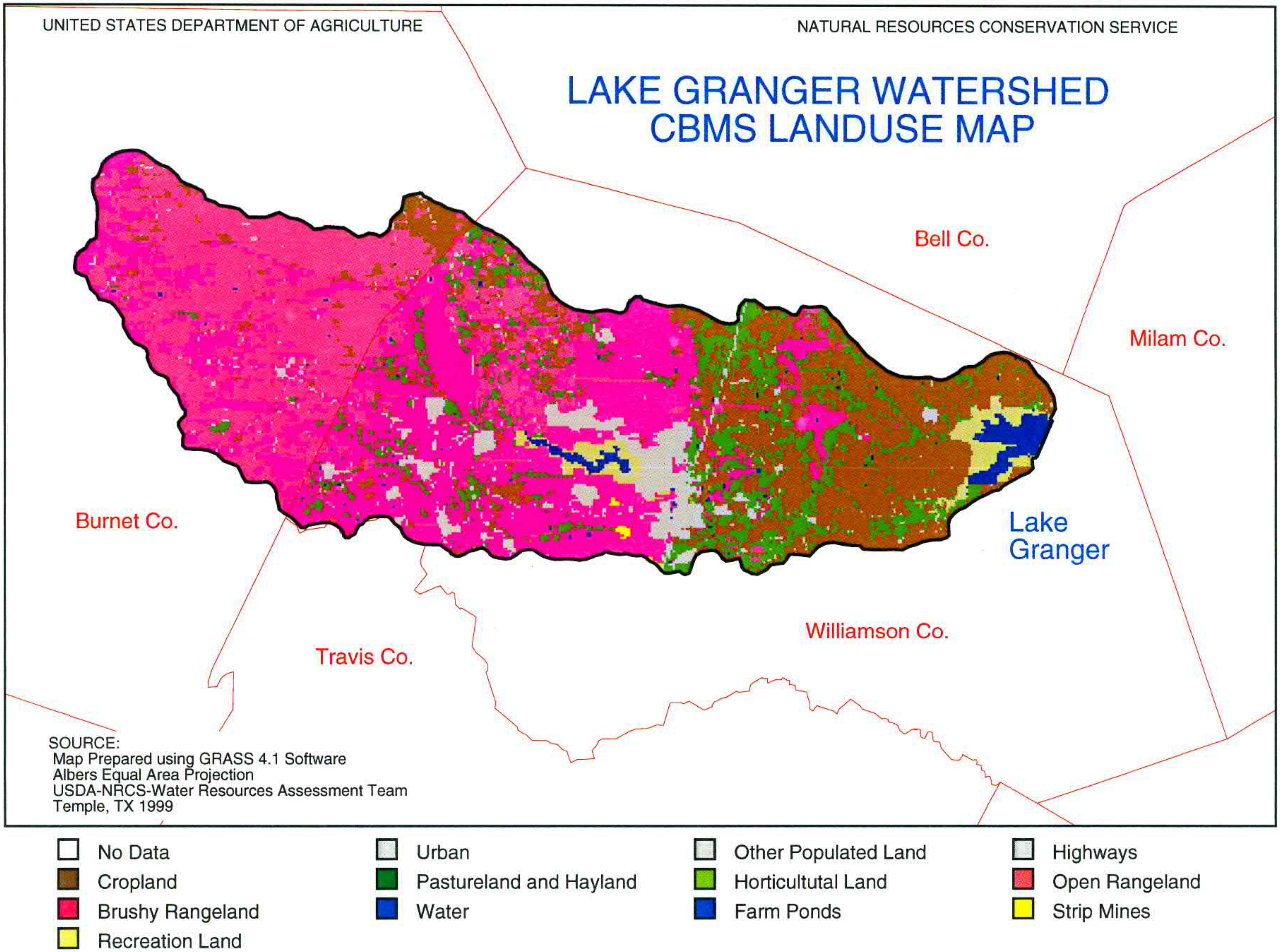

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
CBMS LANDUSE MAP
Bell Co.
Milam Co.
Burnet Co.
Lake Granger
Williamson Co.
Travis Co.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999
No Data
Cropland
Brushy Rangeland
Recreation Land
Urban
Pastureland and Hayland
Water
Other Populated Land
Horticultutal Land
Farm Ponds
Highways
Open Rangeland
Strip Mines

FIGURE 3

Sediment survey data was limited to the volumetric studies carried out by TWDB in October 1995. Accumulated sediment for the life of the reservoir is used in sediment calibration of the model. Six proposed locations for ponds or dams were located in the lower half of the watershed to evaluate their potential for reducing sediment loads into Lake Granger. These locations are identified in Figure 10 and their estimated structural and storage dimensions are listed in Tables A2 and A3 in the Appendix. No investigations were made as to the feasibility of sites to be constructed at these locations regarding land rights, utilities or new features that would limit use of the site.

METHODOLOGY

The watershed was subdivided into subbasins according to the size of each tributary to the main stream. The subwatershed boundaries were hand digitized from the 1:250,000 digital elevation map. This configuration provided 49 subbasins within the Lake Granger Watershed.

The first priority for calibration and validation was the quantity of stream flow. Availability of measured data to compare model simulations was more prevalent for stream flow. USGS stream flow gauge measurements exist for several years of record at each station.

After the model was working well for flow, the focus turned to sediment loadings from subbasins. The strategy employed was to take sediment deposition volumes measured in reservoirs over a span of several years and simulate the watershed with actual weather data for the same period of time. Simulated sediment loadings were then compared to accumulated sediment in the receiving waters.

GEOGRAPHIC INFORMATION SYSTEM

The GIS is an integral part of this overall study. GIS is integrated with SWAT, which is a distributed parameter, continuous time, nonpoint source pollution model. Without GIS, the input of physical data would be most time consuming. Integration of GIS also allows visualization and analysis of the input and output of the model. Developers of SWAT chose a public domain raster GIS designed and developed by the Environmental Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). GRASS is a general purpose, raster graphic modeling and analysis package and is highly interactive and graphically oriented, providing tools for developing, analyzing, and displaying spatial information. GRASS is used by numerous federal, state, and local agencies and private consultants.

Soils

A soils database describes the surface and upper subsurface of a watershed. Older models only use the soil surface moisture and infiltration parameters to determine rainfall runoff. Models such as EPIC (Erosion Productivity Impact Calculator) and SWAT use information about each soil horizon. Parameters describing horizon thickness, depth, texture, water holding capacity, dispersion, etc. must be available to the model. These parameters are used to determine a water budget for the soil profile, daily runoff and erosion.

The NRCS soils database currently available for all of the counties of Texas is the STATSGO (State Soil Geographic Data Base) 1:250,000-scale soils database. The 1:250,000-scale USGS topographic map series was used as the base map for the compilation of this database. The STATSGO database covers the entire United States and all STATSGO soils are defined in the same way. Therefore, for any area within the United States, the STATSGO database can be used by models without a great deal of effort to prepare the soil GIS layer. While this database is usually adequate for predicting erosion from very large watersheds, it usually does not give adequate accuracy for watershed subbasins smaller that the eight digit HUC (Hydrologic Unit Code) or about 1000 square miles. However, it is an excellent tool for initial screening of a large watershed to identify subbasins showing high potential for contributing to non-point source pollution in streams and reservoirs.

Another NRCS soils database, the SSURGO (Soil Survey Geographic Data Base) database is the most detailed soil database available. Currently this database is not available as a vector or high resolution cell (grid) database. This 1:24,000-scale soils database is available as printed county soil surveys for over 90% of Texas counties. The tabular data describing the properties of each soil is available in electronic form and a grid GIS with lower resolution has been created. The CBMS soils database, sometimes referred to as Map Information Assembly Display System (MIADS) database, was created from 1:24,000 scale soil sheets with a cell resolution of 250 meters (820 feet). Normally, a cell resolution of 20 meters would be used for information taken from a 1:24,000 scale base map to adequately show the detail, but it is a lengthy and costly process. Because this database has been developed over a period of many years, soil definition and delineation is not very consistent for areas made up of more than one county.

The CBMS database differs from some grid GIS databases in that the soil mapping unit ID used to determine the attribute of each cell is the soil that occurs under the center point of the cell instead of the soil that makes up the largest percentage of the cell. This method of cell attribute labeling has the advantage of a more accurate measurement of the various soils in an area. The disadvantage is for any given cell the attribute of that cell may not reflect the soil that actually makes up the largest percentage of that cell.

There is one main difference between the STATSGO and SSURGO databases. In the SSURGO database, each soil delineation is a soil, which is, described a single soil series. In the STATSGO database, each soil delineation is a made up of more than one soil series. Some STATSGO soils are made up of as many as twenty SSURGO soil series. Usually there is one SSURGO soil series that dominates a STATSGO soil.

Computer models use the soil series name as the data link between the soils GIS layer and the soils properties tabular database. The SWAT model can use the STATSGO soil name in a GIS soil layer to look up the soil series name that is the dominant series for a specific STATSGO soil. The soil properties tabular database is a component of the computer model and is not developed by the model user.

The Granger study area is represented by the 1:24,000 scale CBMS soils GIS coverage as shown in Figure 2.

Land Use/Cover Classification

Land use and cover affect surface erosion and water runoff in a watershed and are a necessary input of a watershed model.

The USGS Land Use and Land Cover database is available for all of Texas. This database was developed from NASA (National Aeronautics and Space Administration) and NHAP (National High-

Altitude Photography) high-altitude aerial photographs. The 1:250,000-scale topographic map series was generally used as the base map for the compilation of this database.

The NRCS 1:24,000-scale Land Use and Land Cover database is the most detailed land use/cover database presently available. This database is available only in CBMS format. Over 90% of Texas counties have been mapped using this format. The CBMS Land Use and Land Cover database format is the same as the format used for the CBMS soils database.

Similar to the soils GIS layer, the Granger study area is represented by the 1:24,000 scale CBMS landuse GIS coverage as shown in Figure 3.

Topographical Database

Another database that describes the surface of a watershed comes in the form of a topographical or DEM (digital elevation model) database. The DEM database is a grid representation of elevation contour lines. The only DEM database that is currently available for all of Texas is the 1:250,000-scale data. This scale corresponds to a cell resolution of three arc seconds or about 100 meters. This database is usually very adequate for computer models such as SWAT except in very flat watersheds. When using this database, manual digitizing or scanning to develop subbasin boundaries in a watershed may be necessary.

Where the sub-basin size is less that a few hundred acres or in areas that are almost flat, the more detailed 1:24,000-scale DEM should be used for computer delineation of subbasins. The 1:24,000-scale corresponds to a cell resolution of one arc second or about 30 meters. If this database is used in watershed modeling, computer time and storage requirements can become an obstacle.

The entire study area is represented only by the 1:250,000 scale GIS coverage for digital elevation models. See Figure 4 for a depiction of the digital elevation map.

Historical Climatic Data

Historical climatic data is available from the United States Weather Bureau. The EPIC and SWAT models have built in weather generators that generate daily weather based on historical weather from the nearest weather station. The user can also input daily precipitation and daily maximum and minimum temperatures. Table 3 lists precipitation stations (Figure 6) located in or near the watershed of the study area and the time periods for which data is available for each station.

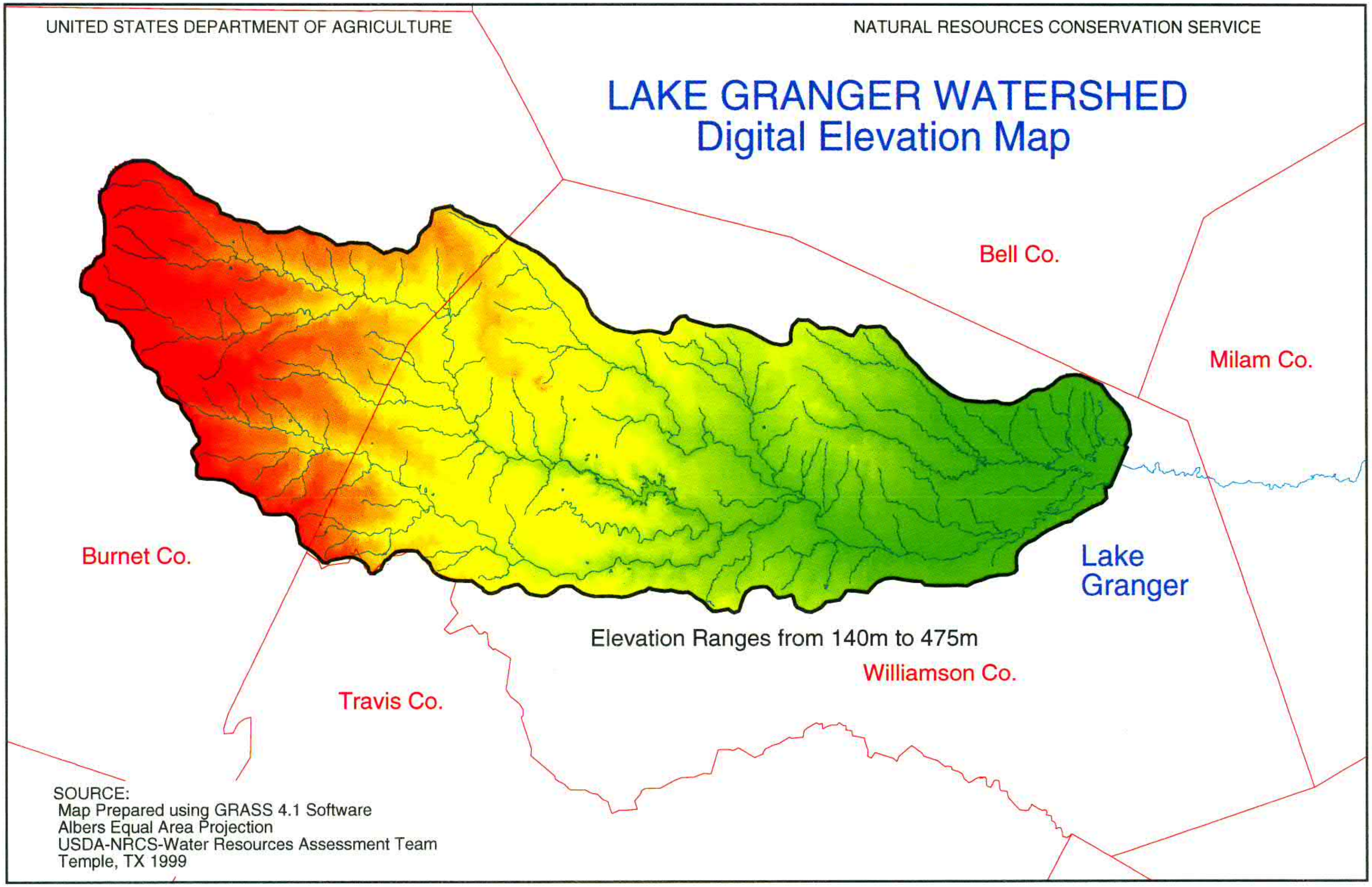

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
Digital Elevation Map
Bell Co.
Milam Co.
Burnet Co.
Lake Granger
Elevation Ranges from 140m to 475m
Williamson Co.
Travis Co.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999

FIGURE 4

Historical Stream Flow

Historical stream flow data is available from the USGS records. Historical stream flow data should be compared to model output whenever possible. Stream gauge locations listed in Table 4 includes stream gauge stations located within the watershed of the study area (Figure 5) and the time periods for which data is available for each station.

TABLE 3 - HISTORICAL CLIMATE DATA

Station Number	Station Name	Start Date	End Date
480246	Andice 1 WNW	1968	1997
480738	Bertram 3 ENE	1968	1997
481250	Burnet	1960	1997
482295	Davilla	1960	1997
483199	Florence 3 SE	1963	1997
483507	Georgetown Lake	1981	1997
483685	Granger	1968	1997
483686	Granger Lake	1980	1997
484556	Jarrell	1960	1997
487791	Round Rock 3 NE	1968	1997
488861	Taylor	1960	1997
489504	Watson	1968	1997

TABLE 4 - HISTORICAL STREAM FLOW GAUGING LOCATIONS

Station Name	Station Number	Start Date	End Date
North Fork San Gabriel River near Georgetown, TX	08104700	1968	1998
South Fork San Gabriel River at Georgetown, TX	08104900	1967	1998
San Gabriel River at Georgetown, TX	08105000	1934	1987
Berry Creek near Georgetown, TX	08105100	1967	1998
Berry Creek at SH971 near Georgetown, TX	08105200	1984	1987
San Gabriel River near Weir, TX	08105300	1976	1990
San Gabriel River near Circleville, TX.	08105400	1967	1976
San Gabriel River at Laneport, TX	08105700	1965	1998

Geographic and Cartographic Features

The Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing system) files can be converted into a GIS database by ARC/INFO or GRASS. The resulting GIS layers consist of features such as highways, roads, city streets, streams, rivers and county lines. Names and classification of many of the features are available in the TIGER files. Statistical area boundaries are also included in the TIGER files. The TIGER lines are grouped into county files and available by state for all of the United States. Stream density and road designations may change when crossing county lines. TIGER files are comparable to 1:100,000-scale topographic maps.

Another source of geographic and cartographic features is the 1:100,000-scale USGS DLG (Digital Line Graph) files. These files have recently become available for almost all of Texas. Unlike the TIGER files, 1:100,000-scale DLG files do not contain political boundaries.

Particular layers are added to a graphical display in GRASS as needed for orientation or interpretation of the spatial data.

Miscellaneous GIS Data Layers

Additional GIS layers were assembled into the database as the need for a particular spatial coverage was determined.

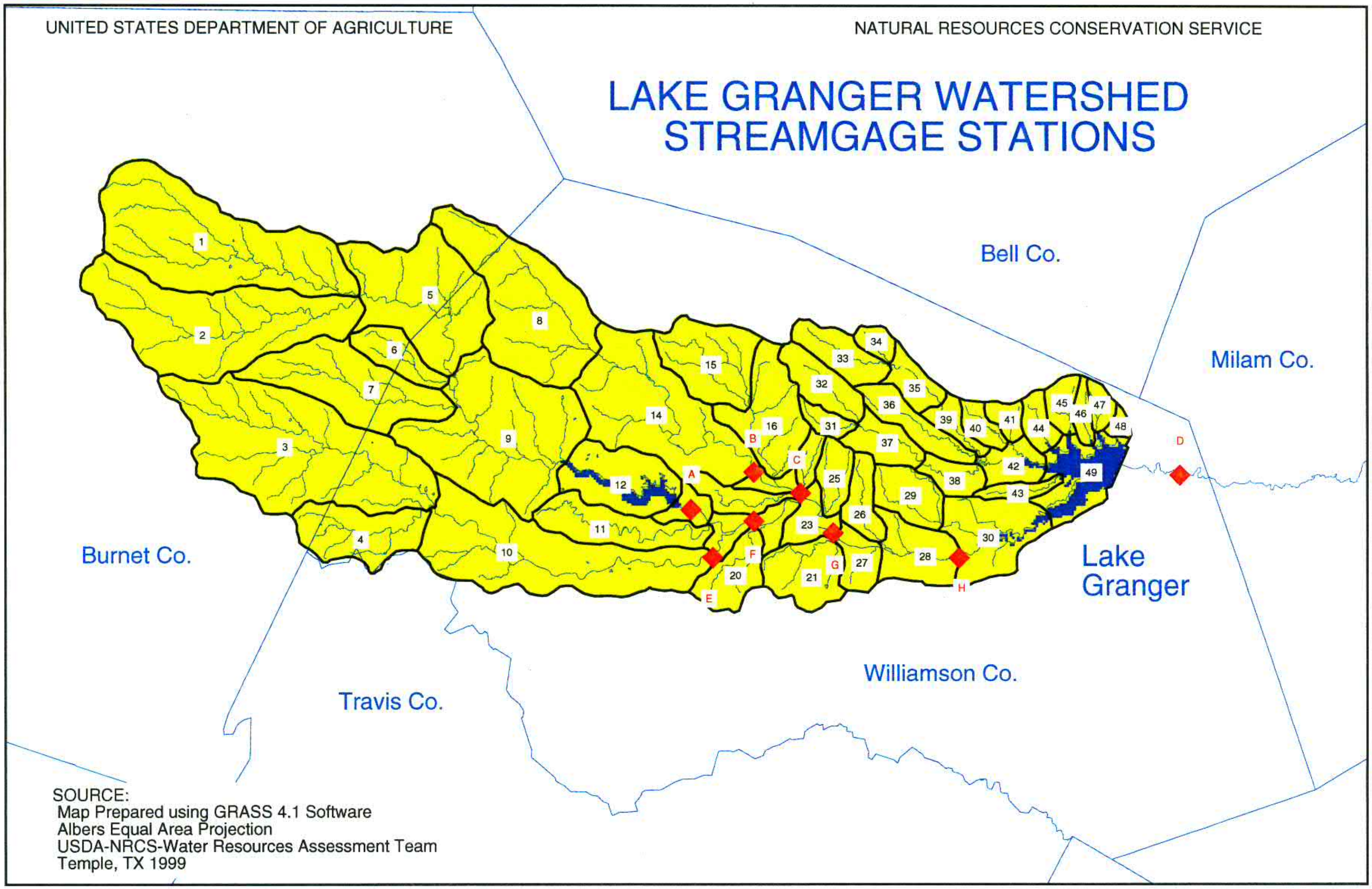
A combination of the USDA-NRCS and TNRCC (Texas Natural Resource Conservation Commission) databases, which inventoried dams and reservoirs across the state, were used to create a reservoir database. It consists of both a spatial layer and a relational database containing all known physical facts about a reservoir such as surface area, drainage area, and storage capacities.

Figure 5 and data in Table 4 indicate the locations of stations where stream flow has been gauged. These locations and the data collected at each station were essential to calibration of the SWAT model.

The location of weather stations is shown in Figure 6 and listed in Table 3. The SWAT model selects appropriate rainfall and temperature data from the nearest weather station to the subbasin under analysis by the model. Weather stations outside the watershed, yet close enough to influence input data to the model, are included in the GIS database.

Geology Data

Figures 7 and 8 display the spatial layers of the geologic atlas sheets and land resource geology respectively within the study area. These layers were not interfaced with SWAT modeling but are displayed to note the variations in geologic formations and to note the existence of these GIS layers for reference.



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E=08104900 F=08105000 G=08105300 H=08105400

FIGURE 5

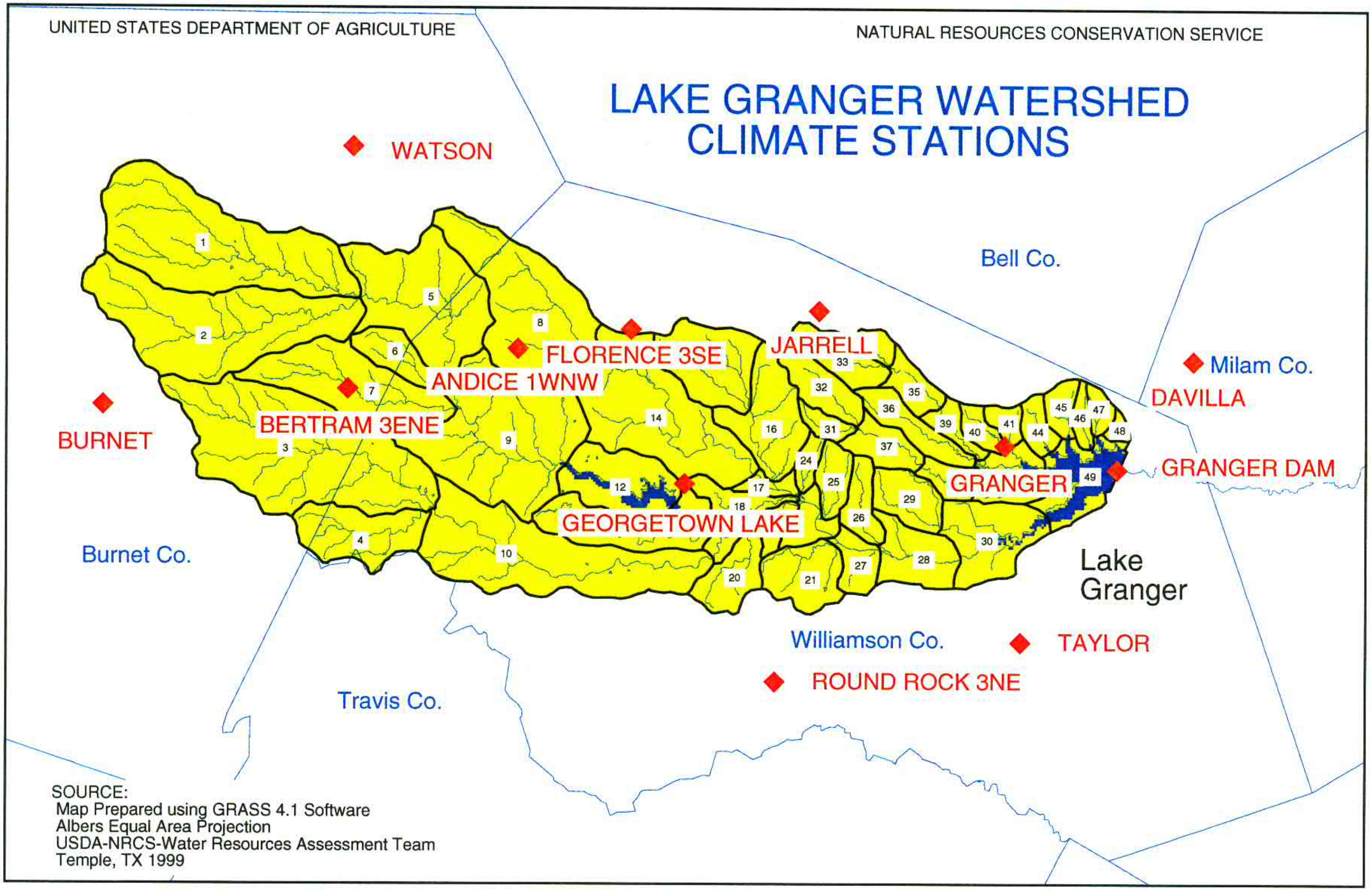

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
CLIMATE STATIONS
WATSON
BURNET
BERTRAM 3ENE
ANDICE 1WNW
FLORENCE 3SE
JARRELL
GEORGETOWN LAKE
GRANGER
GRANGER DAM
DAVILLA
Milam Co.
Bell Co.
Burnet Co.
Travis Co.
Williamson Co.
TAYLOR
ROUND ROCK 3NE
Lake
Granger
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999

FIGURE 6

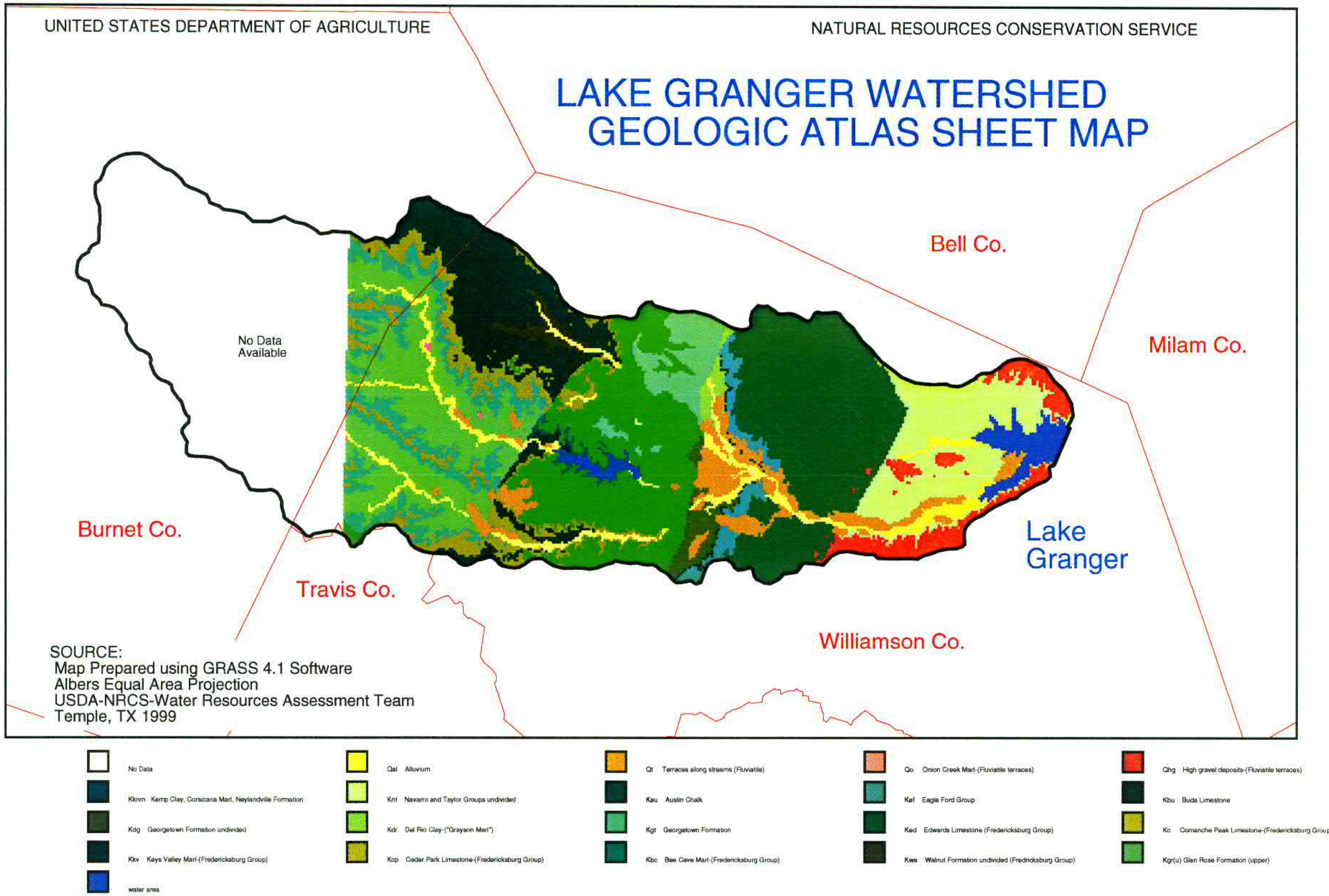

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
GEOLOGIC ATLAS SHEET MAP
Bell Co.
Milam Co.
No Data
Available
Burnet Co.
Travis Co.
Lake
Granger
Williamson Co.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999
No Data
Kknm Kemp Clay, Corsicana Marl, Neylandville Formation
Kdg Georgetown Formation undivided
Kkv Keys Valley Marl-(Fredericksburg Group)
water area
Qal Alluvium
Knt Navarro and Taylor Groups undivided
Kdr Del Rio Clay-("Grayson Marl")
Kcp Cedar Park Limestone-(Fredericksburg Group)
Qt Terraces along streams (Fluviatile)
Kau Austin Chalk
Kgt Georgetown Formation
Kbc Bee Cave Marl-(Fredericksburg Group)
Qo Onion Creek Marl-(Fluviatile terraces)
Kef Eagle Ford Group
Ked Edwards Limestone (Fredericksburg Group)
Kwa Walnut Formation undivided (Fredricksburg Group)
Qhg High gravel deposits-(Fluviatile terraces)
Kbu Buda Limestone
Kc Comanche Peak Limestone-(Fredericksburg Group)
Kgr(u) Glen Rose Formation (upper)

FIGURE 7

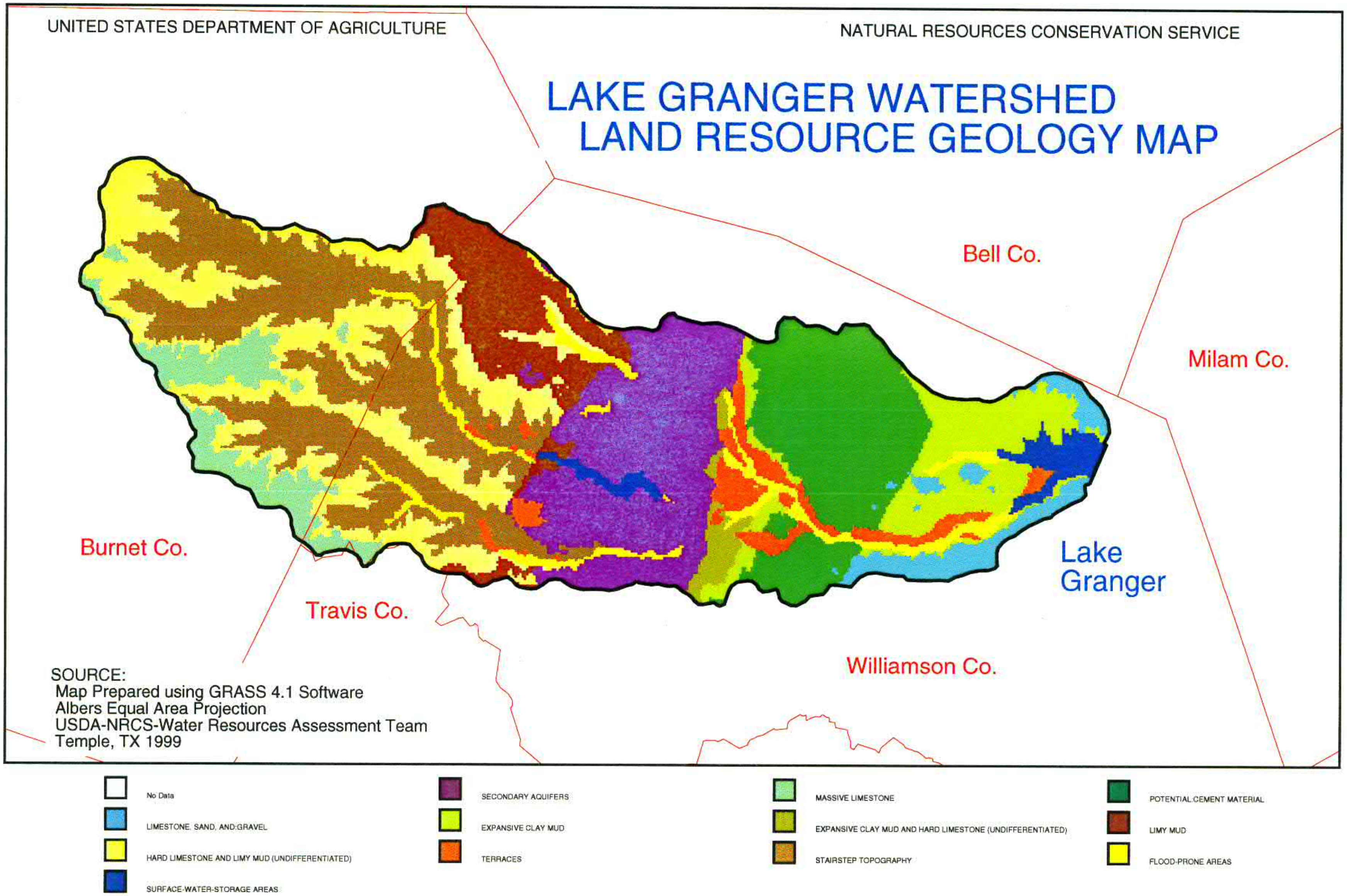
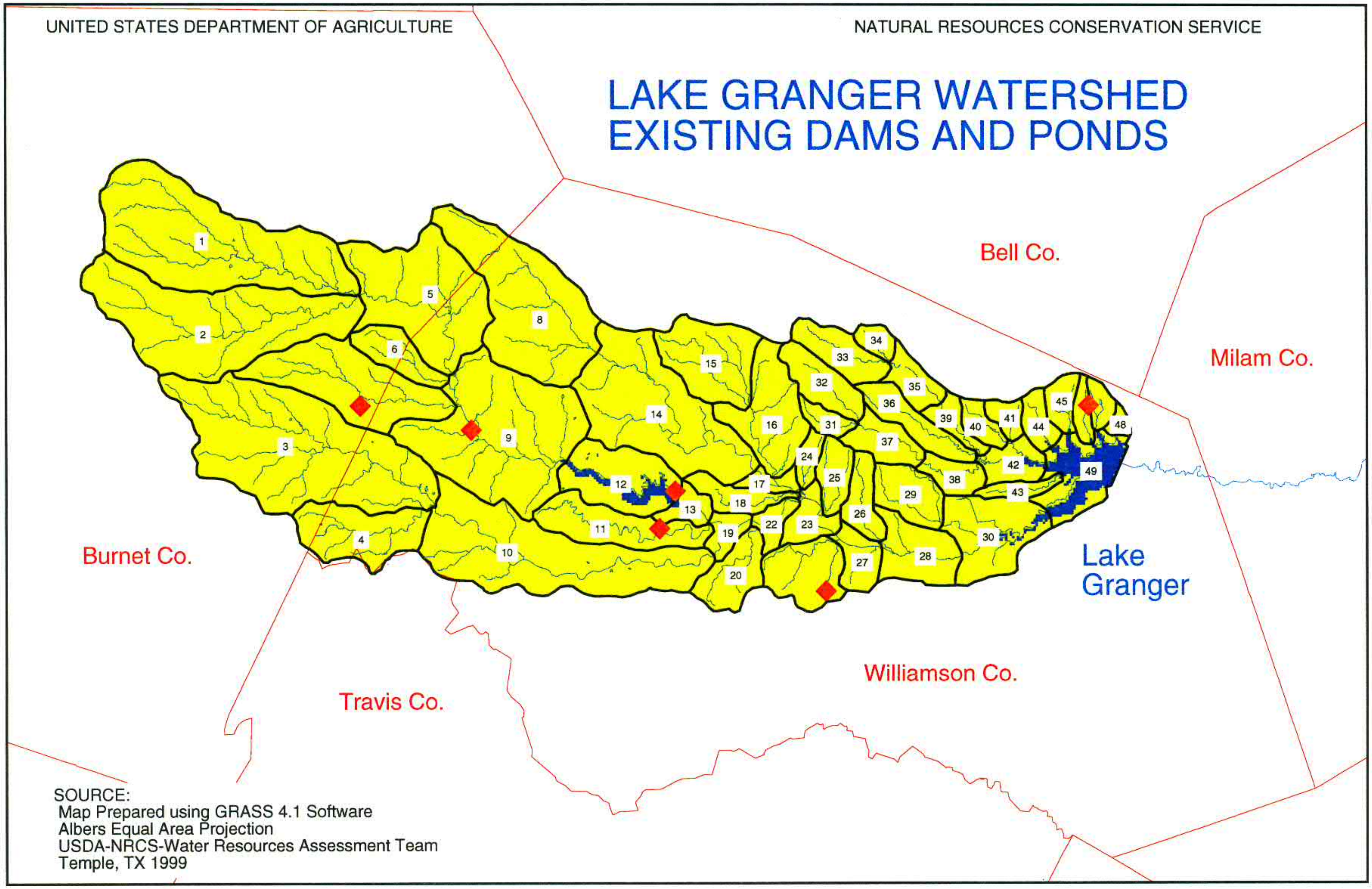

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
LAND RESOURCE GEOLOGY MAP
Bell Co.
Milam Co.
Burnet Co.
Travis Co.
Lake Granger
Williamson Co.
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999
No Data
LIMESTONE, SAND, AND GRAVEL
HARD LIMESTONE AND LIMY MUD (UNDIFFERENTIATED)
SURFACE-WATER-STORAGE AREAS
SECONDARY AQUIFERS
EXPANSIVE CLAY MUD
TERRACES
MASSIVE LIMESTONE
EXPANSIVE CLAY MUD AND HARD LIMESTONE (UNDIFFERENTIATED)
STAIRSTEP TOPOGRAPHY
POTENTIAL CEMENT MATERIAL
LIMY MUD
FLOOD-PRONE AREAS

FIGURE 8


UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
EXISTING DAMS AND PONDS
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Milam Co.
Burnet Co.
Travis Co.
Williamson Co.
Lake Granger
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SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999

FIGURE 9

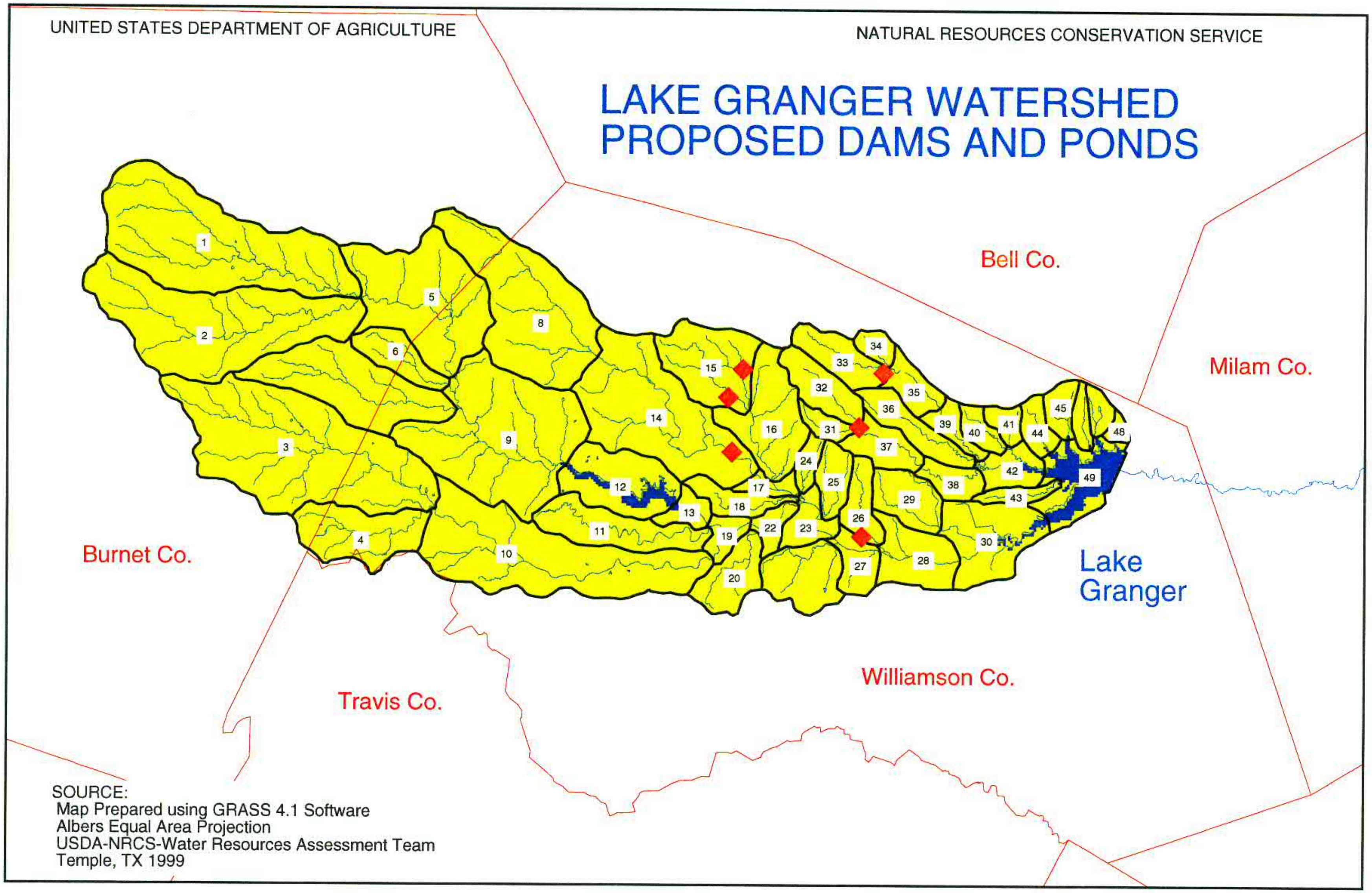

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
LAKE GRANGER WATERSHED
PROPOSED DAMS AND PONDS
Bell Co.
Milam Co.
Burnet Co.
Travis Co.
Williamson Co.
Lake Granger
SOURCE:
Map Prepared using GRASS 4.1 Software
Albers Equal Area Projection
USDA-NRCS-Water Resources Assessment Team
Temple, TX 1999

FIGURE 10

SWAT Model

The SWAT model is the continuation of a long-term effort of nonpoint source pollution modeling with the USDA-Agricultural Research Service (ARS). In the early 1970's, in response to the Clean Water Act, ARS assembled a team of interdisciplinary scientists from across the United States to develop a process-based, nonpoint source simulation model. From that effort, a model called CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was developed. CREAMS is a field scale model developed to simulate the impact of land management on water, sediment, nutrients, and pesticides leaving the edge of a field. By the early and mid-1980's, several models were being developed with origins from the original CREAMS model.

Several of these efforts involved modifying CREAMS to simulate complex watersheds with varying soils, land use, and management. One effort was the SWRRB (Simulator for Water Resources in Rural Basins) model. This model was developed to simulate nonpoint source loadings from watersheds. SWRRB is a continuous time (daily time step) model that allows a basin to be subdivided into a maximum of ten subbasins. The major processes included in the model are surface runoff, percolation, return flow, evapotranspiration, transmission losses, pond and reservoir storage, sedimentation, and crop growth. The NRCS (formerly the Soil Conservation Service (SCS)) curve number technique was selected for use in predicting surface runoff because:

(a) it is a reliable procedure that has been used for many years in the U.S.;
(b) it is computationally efficient;
(c) the required inputs are generally available; and
(d) it relates runoff to soil type, land use, and management practices.

The major changes incorporated into SWRRB were (a) the model was expanded to allow simultaneous computations on several subbasins to predict the basin water yield; (b) a return flow component was added; (c) a reservoir storage component was added for use in determining the effects of farm ponds and reservoirs on water and sediment yield; (d) a weather simulation model (rainfall, solar radiation, and temperature) was added to provide for longer term simulations and more representative weather inputs, both temporally and spatially; (e) a better method was developed for predicting the peak runoff rate; (f) a crop growth model was added to account for annual variation in growth; (g) a simple flood routing component was added; (h) components were added to simulate sediment movement through ponds, reservoirs, streams, and valleys; and (i) transmission losses were calculated. Besides water, SWRRB also simulates sediment yield from rural basins using the Modified Universal Soil Loss Equation (MUSLE) and a sediment routing model.

Sediment deposited into ponds and reservoirs is determined with a series of equations that on a daily basis compute the inflow and outflow sediment concentrations. The initial reservoir concentration is an input to the model. Deposition into the reservoir is determined by functions of reservoir concentration, time in days, decay constant, the "d50" median particle size of the inflow sediment, and the equilibrium sediment concentration (input to the model). Between storms the final reservoir concentration decreases to an equilibrium concentration. The outflow concentration is a function of the reservoir concentration at the beginning and end of the day.

In response to needs to simulate stream flow from much larger basins, ROTO (Routing Outputs to Outlet) was developed to take output from multiple SWRRB runs and route the flows through channels and reservoirs. This reach routing approach overcame the SWRRB subbasin limitation by linking multiple SWRRB runs together.

SWAT is a result of the merging of the SWRRB and ROTO models into one basin scale model. The objective in model development was to predict the impact of management (climate and vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water, sediment, and agricultural chemical yields in large ungauged basins. To satisfy the objective, the model (a) is physically based (calibration is not possible on ungauged basins); (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. SWAT allows a basin to be divided into hundreds or thousands of grid cells or subwatersheds. It is still a continuous time model (daily time step) that is required to look at long-term impacts of management (i.e., reservoir sedimentation over 50-100 years) and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing).

In recent years, there has been considerable effort devoted to utilizing GIS to extract inputs (soils, land use, and topography) for comprehensive simulation models and spatially display model outputs. Much of the initial research was devoted to linking single-event, grid models with raster-based GIS. An interface was developed for SWAT using GRASS. The input interface will extract model input data from map layers and associated relational databases for each subbasin. Soils, land use, weather, management, and topographic data are collected and written to appropriate model input files. The output interface allows the user to display output maps and graph output data by selecting a subbasin from a GIS map.

Flow and Sediment Calibration

The Lake Granger watershed contains two reservoirs of significant size: Lake Granger and Lake Georgetown. Both of these reservoirs have controlled releases. The watershed also contains four additional large farm ponds included in the dams inventory. The physical data for the two reservoirs were obtained from TNRCC records and input to SWAT. However, the data for the four inventory-sized ponds were not input since it was anticipated that they would have minimal effect.

The 1:24,000 scale soils and land use GIS layers were obtained from the NCRS computer based mapping system. The digital elevation model (DEM) with a scale of 1:250,000 was obtained from the USGS. Subbasin boundaries were delineated using the 1:250,000 scale DEM as a guide. Measured daily rainfall and temperatures were obtained from the Utah Climate Center at Utah State University.

Required inputs for the basin and each subbasin were extracted and formatted using the SWAT/GRASS input interface. The input interface divided each subbasin into a maximum of 30 virtual subbasins. A single land use and soil were selected for each virtual subbasin. The number of virtual subbasins within a subbasin was determined by: (1) creating a virtual subbasin for each land use that equaled or exceeded 5 percent of the area of a subbasin; and (2) creating a virtual subbasin for each soil type that equaled or exceeded 10 percent of any of the land uses selected in (1). The soil properties for each of the selected soils were automatically extracted from the model-supported soils database.

Impoundment of water began on Lake Granger in January 1980 and on Lake Georgetown in March 1980. Sediment surveys were conducted by the Texas Water Development Board (TWDB) in October 1995 on Lake Granger and May 1995 on Lake Georgetown. The selected period for calibration was 1980 through 1995, because these years match the dates of the storage surveys on both reservoirs. Good climate data is also available for this period.

The runoff curve number (CN) and soil evaporation compensation factor (ESCO), were adjusted until predicted stream flow reasonably matched measured flow at the five of the USGS stream gauging stations shown on Figure 5. The time series plots of predicted and measured flow and statistical analyses are shown in Figures A-1 through A-5 (Appendix). The coefficient of determination (R^2) varies from 0.35 to 0.75. Stream gauges 08104700 and 08105700 are located immediately downstream of Lakes Georgetown and Granger. The values of R^2 for these two gauges are low because of the effects of the reservoirs on the measured flow. For the other three gauges R^2 values are relatively good (0.63 to 0.75) and predicted mean is close to measured mean.

According to the TWDB sediment survey, the storage capacity of Lake Granger was reduced by 11,230 acre-feet between 1980 and 1995. Assuming the unit weight of submerged sediment is 55 pounds per cubic foot, the amount of sediment deposited in the lake during this period is 12,207,275 metric tons. According to the TWDB survey of Lake Georgetown, the capacity was reduced by 70 acre-feet during the same period. Assuming the same unit weight, the amount of sediment deposited in Lake Georgetown during this period was 76,092 metric tons.

To calibrate SWAT for sediment prediction the USLE "P" factor was assumed to be 1.0 (no contouring, no terracing), the residue decomposition factor was assumed to be 0.05, and the stream channel "K" factor was assumed to be 0.04 west of Lake Georgetown and 0.32 for the remainder of the watershed. Information on typical crops and management was obtained from local NRCS employees familiar with the farms in the watershed.

For the calibration runs, we used a three-year rotation of corn, cotton, and grain sorghum with conventional row-crop tillage. The sediment concentration factor (SPCON) was then adjusted to give the best results for predicted sediment (0.006). With these inputs, the simulated sediment for Lake Granger was 12,398,245 metric tons as shown on Figure A-6. The simulated sediment load for Lake Georgetown was 118,838 metric tons. The simulated sediment at Lake Granger matches well with the measured sediment. However, simulated sediment at Lake Georgetown is about 56 percent higher than measured. It is possible that the measured data is inaccurate, because the measured sediment load is much lower than amounts reasonably expected to occur.

Also shown on Figure A-6 is a map of sediment yield by subbasin for the two highest flow months. As expected, the highest sediment yields occur in the portion of the watershed where cropland is the dominant land use.

Table A-1 in the Appendix shows the average annual sediment load and yield by subbasin in metric tons per hectare. The sediment yield is from the sheet and rill erosion only. Sediment load is from both sheet and rill, and stream channel erosion. Again, sediment yields are higher in subbasins with land use dominated by cropland. High sediment loads in some of the subbasins are an indication of significant stream channel erosion. Negative values for sediment load indicate net deposition of sediment within that subbasin. This table may be an effective tool in prioritizing (by subbasin) the land treatment or installation of best management practices (BMPs).

Although the results of the calibration are satisfactory, it should be noted that the weight of measured sediment is based on an assumed sediment density. In addition, it may be difficult to compare the results of the sediment survey performed by TWDB with the original storage information because the methods used are very different.

Alternative Swat Runs

Four modeling scenarios (including the calibration run) were run on the Lake Granger watershed to examine the effects of BMPs or changes in landuse on the sediment loadings to the lake. Storage data for the two existing lakes (Granger and Georgetown) was also input to all scenarios.

Scenario 1: Calibration

The calibration run best represents the "current" condition with appropriate inputs for typical crops and management techniques (conventional tillage, fertilizer, etc.). For this scenario we assumed no conservation practices such as terraces and contour farming.

Scenario 2: Conversion of Cropland to Grass

To evaluate the effects of land use change, we assumed that all cropland was converted to perennial grass pasture. The results of this scenario should reveal the maximum possible reduction of sediment as a result of cropland treatment. We recognize that this is not a viable alternative as viewed by cropland farmers. However, this scenario is useful in determining effectiveness of cropland treatment with BMPs. If land use conversion did not provide adequate benefits, then any other scenario for cropland treatment would not be effective.

Scenario 3: Apply Terracing, Contouring, and Minimum Tillage

The same crop rotation as used in the calibration scenario was used in this run. Additionally, we assumed cropland was terraced and contoured with minimum tillage practices. The USLE "P" factor was reduced from 1.0 to 0.5, the slope length was reduced by 50 percent, and the runoff curve number was reduced about ten percent on all cropland to simulate the effects of terracing and contouring. A "P" factor of 1.0 represents no conservation treatment and 0.5 represents very good conservation treatment. Typical management practices for minimum tillage on all crops were input to SWAT.

Scenario 4: Construct Sediment Control Dams

In this scenario, we assumed construction of six sediment control dams. There are no NRCS flood prevention dams in the Lake Granger watershed and only four private inventory-sized dams (which were not included in any of the modeling scenarios). We made a quick analysis of potential sites by locating and estimating stage-area-volume relationships for each site using USGS 7.5' quadrangle sheets. The feasibility determination for each site also included factors such as inundation of roads, pipelines and other structural improvements which were evident from the existing quadrangles or GIS layers on hand. No field validation of site potential was made. We also assumed the cropland treatment to be the same as in scenario one (current condition).

Table 5 shows the sediment loads to Lake Granger for each scenario for three different simulation periods. The first period (1980-1995) is the calibration period and is based on dates of the volumetric storage surveys of the reservoir. The second period (1990-1993) represents a period of above average rainfall which would result in a higher than normal sediment load to the lake. The third period (1950-1997) includes the 1950's drought as well as the wetter years in the early 1990's. This simulation gives insight to long term average expected sediment delivery to the lake.

TABLE 5

PREDICTED SEDIMENT LOAD FROM SWAT LAKE GRANGER WATERSHED							
SIMULATION PERIOD		1980-1995		1990-1993		1950-1997	
NO. OF YEARS		16		4		48	
SCENARIO	UNITS	Total	Ave. Annual	Total	Ave. Annual	Total	Ave. Annual
1 (Cal.)	metric tons	12,398,245	774,890	4,591,272	1,147,818	26,918,772	560,808
	acre-feet	11,409	713	4,225	1,056	24,770	516
2 (no crop)	metric tons	9,758,533	609,908	3,587,955	896,989	20,552,332	428,174
	acre-feet	8,980	561	3,302	825	18,912	394
3 (BMP)	metric tons	10,539,743	658,734	3,866,070	966,518	22,513,998	469,042
	acre-feet	9,699	606	3,558	889	20,717	432
4 (Ponds)	metric tons	11,566,343	722,896	4,295,363	1,073,841	24,980,180	520,420
	acre-feet	10,643	665	3,953	988	22,987	479

Results and Discussion

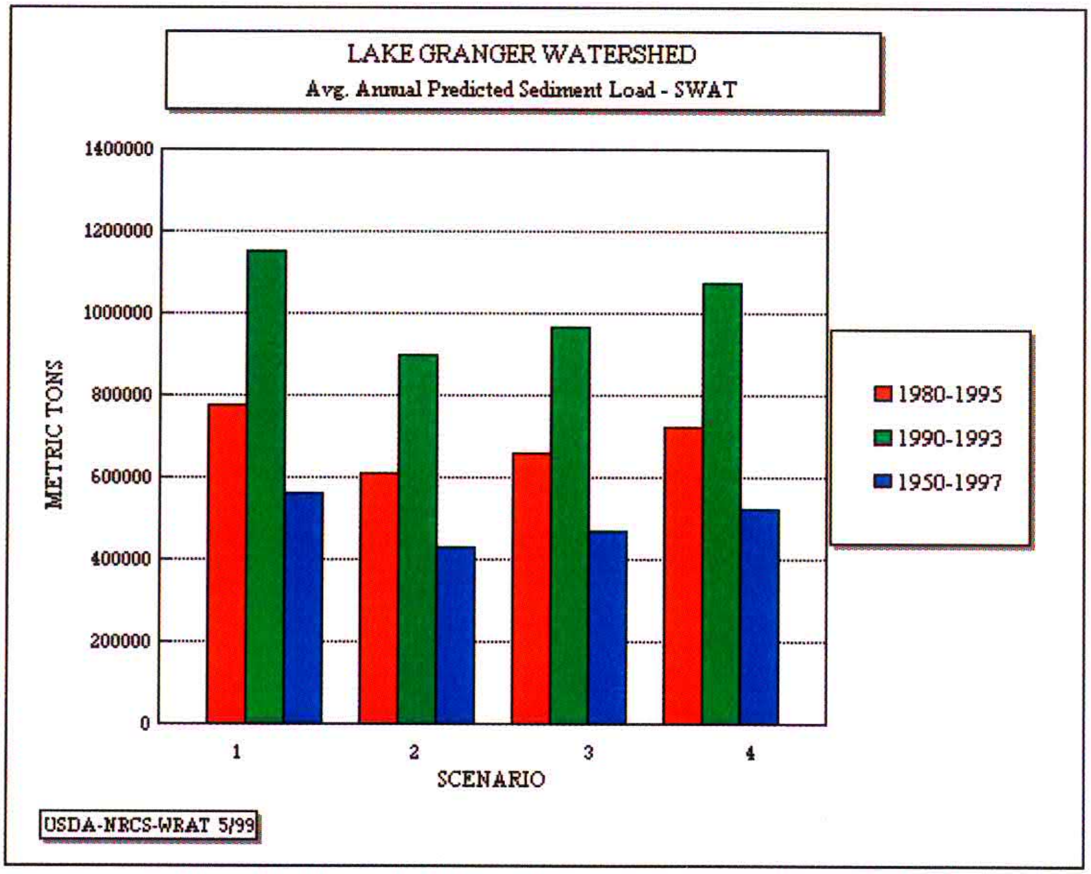
Water storage in Lake Granger is experiencing a drastic decline due to sediment accumulation according to data collected by the Texas Water Development Board in their 1995 volumetric survey of the reservoir. The measured rate of accumulation (1980-1995) is about 2.5 times greater than was projected by the reservoir designers. The original design included a sediment capacity of 28,980 acre-ft for the 100 year evaluation period which equates to 290 acre-ft per year average. The increased accumulation of sediment coupled with the rapid population growth of Williamson County is a cause of concern for Brazos River Authority.

The average annual sediment load for the existing condition (Scenario 1) varies from 1056 acre-feet for the 1990-1993 period to 516 acre-feet for the long-term simulation (1950-1997). The sediment load for the calibration period of 1980-1995 is about 38 % higher than the long-term average obtained from the 1950-1997 simulation. The long-term average sediment prediction may be a better indicator of future sediment delivery to Lake Granger. Revised projections of available reservoir storage for Lake Granger could be based on this long-term average rather than the current history of the reservoir (1980-1995).

In scenarios 2,3, and 4, the sediment load to Lake Granger was reduced from the present condition. Conversion of all cropland to perennial grass produced the greatest reduction (long-term) in sediment - 24 % or about 122 acre-feet per year. Treatment of the cropland with BMPs reduced the sediment about 16 % (84 acre-feet per year) and installation of the sediment retention dams reduced the sediment about 7 % (37 acre-feet per year).

While it is unlikely that all cropland can be converted to grass, it might be beneficial to convert the most critically eroding cropland areas. In addition, the modeling results suggest installation of BMPs on cropland and construction of sediment retention dams may provide significant reduction in sediment. However, urbanization of some portions of the watershed is progressing rapidly, and the potential for construction of medium to large sediment retention reservoirs may be limited.

Subbasins 19, 22, and 23 show very high sediment loads (Table A-1) which may be attributable to stream channel erosion. Additional field investigations or detailed modeling may be warranted to verify the source of this sediment and determine the viability of treatment options.



Comparison of data on the bar graph of average annual predicted sediment load for Lake Granger watershed can be interpreted as follows:

Compared Scenarios	Interpretation of Average Annual Sediment
1 vs. 2	Converting all cropland to grass would reduce sediment by 24%
1 vs. 3	Employing minimum tillage, terraces and contour farming would reduce sediment by 16%
1 vs. 4	Installing planned ponds reduces sediment by 7%
1(a) vs. 1(c)	Long term average is 28 % lower than for period from 1980-95
1(b) vs. 1(c)	Long term average is 51 % lower than for period from 1990-93

A possible alternative that was not evaluated because of limitations in SWAT is to install small on-farm sediment/erosion control structures. These types of structures could be better simulated with the APEX field-scale model in a more detailed study of the watershed.

From conversations with local NRCS employees, there is a great need for installation of BMPs in the watershed. Many existing cropland terraces are broken or ineffective and a significant amount of on-farm gully erosion is occurring. In addition, there are virtually no government cost/share funds to encourage landowners to install BMPs because the watershed is not in an EQIP (Environmental Quality Incentives Program) priority area.

Summary and Conclusions

Study Results

At the point of current development, SWAT has been effectively applied to small watershed applications with reasonable correlation to measured flow and sediment. Current GIS data is suitable for the present level of analysis of the watersheds although there should be a continuous effort to update and add to these databases. Precipitation data is a critical area where additional or supplemental data would be beneficial.

This study was a preliminary study to determine whether detailed assessments were warranted and to focus on where to develop the detailed information. Study results provide a method to evaluate BMPs applied in the watershed to decrease the amount of sediment being transported to the reservoir.

In this particular study, the output data appears to indicate that for long range projections of reservoir volume the long-term simulation of sediment loadings should be applied. For the life of Lake Granger, the difference in estimates of the lake's historical record versus long term SWAT simulations of sediment loads is 38% percent.

Since Lake Granger has a large portion of its watershed controlled by Lake Georgetown, there is virtually no effect of sediment loads to Granger by any measures above Lake Georgetown. Much of the cropland in this watershed is also located below Lake Georgetown. Several new site locations for floodwater retarding or sediment control structures were considered in estimating the effects of such measures on sediment loads. Granger watershed has no past or current NRCS small watershed projects. All existing impoundment structures are privately owned. It appears that new sites are substantially limited by present development, utility easements, and roads.

SWAT simulations including the "planned" structures referenced above would indicate a reduction of sediment by 7% or 1,783 acre feet for the 48-year period. Conversion of all cropland to grass had about 24% reduction in sediment load to Granger or about 5,858 acre-feet for the same 48-year period of simulation. Treatment of cropland with BMPs reduced the sediment load about 16% or 4,053 acre-feet over the 48-year period.

Emphasis on more detailed study should be placed on Granger subbasins 19, 20, and 23 where sediment load appears to be associated with channel/streambank erosion.

Conclusions

SWAT simulations of sediment loads to reservoirs in this preliminary study have demonstrated that considerable insight can be determined for what is happening in a small watershed. Refinement of input data and combining the SWAT basin-scale model with a field-scale model could yield considerably more detailed output. Most efficient use of resources may still be derived from performing a preliminary assessment as was done with this study. It is easy then to step to more detail if the preliminary study indicates the need.

When simulating smaller watersheds, the density or location of rainfall gauges is critical in duplicating historical events. SWAT's daily time step already has some effect on hydrograph peaks of short duration - high intensity storms since the volume is spread over 24 hours. Supplementing the National Weather Service stations with additional rain gauges would help to define storm volume and areal extent for small watershed areas such as Lake Granger.

Use of the NEXRAD precipitation data is also a possibility to enhance the definition of a rainfall event over a watershed. The computerized data can indicate the accumulated amounts of rainfall along with the spatial variation of the event over an area. This data can be used in the future to provide precipitation input to SWAT.

Only some economic analysis of the costs vs. benefits of the measures simulated in Granger watershed will indicate whether the estimated reductions in sediment load are significant.

Certainly it is apparent that emphasis on more detailed study should be placed on Granger subbasins 19, 22, and 23 where sediment load appears to be associated with channel/streambank erosion. These subbasins for the most part are located on the main stem or at confluences of major tributaries in the watershed, which may be the reason, they show higher channel erosion rates.

A primary factor that is affecting implementation of conservation practices has been previously mentioned and is tied to the lack of cost-share funding for landowners. Perhaps the results of this study can be used along with other documentation to qualify the watershed as a priority area for the EQIP program.

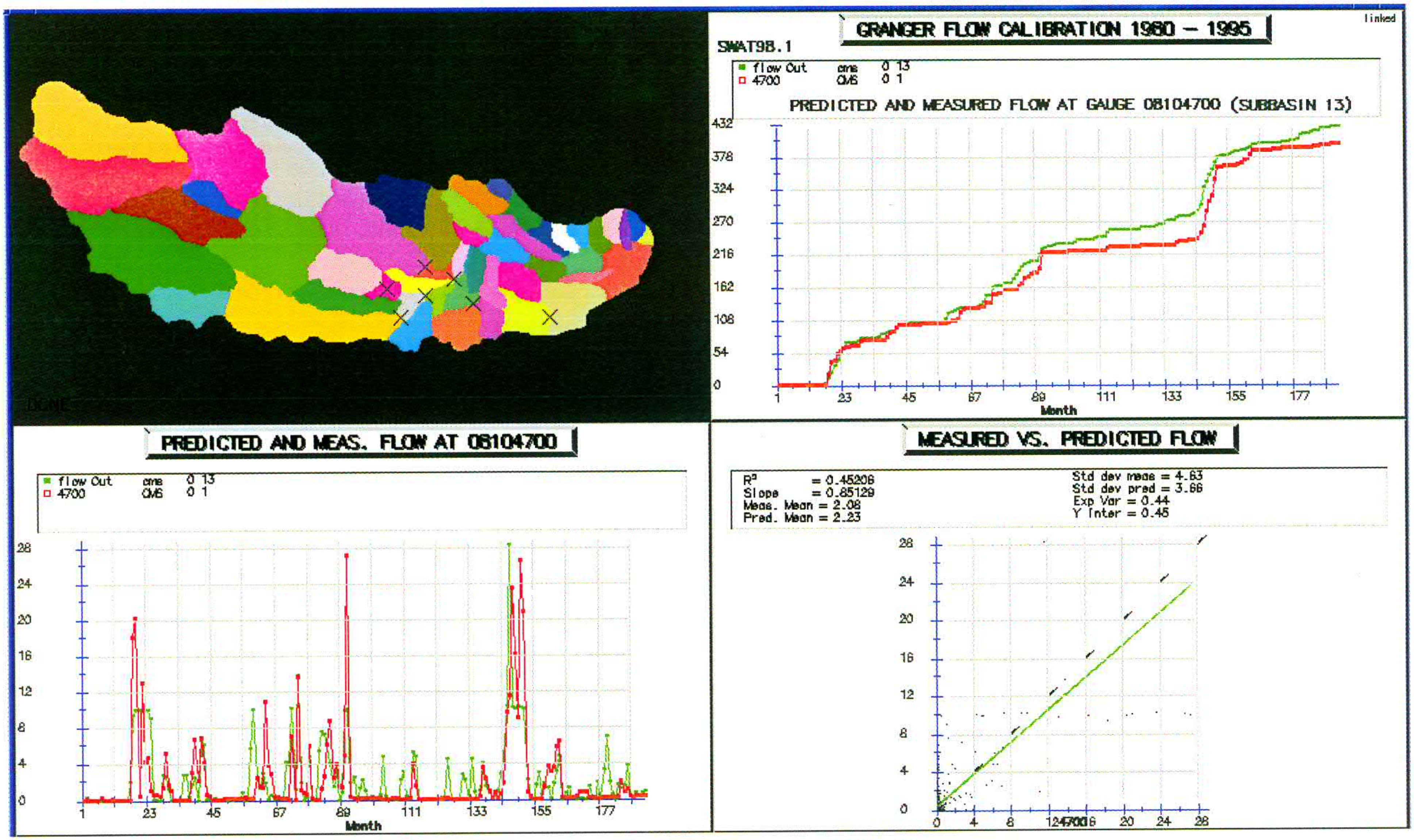


Figure A-1
Flow Calibration at USGS Gauge 08104700 (N. Fork San Gabriel River near Georgetown)

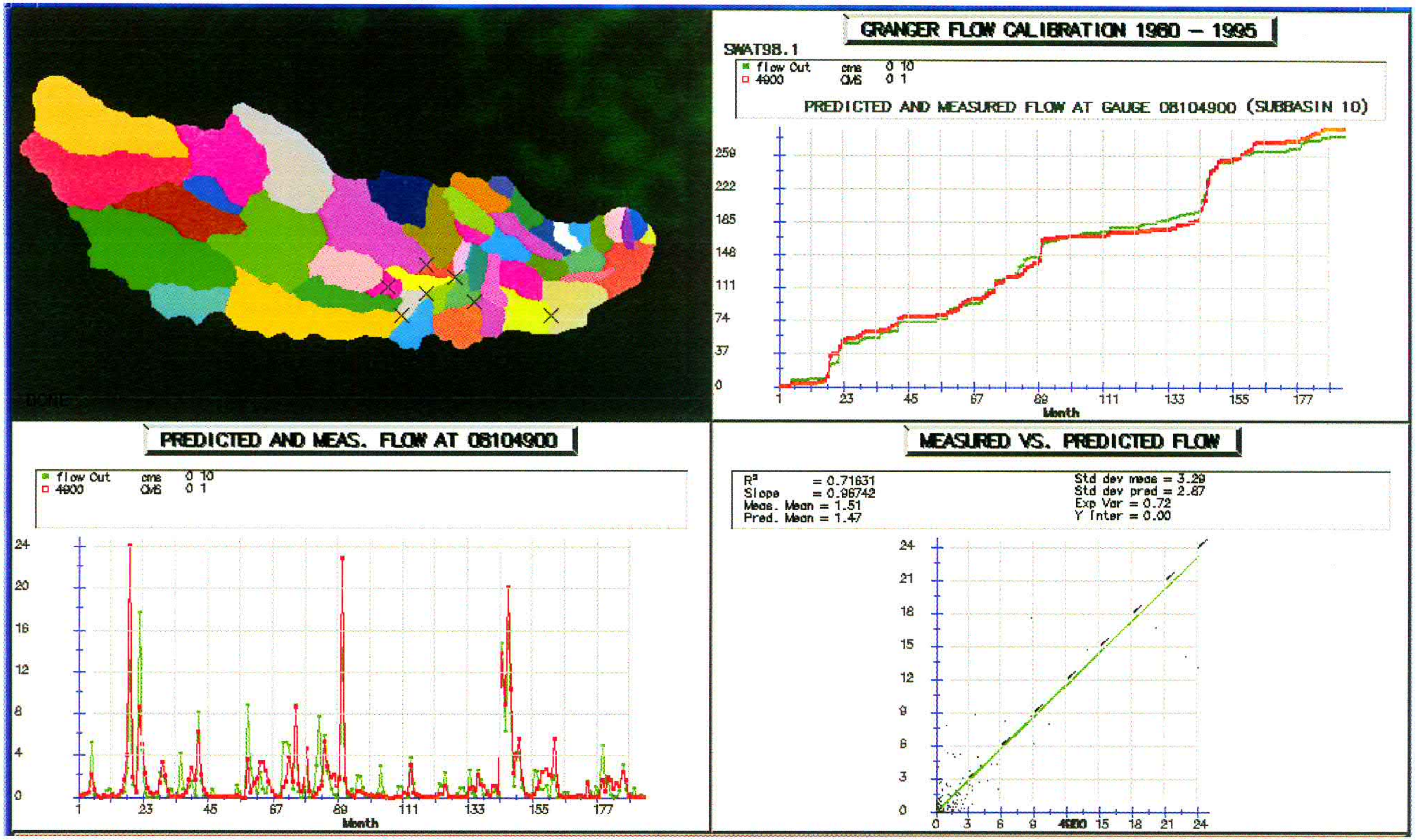


Figure A-2
Flow Calibration at USGS Gauge 08104900 (S. Fork San Gabriel River near Georgetown)

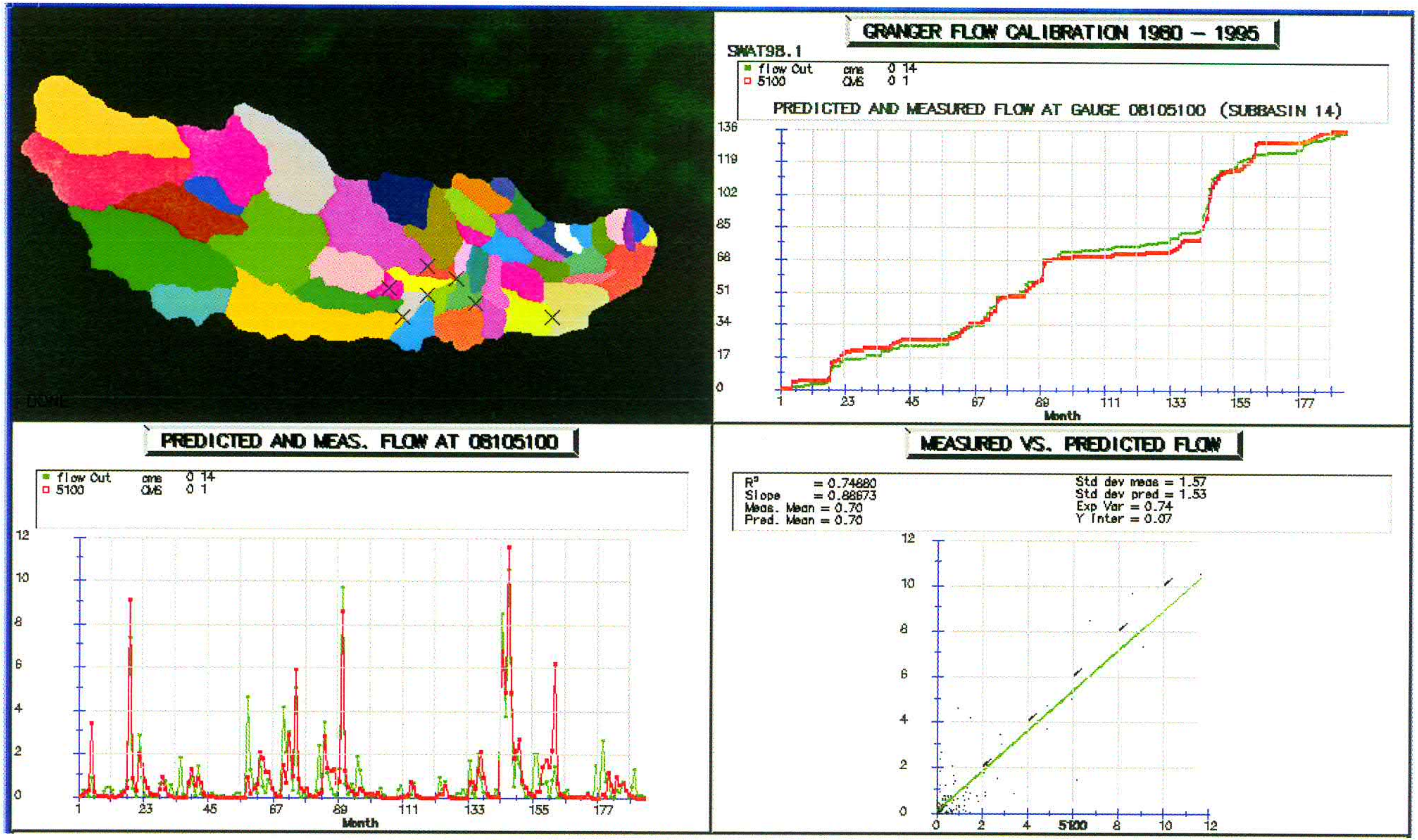


Figure A-3
Flow Calibration at USGS Gauge 08105100 (Berry Creek near Georgetown)

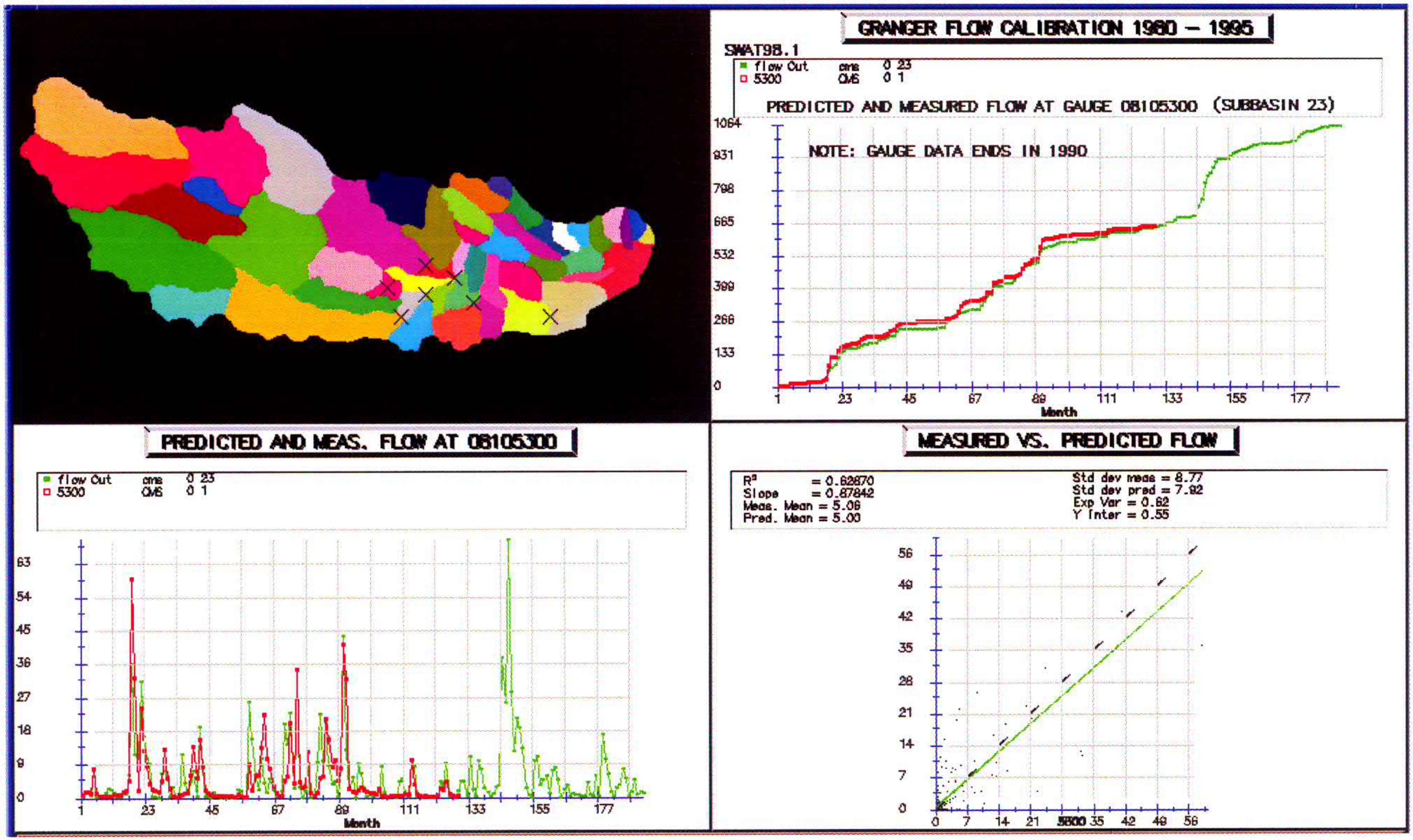


Figure A-4
Flow Calibration at USGS Gauge 08105300 (San Gabriel River near Weir)

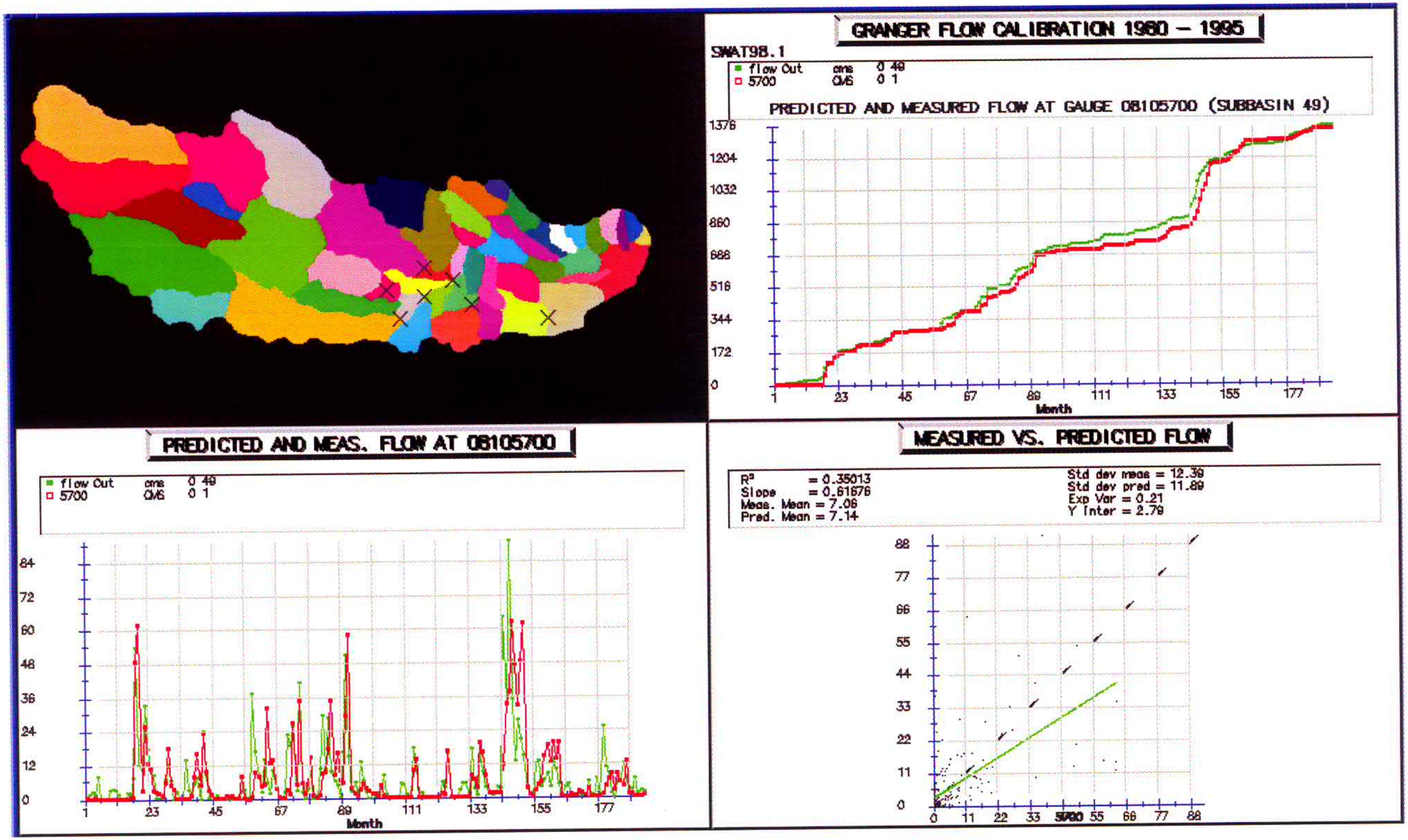


Figure A-5
Flow Calibration at USGS Gauge 08105700 (San Gabriel River at Laneport)

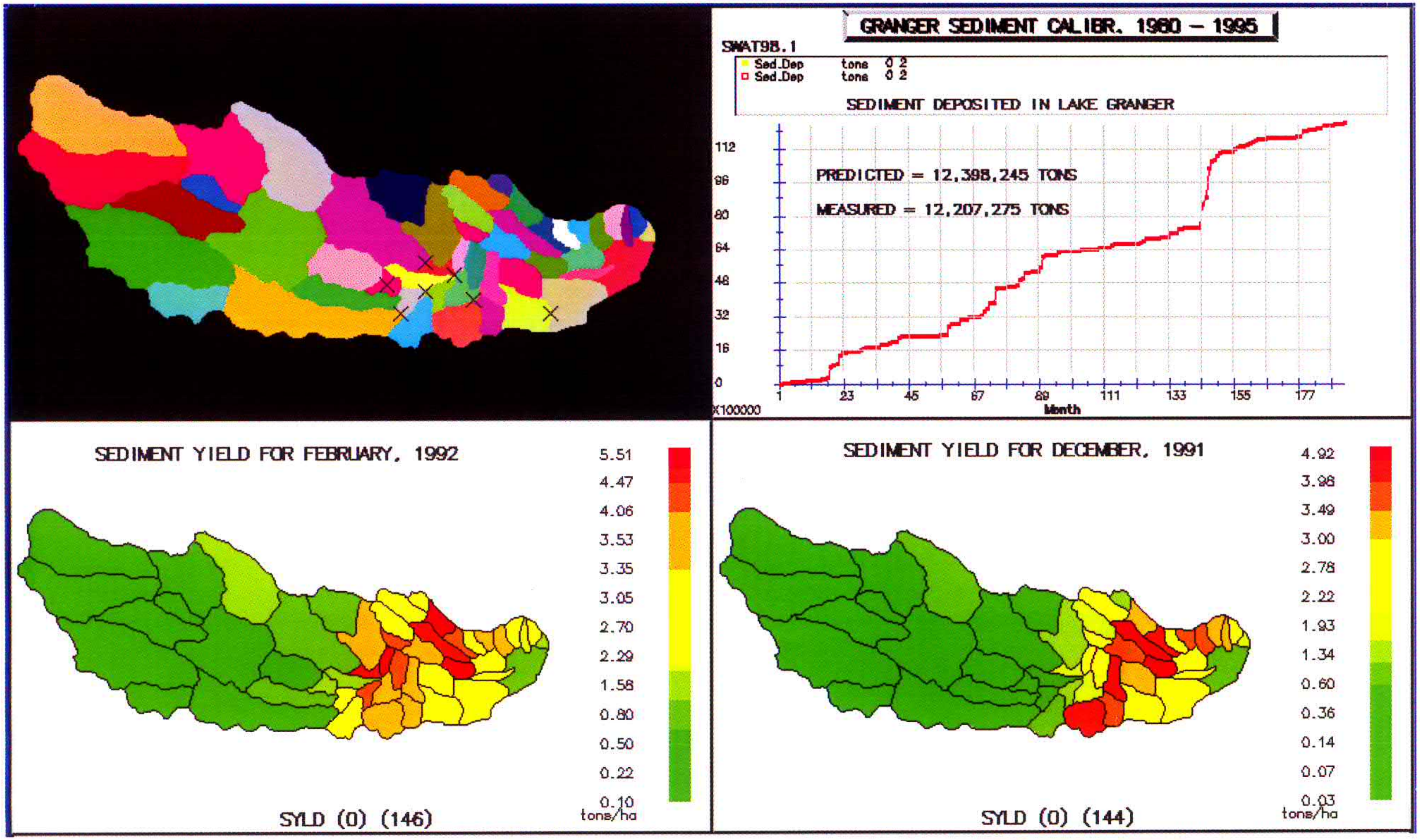


Figure A-6
Simulated Sediment in Granger Lake Watershed

Notes on Table A-1 (Appendix)

The only data on these tables that is extracted directly from SWAT output is ROUTED SEDIMENT and SEDIMENT YIELD. Some liberty has been taken to manipulate these two columns of data to obtain another view of sediment loads in each individual subbasin.

Sediment transport is a very dynamic process as surface runoff flows overland on soil surfaces and through channels in the stream network to the receiving waterbody. To arrive at the portion of the routed sediment load attributable to a particular subbasin, the sediment loads for each upstream subbasin has been subtracted out of the total load passing out of the individual subbasin. There is no measured data to indicate how accurate these loadings may actually be.

Those subbasins containing reservoirs (ie. Lake Georgetown) certainly are suspect as to the actual load of sediment leaving the subbasin since there was no detailed analysis of trap efficiency of the reservoir or concentration of sediment carried in any flow out of the reservoir.

Care should be taken in use of these hand-computed loadings as compared to the two columns of data identified above that came directly from model output.

TABLE A-1							
LAKE GRANGER PREDICTED SEDIMENT LOAD AND YIELD, 1980-1995							
(CORN, COTTON, GR.SRG, CONV TILL, P=1, NO PONDS)							
SUBBASIN	ROUTED SEDIMENT	SUBBASIN SEDIMENT	SUBBASIN AREA	SEDIMENT LOAD	AVE ANNUAL SED. LOAD	SEDIMENT YIELD	AVE.ANNUAL SED. YLD
	TONS	TONS	HA	TONS/HA	TONS/HA/YR	TONS/HA	TONS/HA/YR
1	17,940	17,940	14,260	1.26	0.08	1.25	0.08
2	23,156	23,156	13,224	1.75	0.11	1.75	0.11
3	30,474	30,474	16,868	1.81	0.11	1.80	0.11
4	8,756	8,756	4,420	1.98	0.12	1.96	0.12
5	216,480	175,384	9,424	18.61	1.16	6.22	0.39
6	1,765	1,765	2,128	0.83	0.05	0.82	0.05
7	11,331	11,331	7,368	1.54	0.10	1.54	0.10
8	160,052	160,052	10,620	15.07	0.94	15.09	0.94
9	528,478	298,903	13,132	22.76	1.42	3.85	0.24
10	239,713	200,483	12,504	16.03	1.00	4.06	0.25
11	47,913	47,913	4,080	11.74	0.73	11.83	0.74
12	534,120	5,642	4,652	1.21	0.08	1.33	0.08
13	584,767	274,846	1,036	265.30	16.58	16.06	1.00
14	270,295	110,243	10,904	10.11	0.63	6.11	0.38
15	49,221	49,221	4,792	10.27	0.64	10.27	0.64
16	496,147	446,926	4,764	93.81	5.86	42.56	2.66
17	1,493,277	726,834	760	956.36	59.77	50.83	3.18
18	27,629	27,629	1,568	17.62	1.10	17.78	1.11
19	3,856,252	2,983,858	1,004	2971.97	185.75	23.28	1.46
20	52,242	52,242	2,520	20.73	1.30	20.75	1.30
21	166,293	166,293	3,256	51.07	3.19	50.89	3.18
22	6,265,326	2,356,831	956	2465.30	154.08	45.69	2.86
23	10,351,155	2,418,861	1,508	1604.02	100.25	48.90	3.06
24	55,991	55,991	804	69.64	4.35	71.05	4.44
25	90,071	90,071	1,544	58.34	3.65	58.60	3.66
26	93,880	93,880	1,656	56.69	3.54	55.69	3.48
27	11,134,547	617,099	1,628	379.05	23.69	66.14	4.13
28	11,079,367	-149,060	3,176	-46.93	-2.93	55.34	3.46
29	124,189	124,189	2,460	50.48	3.16	50.92	3.18
30	12,207,081	1,003,525	4,664	215.16	13.45	48.70	3.04
31	57,571	57,571	844	68.21	4.26	67.97	4.25
32	89,128	89,128	2,340	38.09	2.38	37.73	2.36
33	114,643	114,643	2,360	48.58	3.04	48.49	3.03
34	24,549	24,549	756	32.47	2.03	32.21	2.01
35	280,853	141,661	1,492	94.95	5.93	74.13	4.63
36	170,213	170,213	2,364	72.00	4.50	72.93	4.56
37	311,695	164,995	1,928	85.58	5.35	50.28	3.14
38	467,815	156,120	1,372	113.79	7.11	93.47	5.84
39	395,026	114,173	1,044	109.36	6.84	69.34	4.33
40	38,526	38,526	968	39.80	2.49	39.74	2.48
41	43,228	43,228	808	53.50	3.34	54.44	3.40
42	1,468,930	354,122	1,668	212.30	13.27	44.45	2.78
43	33,568	33,568	836	40.15	2.51	39.87	2.49
44	54,585	54,585	1,132	48.22	3.01	48.35	3.02
45	44,073	44,073	1,072	41.11	2.57	41.19	2.57
46	21,977	21,977	720	30.52	1.91	30.91	1.93
47	26,325	26,325	720	36.56	2.29	36.31	2.27
48	11,280	11,280	384	29.38	1.84	29.46	1.84
49	13,733,757	-134,062	3,836	-34.95	-2.18	6.84	0.43

Explanation of Terminology Found in Table A-1

ROUTED SEDIMENT: Total reach routed sediment load (metric tons) from both channel and sheet and rill erosion that is delivered to the outlet of the subbasin. This data is from the *.rch (reach) file and includes all upstream subbasins.

SUBBASIN SEDIMENT: Same as ROUTED SEDIMENT except all upstream subbasins have been subtracted. Therefore, this is the total sediment load (metric tons) from channel and sheet and rill erosion for each individual subbasin.

SUBBASIN AREA: The area of each subbasin in hectares.

SEDIMENT LOAD: SUBBASIN SEDIMENT divided by SUBBASIN AREA (metric tons/hectare). This is the total sediment load from both channel and sheet and rill erosion on a per hectare basis for each individual subbasin.

AVE. ANNUAL SED. LOAD: SEDIMENT LOAD divided by number of years (48) of the swat simulation (metric tons/hectare/year). This is average annual sediment load from both channel and sheet and rill erosion for each subbasin.

SEDIMENT YIELD: Sediment from sheet and rill erosion only (metric tons/hectare) for each individual subbasin. This data comes from the *.bsb (subbasin) file.

AVE. ANNUAL SED. YLD: SEDIMENT YIELD divided by the number of years (48) of swat simulation (metric tons/hectare/year). This is the average annual sediment yield from sheet and rill erosion only for each subbasin.

TABLE A-2

STRUCTURE DATA FOR PLANNED DAMS IN GRANGER WATERSHED										
		Emergency Spillway		Principal Spillway			Emergency Spillway		Principal Spillway	
SITE ID	Drainage Area	Surface Area	Storage	Surface Area	Storage	Drainage Area	Surface Area	Storage	Surface Area	Storage
	Acres	Acres	Acre-Feet	Acres	Acre-Feet	Hectares	Hect.	Hect-m	Hect	Hect-m
site1	8,230	303.0	2,670.0	13.0	65.0	3330.6	122.6	5.3	329.3	8.0
site2	3,400	274.0	2,410.0	26.0	170.0	1375.9	110.9	10.5	297.3	21.0
site3	50,457	845.0	10,630.0	89.0	1,045.0	20419.2	342.0	36.0	1311.2	128.9
site4	5,774	419.0	5,335.0	132.0	1,215.0	2336.7	169.6	53.4	658.1	149.9
site5	2,545	315.0	3,415.0	42.0	210.0	1029.9	127.5	17.0	421.2	25.9
site6	2,044	374.0	4,820.0	28.0	255.0	827.2	151.4	11.3	594.5	31.5

TABLE A-3

PRELIMINARY DATA FOR PLANNED DAMS IN GRANGER WATERSHED

Areas derived from planimetered USGS Quads

PROPOSED SITE	Quad	Lat-Long	D.A. - Ac / Sq Mi	Elev.	Surface Acres	Inc. Ac-Ft.	Storage Acre-Feet	Storage Inches	Esp/Psp	DAM HT / EFF HT / STOR*HT
#1	Cobbs		8,230	810	651.0	4,770.0	6,830.0	9.96		35
	Cavern	30 46 18	12.86	800	303.0	2,060.0	2,670.0	3.89	EMER	30
		97 40		790	109.0	610.0	675.0	0.98		80,100
				780	13.0	65.0	65.0	0.09	PRIN	
				770	0.0	0.0	0.0	0.00		
#2	Cobbs		3,675	810	274.0	1,825.0	2,410.0	7.87	EMER	45
	Cavern	30 45	5.74	800	91.0	585.0	735.0	2.40		40
		97 40 45		790	26.0	150.0	170.0	0.56	PRIN	108,450
				780	4.0	20.0	20.0	0.07		
				770	0.0	0.0	0.0	0.00		
#3	Georgetown		50,457	770	845.0	6,695.0	10,630.0	2.53	EMER	75
		30 42 30	78.84	760	494.0	3,935.0	6,225.0	1.48		70
		97 40 30		750	293.0	2,290.0	3,560.0	0.85		744,100
				740	165.0	1,270.0	1,945.0	0.46		
				730	89.0	675.0	1,045.0	0.25	PRIN	
				720	46.0	370.0	520.0	0.12		
				710	28.0	150.0	155.0	0.04		
				700	2.0	5.0	5.0	0.00		
				695	0	0.0	0.0	0.00		
#4	Jarrell		5,805	760	627.0	5,230.0	8,615.0	17.81		65
		30 46 15	9.07	750	419.0	3,385.0	5,335.0	11.03	EMER	55
		97 32 30		740	258.0	1,950.0	2,860.0	5.91		293,425
				730	132.0	910.0	1,215.0	2.51	PRIN	
				720	50.0	305.0	370.0	0.76		
				710	11	65.0	70.0	0.14		
				700	2	5.0	5.0	0.01		
				695	0	0.0	0.0	0.00		
#5	Weir		2,545	660	505.0	4,100.0	6,490.0	30.60		35
		30 38 45	3.98	650	315.0	2,390.0	3,415.0	16.10	EMER	30
		97 33 30		640	163.0	1,025.0	1,235.0	5.82		102,450
				630	42.0	210.0	210.0	0.99	PRIN	
				620	0.0	0.0	0.0	0.00		

PRELIMINARY DATA FOR PLANNED DAMS IN GRANGER WATERSHED

Areas derived from planimetered USGS Quads

PROPOSED SITE	Quad	Lat-Long	D.A. - Ac / Sq Mi	Elev.	Surface Acres	Inc. Ac-Ft.	Storage Acre-Feet	Storage Inches	Esp/Psp	DAM HT / EFF HT / STOR*HT
#6	Weir		2,541	760	374.0	3,010.0	4,820.0	22.76	EMER	70
		30 43 45	3.97	750	228.0	1,810.0	2,850.0	13.46		65
		97 33 45		740	134.0	1,040.0	1,550.0	7.32		313,300
				730	74.0	510.0	700.0	3.31		
				720	28.0	190.0	255.0	1.20	PRIN	
				710	10	65.0	72.5	0.34		
				700	3	7.5	7.5	0.04		
				695	0	0.0	0.0	0.00		

RASTER MAP CATEGORY REPORT

LOCATION: Gulf   Page 1   Thu Apr 29 15:21:41 1999

REGION   north: 886800   east: -106200
          south: 812800   west: -221600
          res: 200   res: 200

MASK: granger.bnd in workspace, categories 1

MAPS: Lake Granger Watershed (granger.wshed in steve)
      granger landuse reclassed for swat (granger.mod.lu in bra)

Category Information

#	#	description	acres	% cover
1			35,236.46	7.57
	11	URBN	385.48	1.09
	21	AGRL	1452.95	4.12
	31	RNGE	25,817.01	73.27
	32	RNGB	7581.03	21.51
2			32,676.50	7.02
	11	URBN	306.40	0.94
	21	AGRL	494.20	1.51
	23	PAST	217.45	0.67
	31	RNGE	20,479.65	62.67
	32	RNGB	11,070.08	33.88
	51	WATR	108.72	0.33
3			41,680.83	8.96
	11	URBN	1680.28	4.03
	21	AGRL	326.17	0.78
	23	PAST	1848.31	4.43
	31	RNGE	19,777.88	47.45
	32	RNGB	17,998.76	43.18
	51	WATR	49.42	0.12
4			10,921.82	2.35
	0		19.77	0.18
	11	URBN	454.66	4.16
	21	AGRL	385.48	3.53
	23	PAST	859.91	7.87
	31	RNGE	1166.31	10.68
	32	RNGB	7956.62	72.85
	51	WATR	79.07	0.72

RASTER MAP CATEGORY REPORT

LOCATION: Gulf | Page 2 | Thu Apr 29 15:21:41 1999

REGION				
	north:	886800	east:	-106200
	south:	812800	west:	-221600
	res:	200	res:	200

MAPS: Lake Granger Watershed (granger.wshed in steve)
granger landuse reclassed for swat (granger.mod.lu in bra)

#		description	acres	% cover
5			23,286.70	5.00
	0		19.77	0.08
	11	URBN	336.06	1.44
	21	AGRL	2372.16	10.19
	23	PAST	899.44	3.86
	31	RNGE	13,125.95	56.37
	32	RNGB	6503.67	27.93
	51	WATR	29.65	0.13
6			5258.29	1.13
	21	AGRL	138.38	2.63
	23	PAST	148.26	2.82
	31	RNGE	3785.57	71.99
	32	RNGB	1166.31	22.18
	51	WATR	19.77	0.38
7			18,206.33	3.91
	0		9.88	0.05
	11	URBN	385.48	2.12
	21	AGRL	632.58	3.47
	23	PAST	652.34	3.58
	31	RNGE	11,159.04	61.29
	32	RNGB	5327.48	29.26
	51	WATR	39.54	0.22
8			26,242.02	5.64
	11	URBN	810.49	3.09
	21	AGRL	7867.66	29.98
	23	PAST	3795.46	14.46
	31	RNGE	8905.48	33.94
	32	RNGB	4773.97	18.19
	51	WATR	88.96	0.34
9			32,449.17	6.97
	11	URBN	2935.55	9.05
	21	AGRL	958.75	2.95
	23	PAST	3261.72	10.05
	31	RNGE	5011.19	15.44
	32	RNGB	20,212.78	62.29
	51	WATR	69.19	0.21

RASTER MAP CATEGORY REPORT

LOCATION: Gulf   Page 3   Thu Apr 29 15:21:41 1999

REGION		
	north: 886800	east: -106200
	south: 812800	west: -221600
	res: 200	res: 200

MAPS: Lake Granger Watershed (granger.wshed in steve)
granger landuse reclassed for swat (granger.mod.lu in bra)

#		description (Category Information)	acres	% cover
10		Streamgauge 08104900	30,897.38	6.64
	11	URBN	3548.36	11.48
	21	AGRL	1126.78	3.65
	23	PAST	2490.77	8.06
	31	RNGE	840.14	2.72
	32	RNGB	22,802.39	73.80
	51	WATR	88.96	0.29
11			10,081.68	2.17
	11	URBN	1561.67	15.49
	21	AGRL	672.11	6.67
	23	PAST	761.07	7.55
	31	RNGE	138.38	1.37
	32	RNGB	6938.57	68.82
	51	WATR	9.88	0.10
12		Streamgauge 08104700, Lake Georgetown	11,495.09	2.47
	11	URBN	1551.79	13.50
	23	PAST	3390.21	29.49
	31	RNGE	355.82	3.10
	32	RNGB	4398.38	38.26
	51	WATR	1798.89	15.65
13			2559.96	0.55
	11	URBN	1759.35	68.73
	23	PAST	444.78	17.37
	32	RNGB	336.06	13.13
	51	WATR	19.77	0.77
14		Streamgauge 08105100	26,943.78	5.79
	11	URBN	4339.08	16.10
	21	AGRL	1789.00	6.64
	23	PAST	1976.80	7.34
	31	RNGE	2965.20	11.01
	32	RNGB	15,834.17	58.77
	51	WATR	39.54	0.15

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|                        RASTER MAP CATEGORY REPORT                           |
|LOCATION: Gulf                   Page 4            Thu Apr 29 15:21:41 1999|
|-----------------------------------------------------------------------------|
|          north: 886800    east: -106200                                     |
|REGION    south: 812800    west: -221600                                     |
|          res:      200    res:      200                                     |
|-----------------------------------------------------------------------------|
|MAPS: Lake Granger Watershed (granger.wshed in steve)                        |
|        granger landuse reclassed for swat (granger.mod.lu in bra)           |
|-----------------------------------------------------------------------------|
|                     Category Information                 |          |   %  |
| #|description                                           |     acres| cover|
|-----------------------------------------------------------------------------|
|15|                                                      | 11,841.03|  2.54|
|  |------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . |     79.07|  0.67|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . |   1551.79| 13.11|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . |    642.46|  5.43|
|  |31|RNGE . . . . . . . . . . . . . . . . . . . . . . . |    118.61|  1.00|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . |   9429.34| 79.63|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . |     19.77|  0.17|
|---------------------------------------------------------|----------|------|
|16|                                                      | 11,771.84|  2.53|
|  |------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . |    593.04|  5.04|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . |   5357.13| 45.51|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . |   3923.95| 33.33|
|  |31|RNGE . . . . . . . . . . . . . . . . . . . . . . . |    217.45|  1.85|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . |   1660.51| 14.11|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . |     19.77|  0.17|
|---------------------------------------------------------|----------|------|
|17|Streamgauge 08105200(limited data)                    |   1877.96|  0.40|
|  |------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . |    158.14|  8.42|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . |    632.58| 33.68|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . |    593.04| 31.58|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . |    484.32| 25.79|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . |      9.88|  0.53|
|---------------------------------------------------------|----------|------|
|18|                                                      |   3874.53|  0.83|
|  |------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . |   2174.48| 56.12|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . |    425.01| 10.97|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . |    780.84| 20.15|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . |    494.20| 12.76|
|---------------------------------------------------------|----------|------|
|19|Streamgauge 08105000                                  |   2480.88|  0.53|
|  |------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . |   1798.89| 72.51|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . |     88.96|  3.59|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . |    207.56|  8.37|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . |    316.29| 12.75|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . |     69.19|  2.79|
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RASTER MAP CATEGORY REPORT

LOCATION: Gulf Page 5 Thu Apr 29 15:21:41 1999

REGION north: 886800 east: -106200
south: 812800 west: -221600
res: 200 res: 200

MAPS: Lake Granger Watershed (granger.wshed in steve)
granger landuse reclassed for swat (granger.mod.lu in bra)

Category Information

#	#	description	acres	% cover
20			6226.92	1.34
	11	URBN	2550.07	40.95
	21	AGRL	741.30	11.90
	23	PAST	1749.47	28.10
	31	RNGE	168.03	2.70
	32	RNGB	968.63	15.56
	51	WATR	49.42	0.79
21			8045.58	1.73
	11	URBN	504.08	6.27
	21	AGRL	3123.34	38.82
	23	PAST	3874.53	48.16
	31	RNGE	405.24	5.04
	32	RNGB	108.72	1.35
	51	WATR	29.65	0.37
22			2362.28	0.51
	11	URBN	316.29	13.39
	21	AGRL	711.65	30.13
	23	PAST	583.16	24.69
	31	RNGE	9.88	0.42
	32	RNGB	682.00	28.87
	51	WATR	59.30	2.51
23		Streamgauge 08105300	3726.27	0.80
	11	URBN	345.94	9.28
	21	AGRL	1373.88	36.87
	23	PAST	1611.09	43.24
	32	RNGB	336.06	9.02
	51	WATR	59.30	1.59
24			1986.68	0.43
	11	URBN	69.19	3.48
	21	AGRL	1443.06	72.64
	23	PAST	355.82	17.91
	32	RNGB	108.72	5.47
	51	WATR	9.88	0.50

RASTER MAP CATEGORY REPORT

LOCATION: Gulf — Page 6 — Thu Apr 29 15:21:41 1999

REGION	north: 886800	east: -106200
	south: 812800	west: -221600
	res: 200	res: 200

MAPS: Lake Granger Watershed (granger.wshed in steve)
granger landuse reclassed for swat (granger.mod.lu in bra)

Category Information #		description	acres	% cover
25			3815.22	0.82
	11	URBN	168.03	4.40
	21	AGRL	2391.93	62.69
	23	PAST	1235.50	32.38
	32	RNGB	19.77	0.52
26			4091.98	0.88
	21	AGRL	2559.96	62.56
	23	PAST	1136.66	27.78
	32	RNGB	385.48	9.42
	51	WATR	9.88	0.24
27			4022.79	0.86
	11	URBN	187.80	4.67
	21	AGRL	2144.83	53.32
	23	PAST	1690.16	42.01
28	Streamgauge 08105400		7847.90	1.69
	11	URBN	79.07	1.01
	21	AGRL	6335.64	80.73
	23	PAST	1363.99	17.38
	32	RNGB	69.19	0.88
29			6078.66	1.31
	11	URBN	9.88	0.16
	21	AGRL	4329.19	71.22
	23	PAST	1156.43	19.02
	32	RNGB	543.62	8.94
	51	WATR	39.54	0.65
30			11,524.74	2.48
	11	URBN	365.71	3.17
	21	AGRL	7768.82	67.41
	23	PAST	3202.42	27.79
	31	RNGE	29.65	0.26
	51	WATR	158.14	1.37

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|                         RASTER MAP CATEGORY REPORT                          |
|LOCATION: Gulf                         Page 7          Thu Apr 29 15:21:41 1999|
|-----------------------------------------------------------------------------|
|          north: 886800    east: -106200                                      |
|REGION    south: 812800    west: -221600                                      |
|          res:      200    res:      200                                      |
|-----------------------------------------------------------------------------|
|MAPS: Lake Granger Watershed (granger.wshed in steve)                         |
|        granger landuse reclassed for swat (granger.mod.lu in bra)           |
|-----------------------------------------------------------------------------|
|                    Category Information                  |          |   %  |
| #|description                                            |     acres| cover|
|-----------------------------------------------------------------------------|
|31|                                                        |   2085.52|  0.45|
|  |--------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . . |    138.38|  6.64|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . . |   1166.31| 55.92|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . . |    632.58| 30.33|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . . |    128.49|  6.16|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . . |     19.77|  0.95|
|-----------------------------------------------------------|----------|------|
|32|                                                        |   5782.14|  1.24|
|  |--------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . . |    187.80|  3.25|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . . |   2144.83| 37.09|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . . |   2589.61| 44.79|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . . |    850.02| 14.70|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . . |      9.88|  0.17|
|-----------------------------------------------------------|----------|------|
|33|                                                        |   5831.56|  1.25|
|  |--------------------------------------------------------|----------|------|
|  |11|URBN . . . . . . . . . . . . . . . . . . . . . . . . |    118.61|  2.03|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . . |   2629.14| 45.08|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . . |   1443.06| 24.75|
|  |31|RNGE . . . . . . . . . . . . . . . . . . . . . . . . |     39.54|  0.68|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . . |   1591.32| 27.29|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . . |      9.88|  0.17|
|-----------------------------------------------------------|----------|------|
|34|                                                        |   1868.08|  0.40|
|  |--------------------------------------------------------|----------|------|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . . |    642.46| 34.39|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . . |    474.43| 25.40|
|  |31|RNGE . . . . . . . . . . . . . . . . . . . . . . . . |    207.56| 11.11|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . . |    543.62| 29.10|
|-----------------------------------------------------------|----------|------|
|35|                                                        |   3686.73|  0.79|
|  |--------------------------------------------------------|----------|------|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . . |   2905.90| 78.82|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . . |    682.00| 18.50|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . . |     98.84|  2.68|
|-----------------------------------------------------------|----------|------|
|36|                                                        |   5841.44|  1.26|
|  |--------------------------------------------------------|----------|------|
|  |21|AGRL . . . . . . . . . . . . . . . . . . . . . . . . |   4260.00| 72.93|
|  |23|PAST . . . . . . . . . . . . . . . . . . . . . . . . |   1492.48| 25.55|
|  |32|RNGB . . . . . . . . . . . . . . . . . . . . . . . . |     39.54|  0.68|
|  |51|WATR . . . . . . . . . . . . . . . . . . . . . . . . |     49.42|  0.85|
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RASTER MAP CATEGORY REPORT

LOCATION: Gulf — Page 8 — Thu Apr 29 15:21:41 1999

REGION		
	north: 886800	east: -106200
	south: 812800	west: -221600
	res: 200	res: 200

MAPS: Lake Granger Watershed (granger.wshed in steve)
granger landuse reclassed for swat (granger.mod.lu in bra)

#		description	acres	% cover
37			5841.44	1.26
	21	AGRL	1749.47	36.72
	23	PAST	1067.47	22.41
	32	RNGB	1927.38	40.46
	51	WATR	19.77	0.41
38			3390.21	0.73
	11	URBN	59.30	1.75
	21	AGRL	2698.33	79.59
	23	PAST	543.62	16.03
	32	RNGB	88.96	2.62
39			2579.72	0.55
	21	AGRL	2026.22	78.54
	23	PAST	543.62	21.07
	51	WATR	9.88	0.38
40			2391.93	0.51
	11	URBN	365.71	15.29
	21	AGRL	1848.31	77.27
	23	PAST	177.91	7.44
41			1996.57	0.43
	11	URBN	39.54	1.98
	21	AGRL	1828.54	91.58
	23	PAST	118.61	5.94
	51	WATR	9.88	0.50
42			4121.63	0.89
	11	URBN	49.42	1.20
	21	AGRL	2550.07	61.87
	23	PAST	1502.37	36.45
	51	WATR	19.77	0.48

RASTER MAP CATEGORY REPORT

LOCATION: Gulf — Page 9 — Thu Apr 29 15:21:41 1999

REGION			
north:	886800	east:	-106200
south:	812800	west:	-221600
res:	200	res:	200

MAPS: Lake Granger Watershed (granger.wshed in steve)
granger landuse reclassed for swat (granger.mod.lu in bra)

#		description (Category Information)	acres	% cover
43			2065.76	0.44
	11	URBN	19.77	0.96
	21	AGRL	1650.63	79.90
	23	PAST	395.36	19.14
44			2797.17	0.60
	11	URBN	9.88	0.35
	21	AGRL	1907.61	68.20
	23	PAST	879.68	31.45
45			2648.91	0.57
	11	URBN	19.77	0.75
	21	AGRL	2204.13	83.21
	23	PAST	405.24	15.30
	51	WATR	19.77	0.75
46			1779.12	0.38
	21	AGRL	1423.30	80.00
	23	PAST	355.82	20.00
47			1779.12	0.38
	11	URBN	9.88	0.56
	21	AGRL	1611.09	90.56
	23	PAST	148.26	8.33
	51	WATR	9.88	0.56
48			948.86	0.20
	11	URBN	59.30	6.25
	21	AGRL	632.58	66.67
	23	PAST	256.98	27.08
49		Lake Granger	9478.76	2.04
	11	URBN	29.65	0.31
	21	AGRL	850.02	8.97
	23	PAST	3340.79	35.25
	51	WATR	5258.29	55.47
TOTAL			465,348.60	100.00

Appendix C

Water Quality Management Plan Best Management Practice Inventory

Little River-San Gabriel SWCD
TSSWCB Project 05-09

Water Quality Management Plan Best Management Practice Inventory

Red - Installed/Cost-Shared

Plan Number	County	Acres	PRACTICES	512 - Pasture/Hayland Planting	600 - Terraces in Conservation Plan	600 - Terraces Installed	412 - Grassed Waterways in Consv. Plan	412 - Grassed Waterways Installed	330 - Contour Farming	378 - Livestock Pond	342 - Critical Area Planting	511 - Forage Harvest Management	328 - Conservation Crop Rotation	528A - Prescribed Grazing	590 - Nutrient Management	595 - Pest Management	329 - Conservation Tillage	344 - Residue Management-Seasonal
				ac.	ft.	ft.	ac.	ac.	ac.	no.	ac.	ac.	ac.	ac.	ac.	ac.	ac.	ac.
101	Williamson	56.0			12400.0		3	3.0	47.0				53.0		56.0	56.0	53.0	53.0
102	Williamson	51.0		34.2	7800.0		4	1.8	43.0				43.0		47.0	47.0	43.0	43.0
103	Williamson	188.0			38000.0	4837	7	1.4	144.0				144.0	35.0	186.0	186.0	144.0	144.0
104	Williamson	42.0								1	2.0			42.0	42.0	42.0		
105	Williamson	276.0		17.5	47138.0	19726	8	2.1	215.0				215.0	51.0	274.0	274.0	215.0	215.0
106	Williamson	100.0		49.4						1				100.0	100.0	100.0		
107	Williamson	190.0		38.8	14000.0		2		50.0	1		39.0	50.0	97.0	188.0	188.0	50.0	50.0
108	Williamson	25.0		7.5							1.3	11.0		13.0	24.0	24.0		
109	Williamson	30.0		27.7										30.0	30.0	30.0		
110	Williamson	340.0		14.3				1.2			3.2							
111	Williamson	105.0		6.8	7000.0	5713	1		55.0		1.4	8.0	55.0	40.0	104.0	104.0	55.0	55.0
112	Williamson	157.0		138.5								144.0		13.0	157.0	157.0		
113	Williamson	19.0		19.0								19.0			19.0	19.0		
114	Williamson	114.0			14500.0		2		75.0	1			99.0	13.0	114.0	114.0	99.0	99.0
115	Williamson	203.0		37.3	26000.0		2		100.0	1	1.9	42.0	141.0	17.0	202.0	202.0	141.0	141.0
116	Williamson	139.0			9900.0	9020	3	0.9	36.0				136.0		139.0	139.0	136.0	136.0
117	Williamson	300.0			74000.0		20	11.5	280.0				280.0		300.0	300.0	280.0	280.0
118	Williamson	35.0			3500.0	2910	3	1.7	30.0				30.0		30.0	30.0	30.0	30.0
119	Williamson	238.0			42500.0	27881	6		172.0			15.0	172.0	45.0	238.0	238.0	172.0	172.0
120	Williamson	930.0			193800.0	11601	27	2.1	753.0			43.0	753.0	107.0	930.0	930.0	753.0	753.0
121	Williamson	120.0			21000.0	19492	3		76.0				87.0	30.0	120.0	120.0	87.0	87.0
122	Williamson	201.0			39000.0	22763	11	1.5	190.0				190.0		201.0	201.0	190.0	190.0

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				Red - Installed/Cost-Shared														
				ac.	ft.	ft.	ac.	ac.	ac.	no.	ac.	ac.	ac.	ac.	ac.	ac.	ac.	ac.
123	Williamson	155.0			22000.0	18487	3	1.7	124.0				133.0		136.0	136.0	133.0	133.0
124	Williamson	412.0			72000.0		12	3.6	317.0			19.0	332.0	36.0	399.0	399.0	332.0	332.0
125	Williamson	28.0		11.0	3000.0		4	2.6	22.0				22.0		26.0	26.0	22.0	22.0
126	Williamson	60.0		25.5								40.0		18.0	58.0	58.0		
127	Williamson	106.0			10000.0	7232	4.5	2.2	65.5				81.5	20.0	86.0	86.0	81.5	81.5
128	Williamson	canceled																
129	Williamson	canceled																
130	Williamson	242.0		4.0	35000.0	8210	5	1.9	200.0				200.0	37.0	242.0	242.0	200.0	200.0
131	Williamson	29.0		7.8										27.0	27.0	27.0		
132	Williamson	75.0		47.0										73.0	73.0	73.0		
133	Williamson	1,111.0		8.3							5.0			1111.0	1111.0	1111.0		
134	Williamson	128.0			26600.0		2		103.0				103.0	23.0	128.0	128.0	103.0	103.0
135	Williamson	185.0			27000.0	18240	5	3.0	180.0				180.0		185.0	185.0	180.0	180.0
136	Williamson	363.0			43700.0		10	1.0	323.0				323.0	30.0	363.0	363.0	323.0	323.0
137	Williamson	288.0			41700.0	17563	5.7	3.0	242.3		1.2		242.3		249.0	249.0		242.3
139	Williamson	10.0		9.7								10.0			10.0	10.0		
140	Williamson	Active 75																
141	Williamson	148.0										45.0		103.0	45.0	45.0		
142	Williamson	83.0		18.4										83.0	83.0	83.0		
143	Williamson	243.0			33000.0		1	0.6	164.0		1.3		164.0	73.0	238.0	238.0	164.0	164.0
144	Williamson	79.0			18400.0	10134	5	1.6	74.0				74.0		79.0	79.0	74.0	74.0
145	Williamson	114.0		35.4										114.0	38.0	38.0		

Little River-San Gabriel SWCD
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				Red - Installed/Cost-Shared														
				ac.	ft.	ft.	ac.	ac.	ac.	no.	ac.	ac.	ac.	ac.	ac.	ac.	ac.	ac.
146	Williamson	70.0		31.1								5.0		65.0	44.0	44.0		
147	Williamson	220.0		2.8	44000.0	9389	13	5.8	187.0				187.0	17.0	217.0	217.0	187.0	187.0
148	Williamson	Active 60																
149	Williamson	66.0			13000.0	12382	2		64.0				64.0		66.0	66.0		64.0
150	Williamson	212.0			34500.0	528	6.5	1.2	205.5				205.5		212.0	212.0	205.5	205.5
151	Williamson	191.0		87.3	47600.0		10	9.0	181.0				181.0		191.0	191.0	181.0	181.0
152	Williamson	10.0		10.0								10.0			10.0	10.0		
153	Williamson	canceled																
154	Williamson	455.0			24000.0		3	0.9	92.0				104.0		107.0	107.0		104.0
155	Williamson	806.0			122000.0	8356	12		653.0				653.0	116.0	781.0	781.0		653.0
156	Williamson	21.0		7.2								8.0		12.0	20.0	20.0		
157	Williamson	165.0		27.6										165.0	92.1			
158	Williamson	170.0		26.0	4200.0		1		29.0			60.0	29.0	80.0	90.0	90.0		29.0
159	Williamson	canceled																
160	Williamson	80.0		12.3								41.0		39.0	41.0	41.0		
161	Williamson	43.0			8000.0	7688	2		41.0				41.0		43.0	43.0		41.0
162	Williamson	112.0			24000.0	2321	6	3.4	98.0				98.0	6.0	110.0	110.0		98.0
163	Williamson	39.0																
164	Williamson	182.0			40205.0		10	0.4	149.0				149.0	23.0	182.0	182.0		149.0
166	Williamson	77.0			14000.0	2404	5.4	2.3	71.6				71.6		77.0	77.0		71.6
167	Williamson	180.0			26000.0		2	1.3	131.0	1			131.0	42.0	175.0	175.0		131.0
169	Williamson	145.0		13.3	20000.0		5		71.0	1		11.0	71.0	58.0	145.0	145.0		71.0

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				Red - Installed/Cost-Shared														
				ac.	ft.	ft.	ac.	ac.	ac.	no.	ac.	ac.	ac.	ac.	ac.	ac.	ac.	ac.
170	Williamson	195.0		90.1									11.0	184.0	113.0	113.0		11.0
171	Williamson	114.0		44.7										111.0	32.0	32.0		
173	Williamson	208.0		37.8	5000.0				22.0				22.0	185.0	70.0	70.0	22.0	22.0
174	Williamson	22.0		18.5								22.0			22.0	22.0		
175	Williamson	102.0		7.0	4000.0				37.0	1			37.0	64.0	72.0	72.0		37.0
176	Williamson	224.0			52000.0		16	3.0	200.0			5.0	200.0		211.0	221.0		200.0
177	Williamson	61.0			13500.0		2	1.10	57.0				57.0		59.0	59.0		57.0
178	Williamson	86.0								1								
179	Williamson	60.0		9.5	7000.0				37.0	1			46.0	14.0	60.0	60.0		46.0
180	Williamson	83.0		16.9	9000.0	7026	1.5	1.2	81.5				81.5		83.0	83.0		81.5
181	Williamson	98.0			26000.0	3489	6	4.8	92.0				92.0		98.0	98.0		92.0
182	Williamson	canceled																
183	Williamson	Active 57										57.0			57.0	57.0		
		12,215.0		1000.2		257392.0		82.8	6580.4	10.0	17.3	654.0	6834.4	3562.0	10557.1	10475.0	4656.0	6834.4