GRANGER LAKE SEDIMENTATION AND WATERSHED CONSERVATION IMPLEMENTATION ASSESSMENT

A Thesis

by

JASON ROSS MCALISTER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2011

Major Subject: Rangeland Ecology and Management

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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

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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.

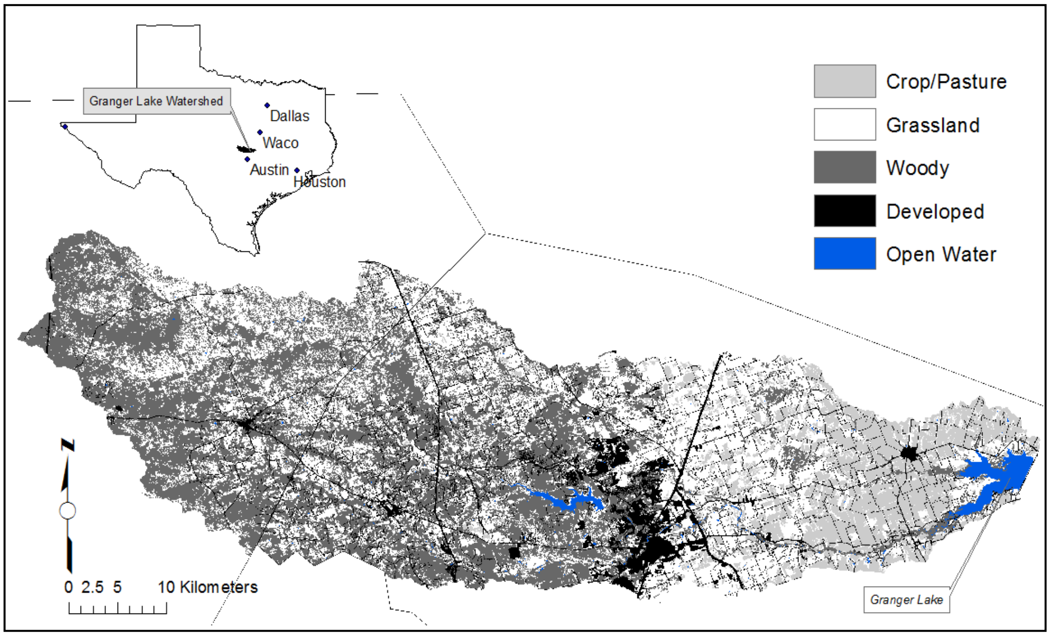
Ho: There is no change in watershed sediment delivery as a result of conservation practice implementation.

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).

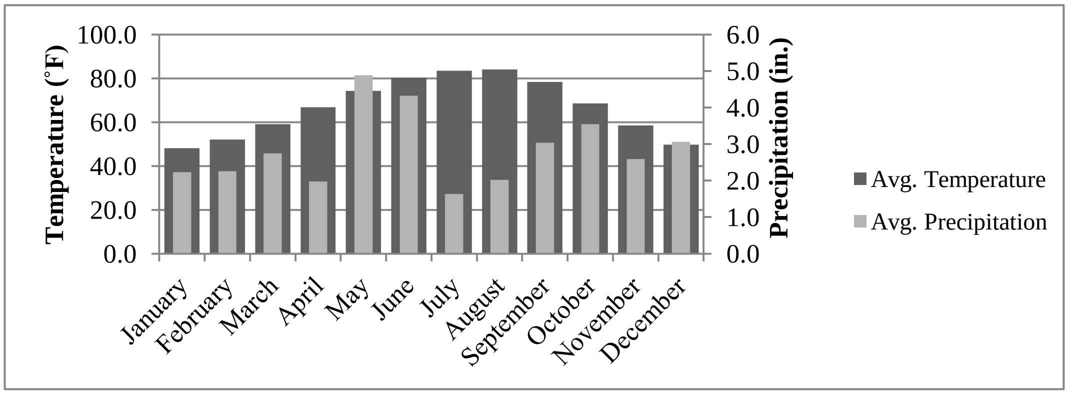
Table 2: Granger Lake Watershed conservation practices cost-shared 2007-2010.

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.



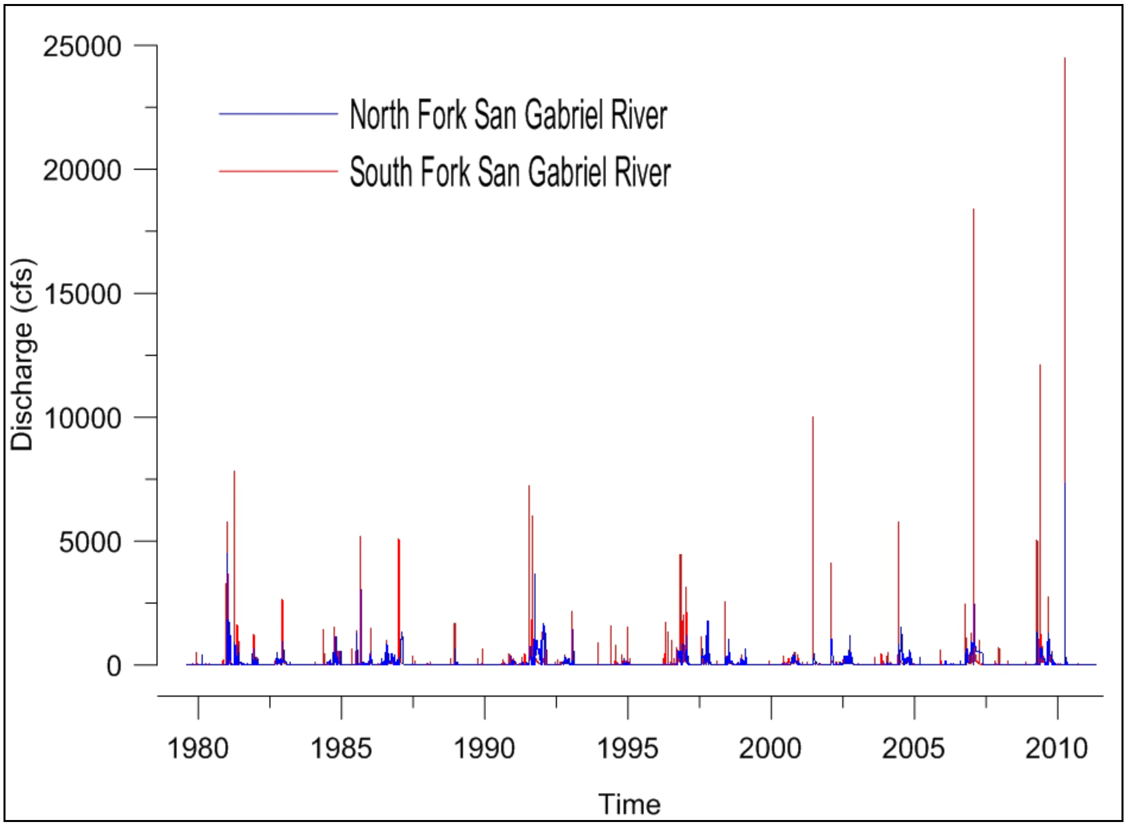
2.5 Soils

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.

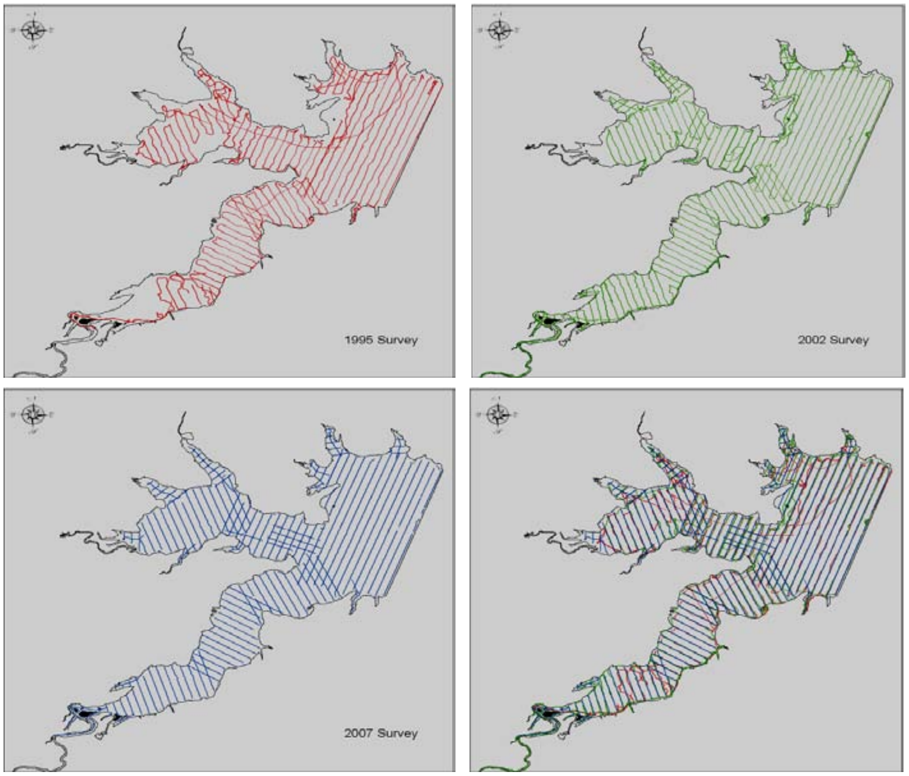
Aerial Imagery	Resolution	Date of Acquisition	Lake Elevation (ft)
Texas Orthoimagery Program Granger NE	1m	23-Jan-1995	504.18
Texas Orthoimagery Program Granger SE	1m	23-Jan-1995	504.18
Texas Orthoimagery Program Granger Lake NW	1m	23-Jan-1995	504.18
Texas Orthoimagery Program Granger Lake SW	1m	23-Jan-1995	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.

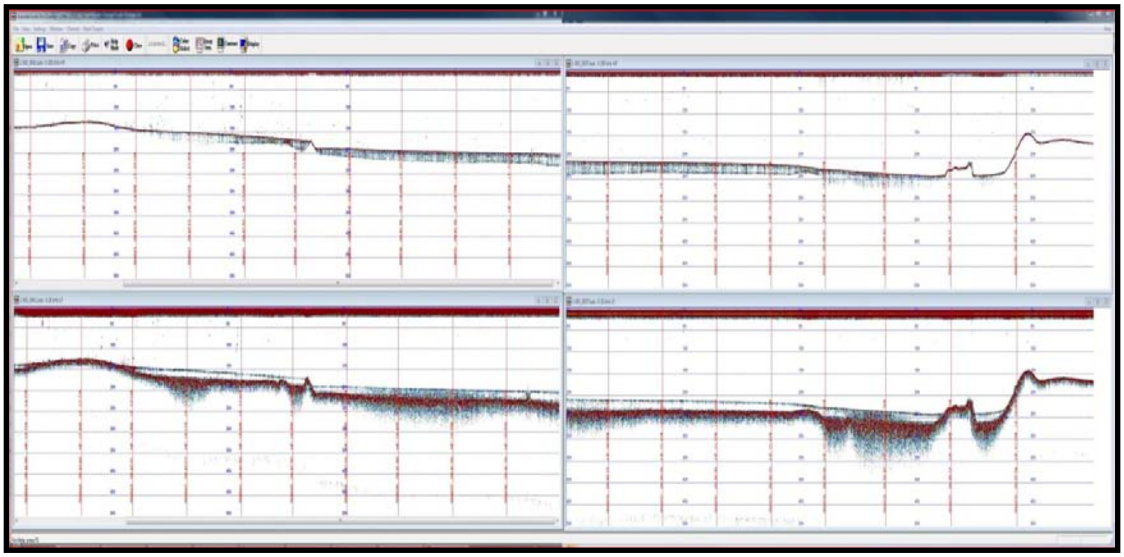
The hydro-acoustic sediment profiling system used in the survey was developed by Knudsen Engineering, Ltd. Knudsen echosounders are used for precision measurement of water depths for hydrographic survey, dredging, ship navigation, defense, and scientific applications. The system used consists of a Knudsen 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.

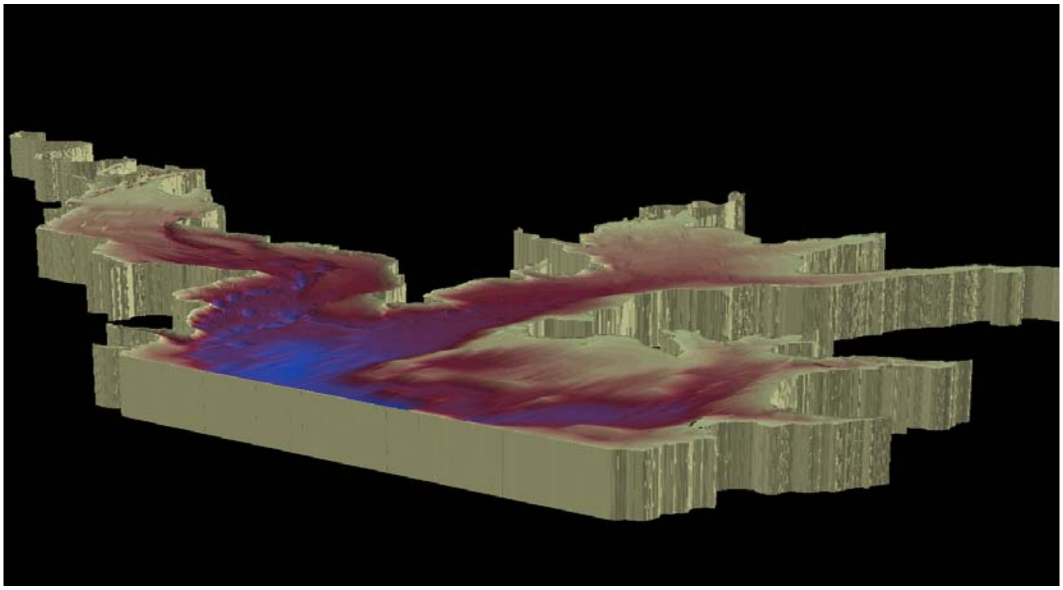


Volume and area calculations were referenced to water levels provided by the Granger Lake USGS gage.

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.

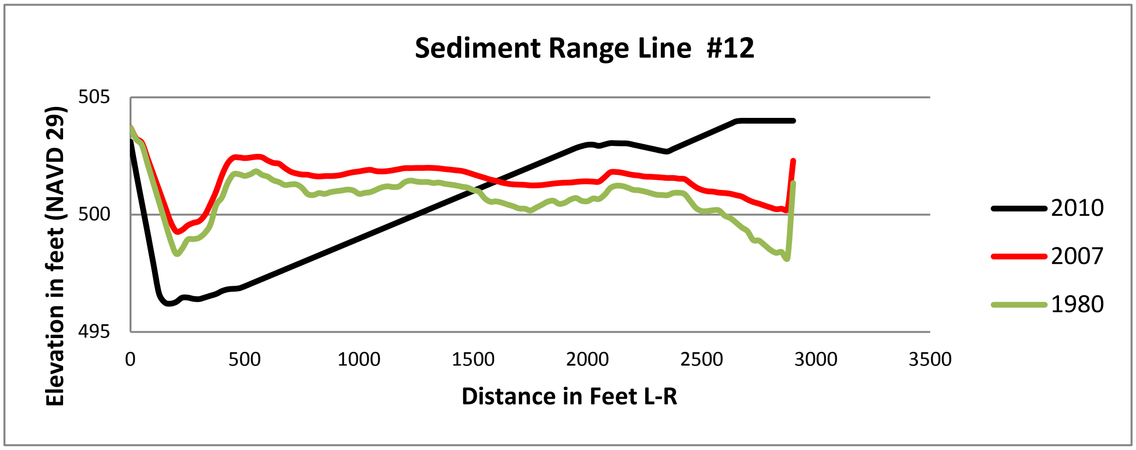
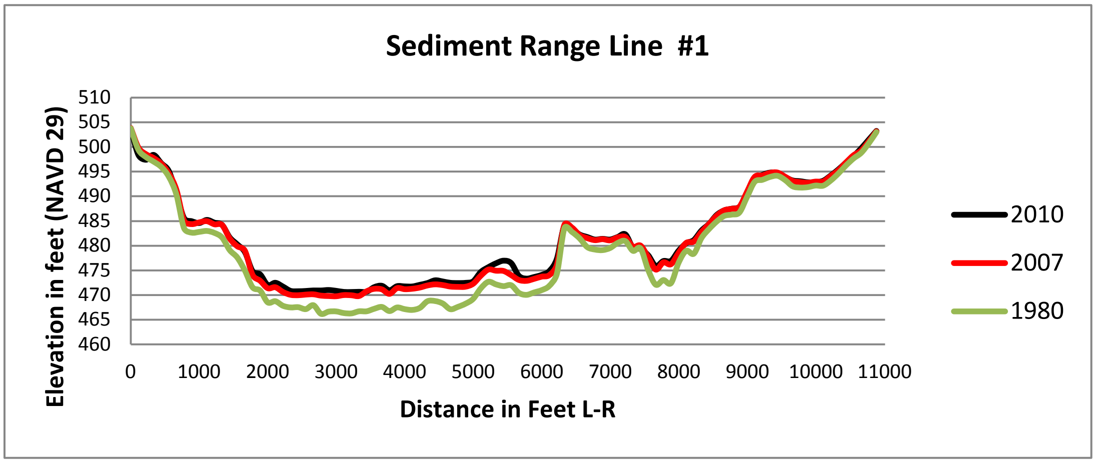


Figure 9: Example of range-line extracted from TIN illustrating change in channel morphology and inaccessibility of survey area.



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.

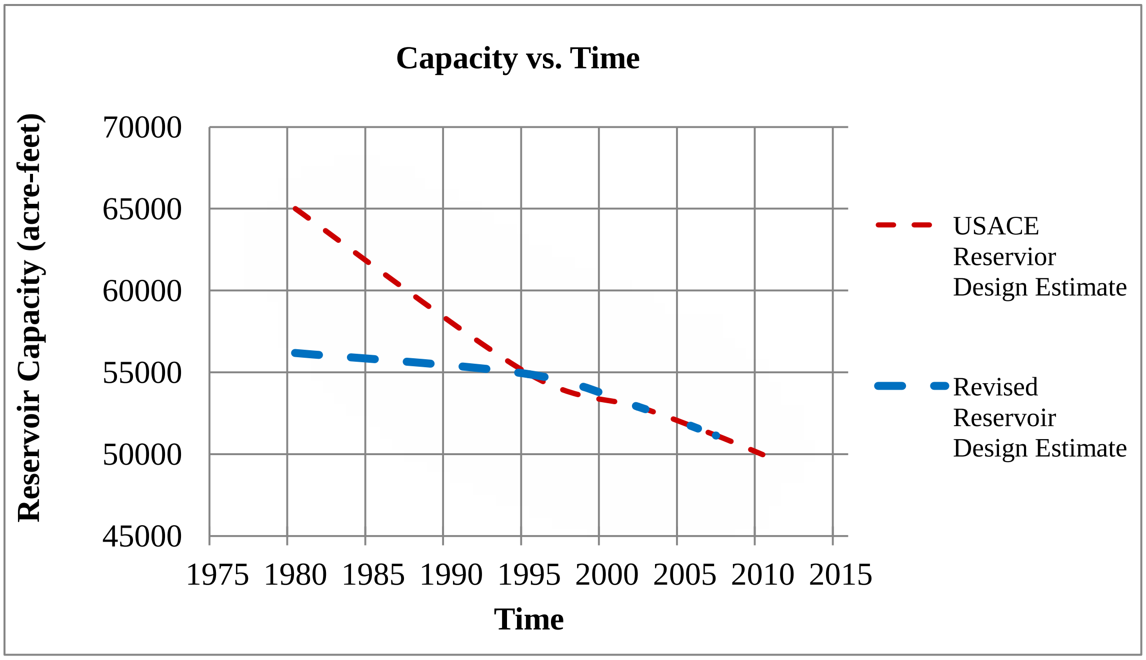
4.1 Assessment of Pre-impoundment Capacity

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.

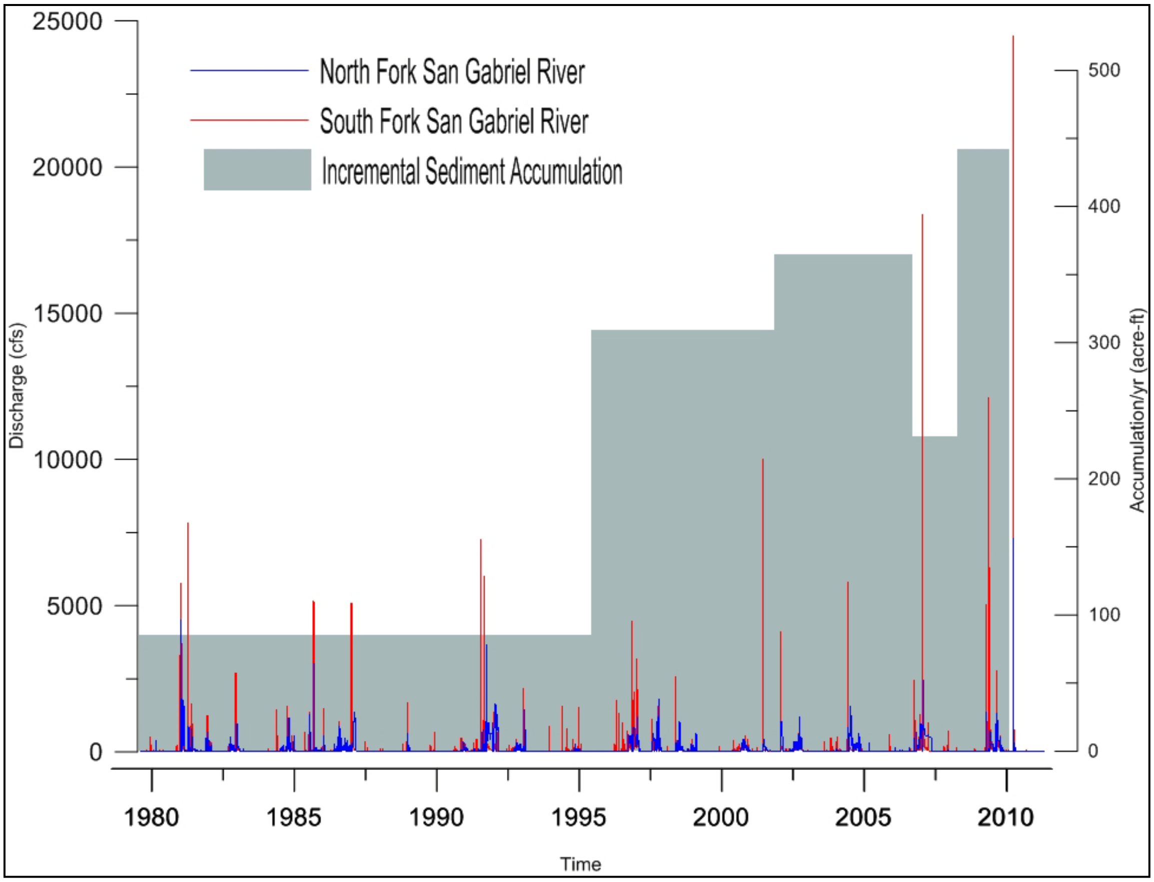
4.3 Watershed Conservation Effect on Reservoir Sedimentation

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.

REFERENCES

Allen, P., P. Higley, and J. Dunbar. 1999. Multifrequency acoustic profiling for water reservoir sedimentation studies. Journal of Sedimentary Research 69 (2):521-527.

Ambers, K.R. 2001. Using the sediment record in a western Oregon flood-control reservoir to assess the influence of storm history and logging on sediment yield. Journal of Hydrology 244 (3-4):181-200.

Chanson, H., and P. James. 1998. Rapid reservoir sedimentation of four historic thin arch dams in Australia. Journal of Performance of Constructed Facilities 12 (2):85-92.

Cox, C. 2008. U.S. Agriculture conservation policy & programs: History, trends, and implications. In U.S. Agricultural Policy and the 2007 Farm Bill. Stanford CA: Woods Institute for the Environment.

Crowder, B.M. 1987. Economic costs of reservoir sedimentation: A regional approach to estimating cropland erosion damage. Journal of Soil and Water Conservation 42 (3):194-197.

Davis, J.A., I.D. Rutherfurd, and B.L. Finlayson. 1999. The Eppalock Soil Conservation Project, Victoria, Australia: The prevention of resevoir sedementation and the politics of catchment management. Australian Geographical Studies 37 (1):37-49.

Dendy, F.E., and W.A. Champion. 1978. Sediment deposited in U.S. reservoirs: Summary of data reported through 1975, U.S. Department of Agriculture: Miscellaneous Publication No. 1362. Washington DC: Agricultural Research Service, U.S. Department of Agriculture.

Dunbar, J.A., P.M. Allen, and P.D. Higley. 1999. Multifrequency acoustic profiling for water reservoir sedimentation studies. Journal of Sedimentary Research 69 (2):521-527.

Furnans, J., and B. Austin. 2008. Hydrographic survey methods for determining reservoir volume. Environmental Modeling & Software 23 (2):139-146.

Garbrecht, J., and P. Starks. 2009. Watershed sediment yield reduction through soil conservation in a west-central Oklahoma watershed. Ecohydrology 2 (3):313-320.

Knudsen Engineering, L. 1998. User's manual, echosounder concepts technical note. Perth, Ontario, Canada: Knudsen Engineering, Ltd.

Morris, G.L., and J. Fan. 1997. Reservoir sedimentation handbook: Design and management of dams, reservoirs, and watersheds for sustainable use. New York: McGraw-Hill.

NRCS (Natural Resources Conservation Service). 1999. Assessment of flow and sediment loadings and bmp analysis for Lake Granger. Water Resources Assessment Team. Temple, TX: United states Department of Agriculture, Natural Resources Conservation Service

Odhiambo, B.K., and S.K. Boss. 2004. Integrated echosounder, gps, and gis for reservoir sedimentation studies: Examples from two Arkansas lakes. Journal of American Water Resources Association 40 (4):981-997.

Renwick, W.H. 2005. Trends in recent reservoir sedimentation rates in southwestern Ohio. Journal of Soil and Water Conservation 60 (2):72-79.

Santhi, C., R. Srinivasan, J.G. Arnold, and J.R. Williams. 2005. A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. Journal of Environmental Modeling & Software 21 (8):1141-1157.

Strand, R.I., and E.L. Pemberton. 1982. Reservoir sedimentation: Technical guideline for Bureau of Reclamation: Denver, CO: Bureau of Reclamation.

Syvitski, J.P.M. 2003. Supply and flux of sediment along hydrological pathways: Research for the 21st century. Global and Planetary Change 39 (1-2):1-11.

Trimble Navigation, L. 2004. Whitepaper - waas performance with trimble gps receivers. Westminster, CO: Trimble Navigation Limited.

TWDB (Texas Water Development Board). 1973. Report 126, engineering data on dams and reservoirs in Texas, part ii. Austin, Texas: Texas Water Development Board.

TWDB (Texas Water Development Board). 1995. Volumetric survey of Granger Lake. Austin, TX: Texas Water Development Board.

TWDB (Texas Water Development Board). 2002. Volumetric survey report of Granger Lake, April 2002 survey. Austin, TX: Texas Water Development Board.

TWDB (Texas Water Development Board). 2009. Volumetric and sedimentation survey of Granger Lake, August 2008 survey. Austin, Texas: Texas Water Development Board.

USACE (U.S. Army Corps of Engineers). 2011. Lake information 2011. Available from http://www.swf-wc.usace.army.mil/granger/Information/index.asp. Accessed: April 14, 2011.

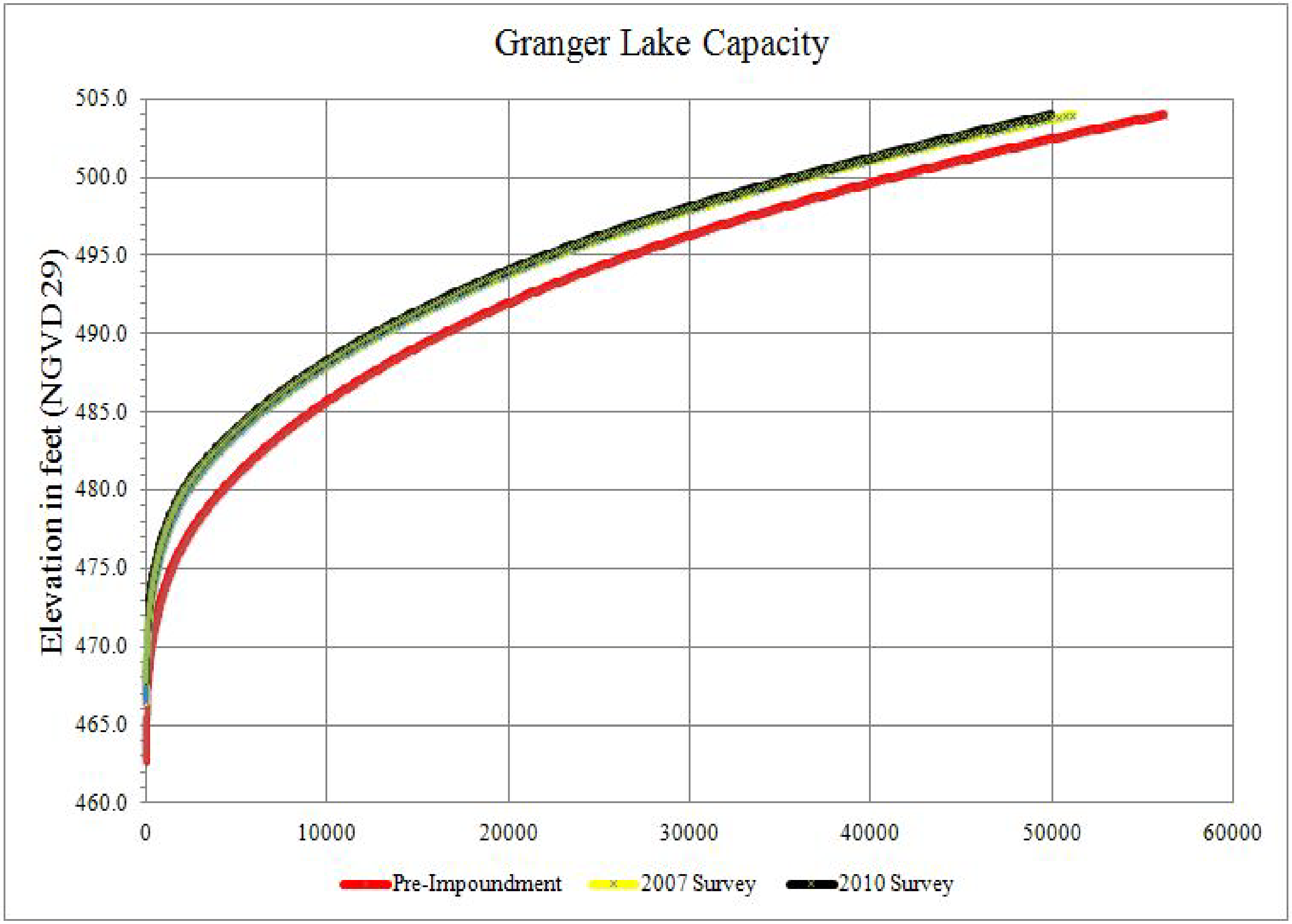
Verstraeten, G., J. Poesen, J. de Vente, and X. Koninckx. 2003. Sediment yield variability in Spain: A quantitative and semiqualitative analysis using reservoir sedimentation rates. Geomorphology 50 (4):327-348.

WCD (World Commission on Dams). 2000. Dams and development: A new framework for decision-making. London, UK: Earthscan Publications.

Werchan, L.E., and J.L. Coker. 1983. Soil survey of Williamson County Texas. Available from http://soildatamart.nrcs.usda.gov/Manuscripts/TX491 /0/williamson.pdf. Accessed: April 14, 2011.

Zarris, D., and E. Lykoudi. 2002. Sediment yield estimation from a hydrographic survey: A case study for Kremasta Reservoir Basin. Paper read at Water Resources Management in the Era of Transition, September 4-8, 2002, at Athens, Greece.

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

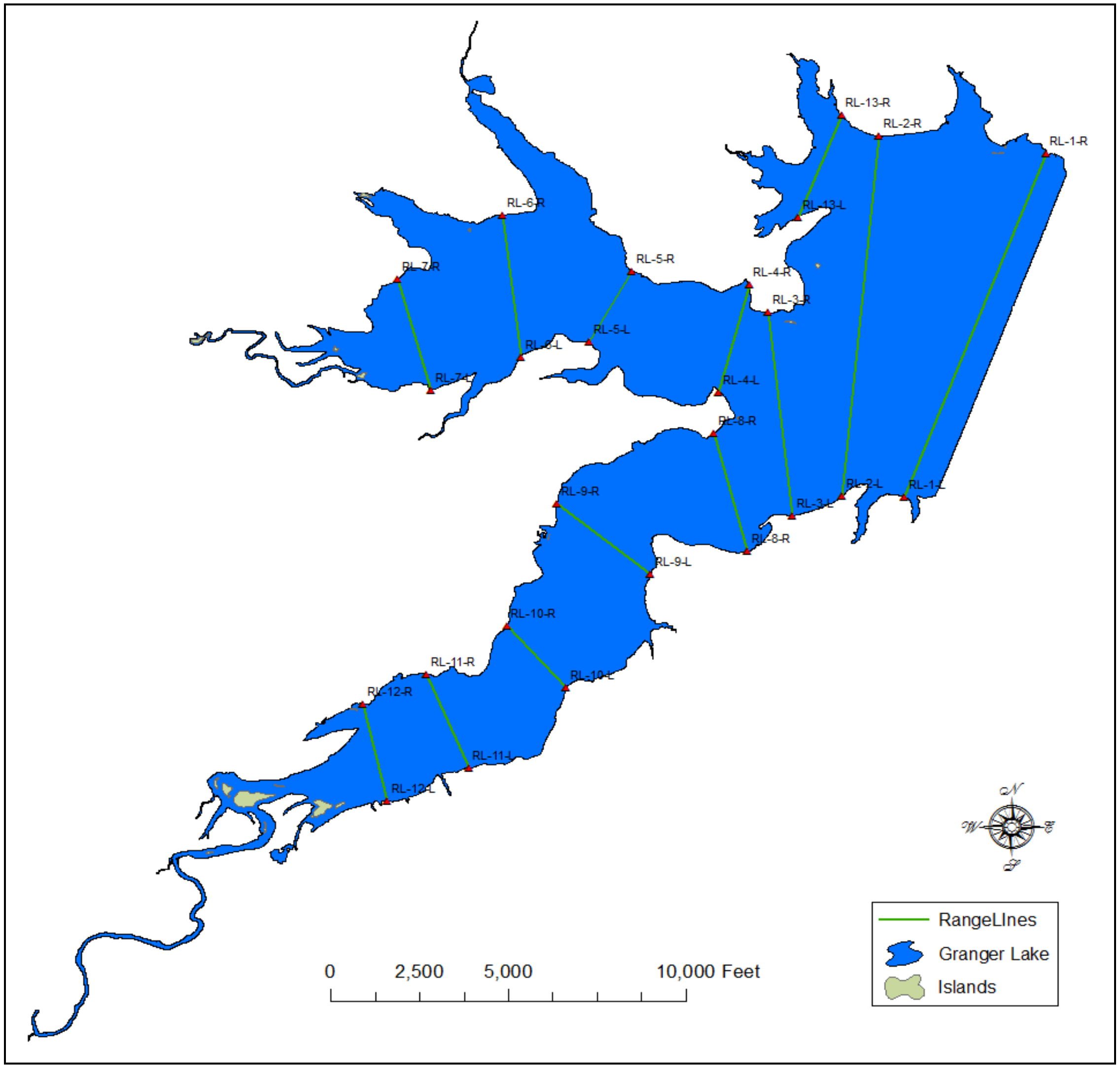
Granger Lake
2010 RESERVOIR AREA TABLE
Area in acres by tenth foot elevation increments
Determined by High-frequency Acoustics

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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RangeLInes
Granger Lake
Islands
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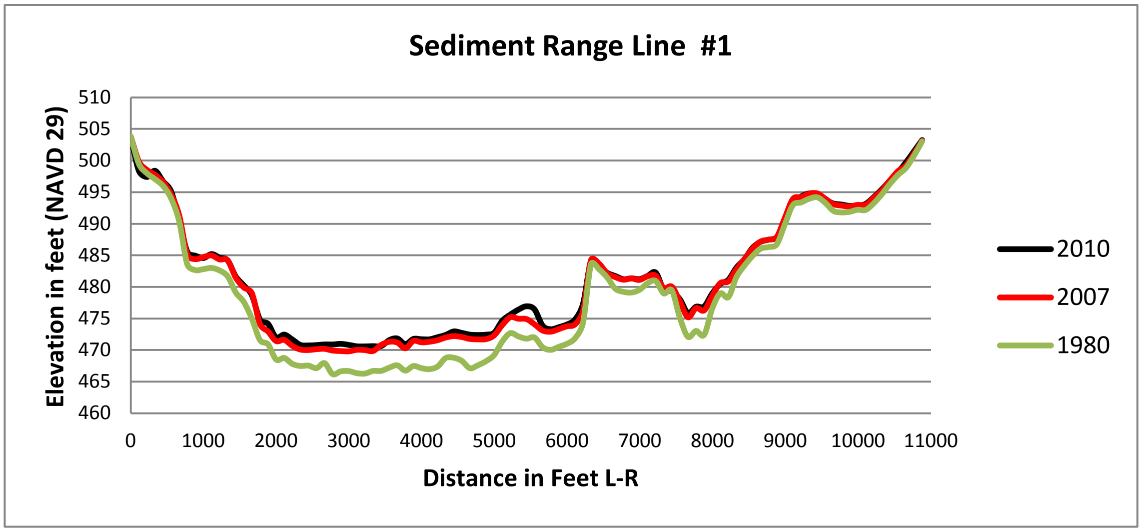
5,000
10,000 Feet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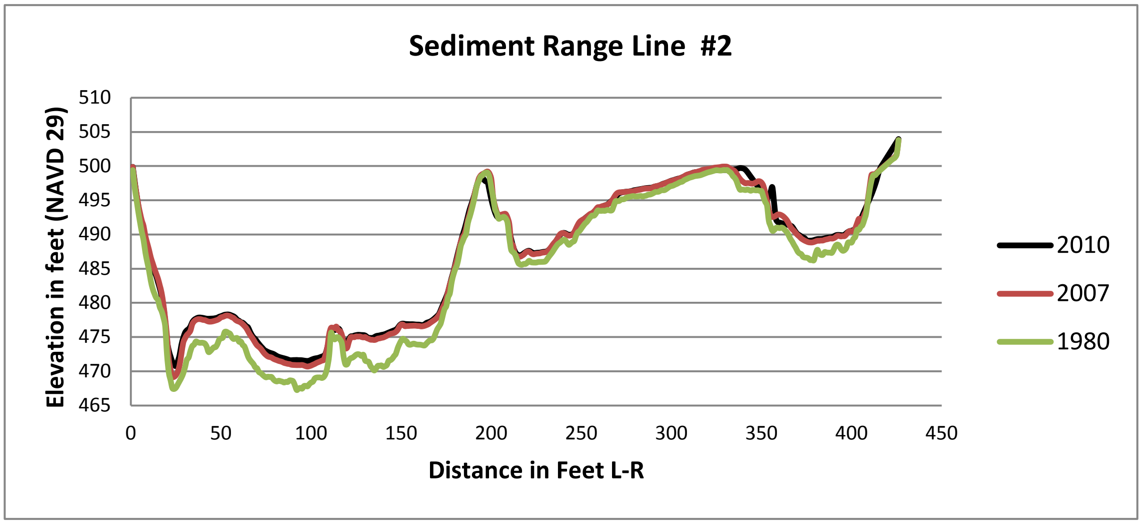
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
470
465
460
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
Distance in Feet L-R
2010
2007
1980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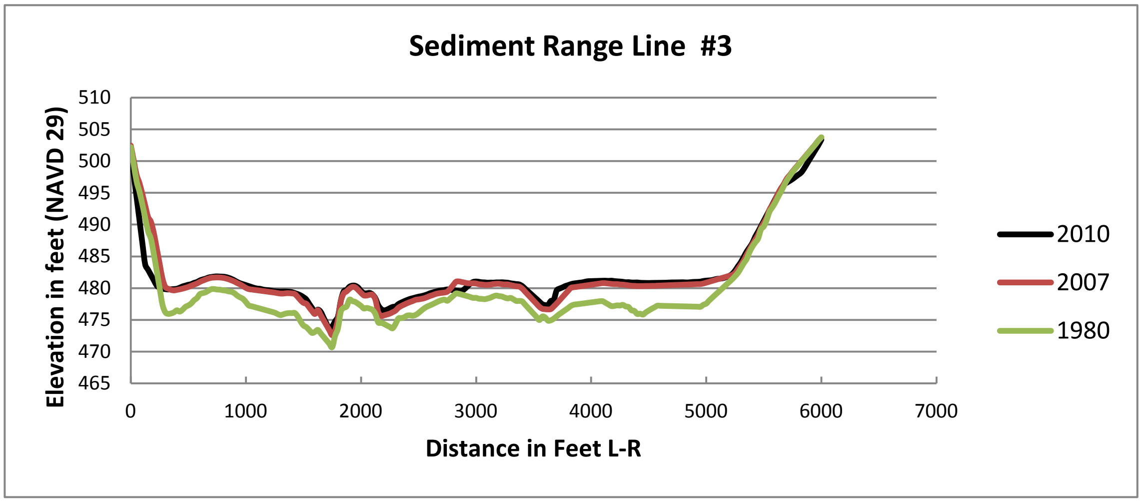
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
470
465
0
50
100
150
200
250
300
350
400
450
Distance in Feet L-R
2010
2007
1980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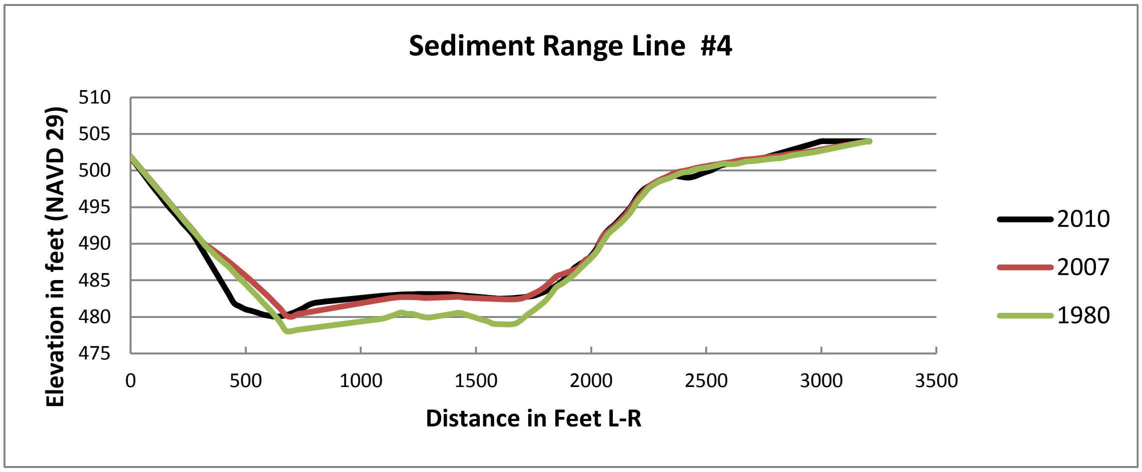
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
470
465
0
1000
2000
3000
4000
5000
6000
7000
Distance in Feet L-R
2010
2007
1980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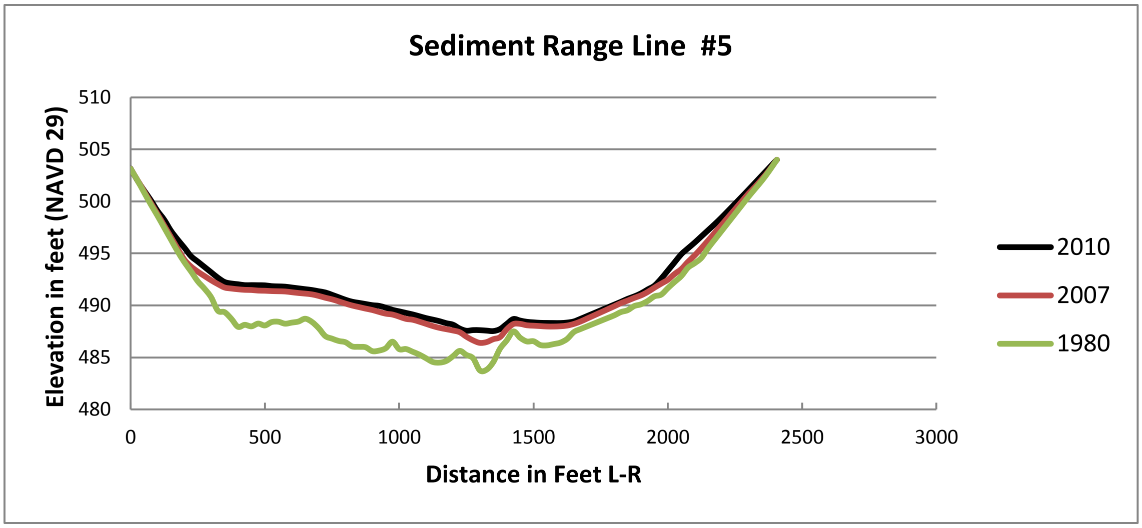
Elevation in feet (NAVD 29)
510
505
500
495
490
485
480
475
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980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Elevation in feet (NAVD 29)
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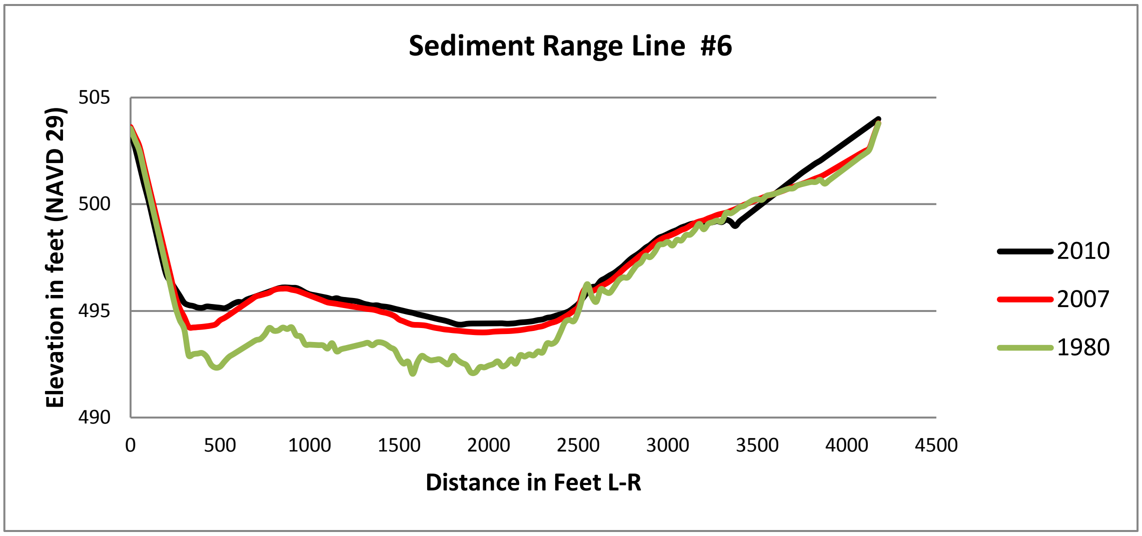
505
500
495
490
485
480
0
500
1000
1500
2000
2500
3000
Distance in Feet L-R
2010
2007
1980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Elevation in feet (NAVD 29)
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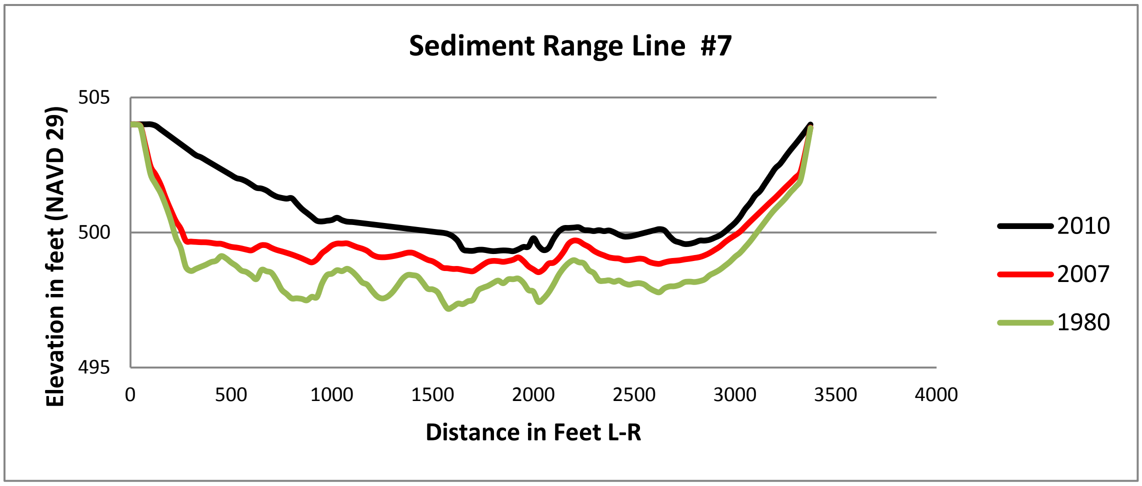
500
495
490
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance in Feet L-R
2010
2007
1980


Sediment Range Line #7
Elevation in feet (NAVD 29)
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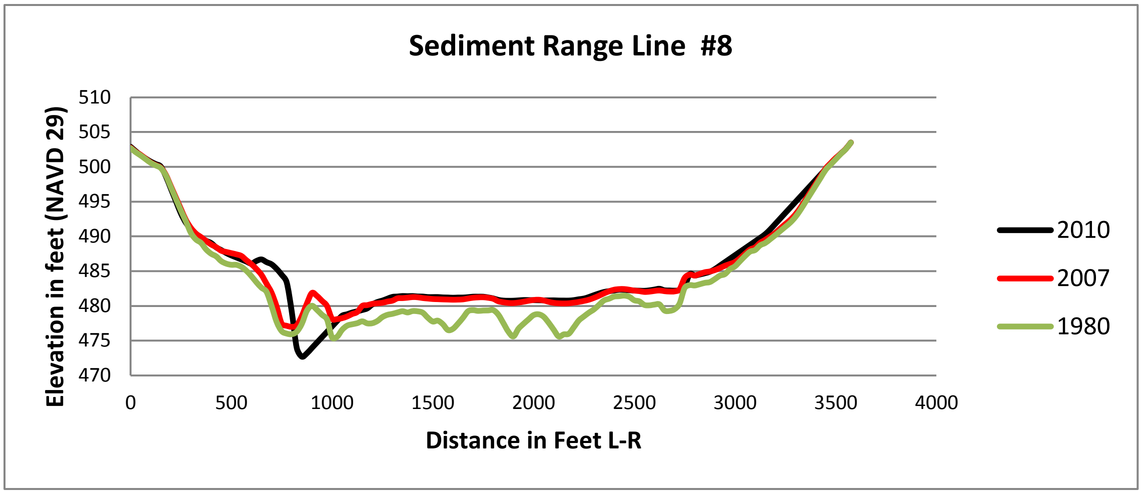
500
495
0
500
1000
1500
2000
2500
3000
3500
4000
Distance in Feet L-R
2010
2007
1980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Elevation in feet (NAVD 29)
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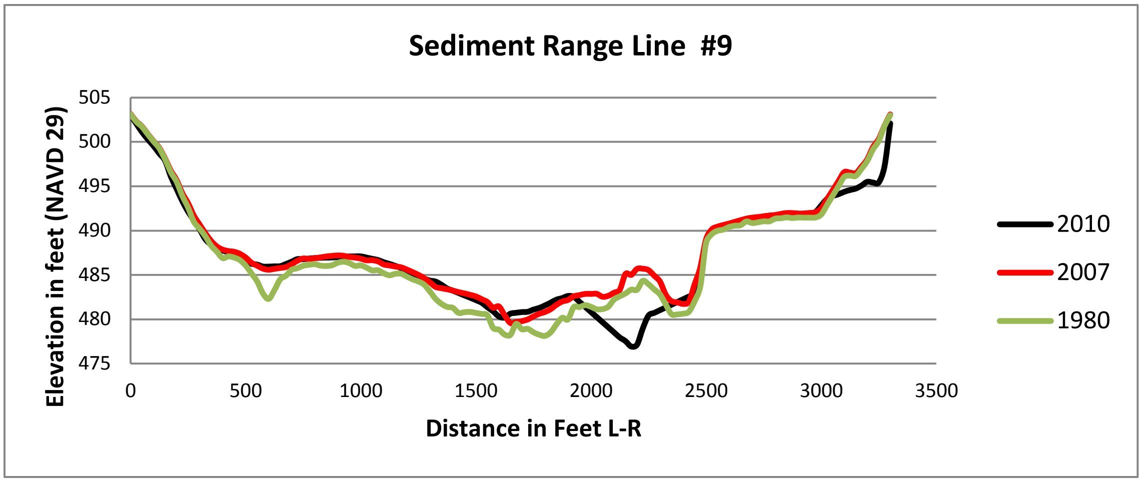
505
500
495
490
485
480
475
470
0
500
1000
1500
2000
2500
3000
3500
4000
Distance in Feet L-R
2010
2007
1980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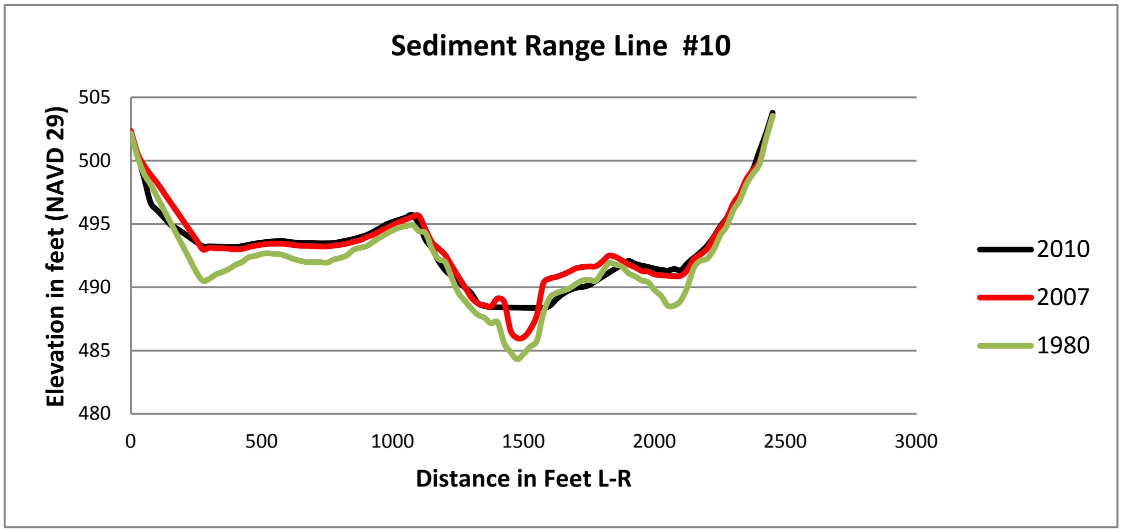
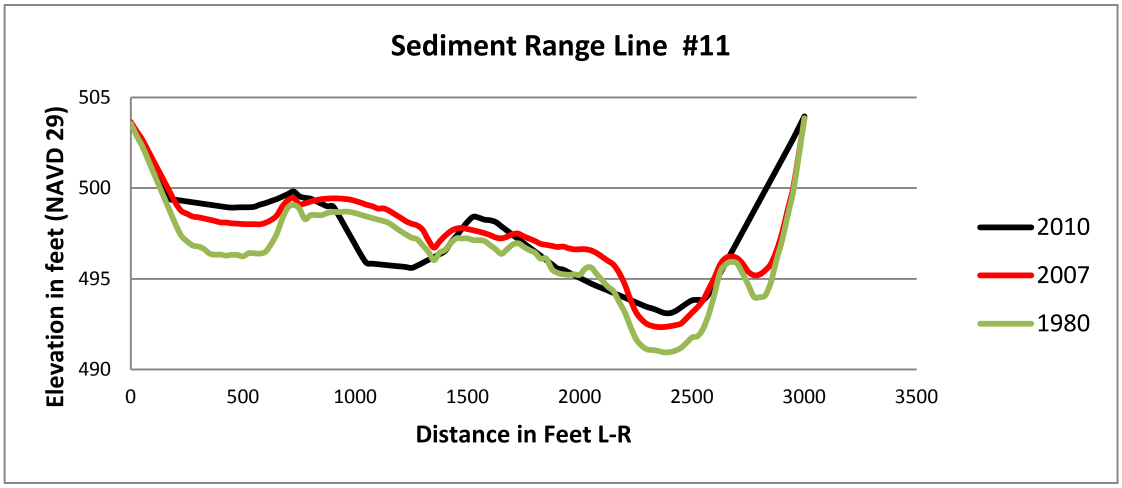
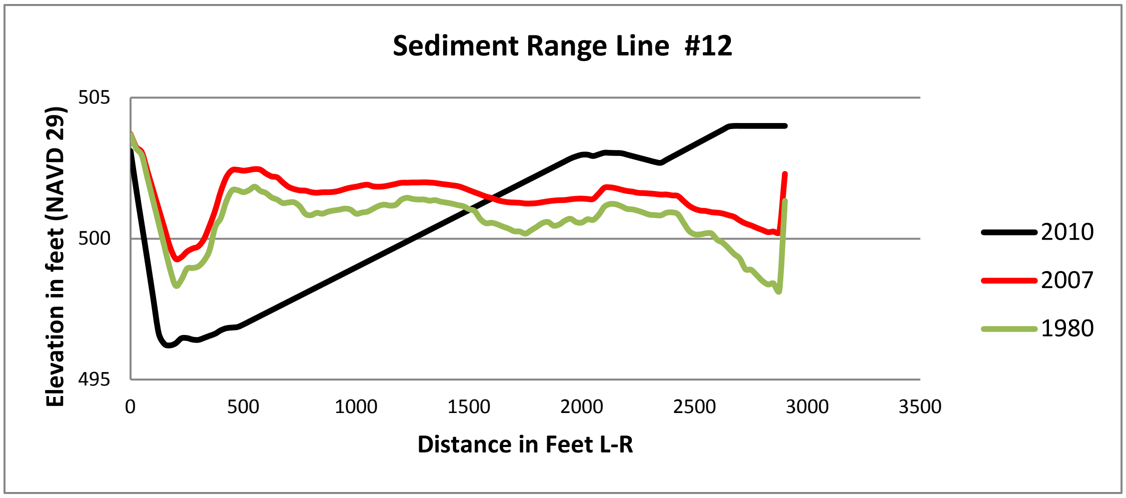
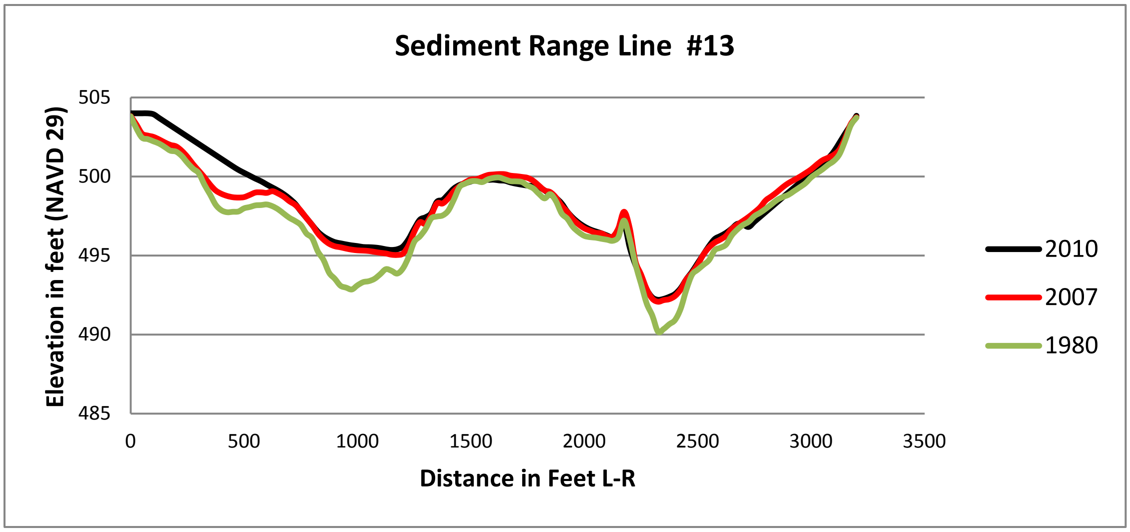
Elevation in feet (NAVD 29)
505
500
495
490
485
480
475
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980

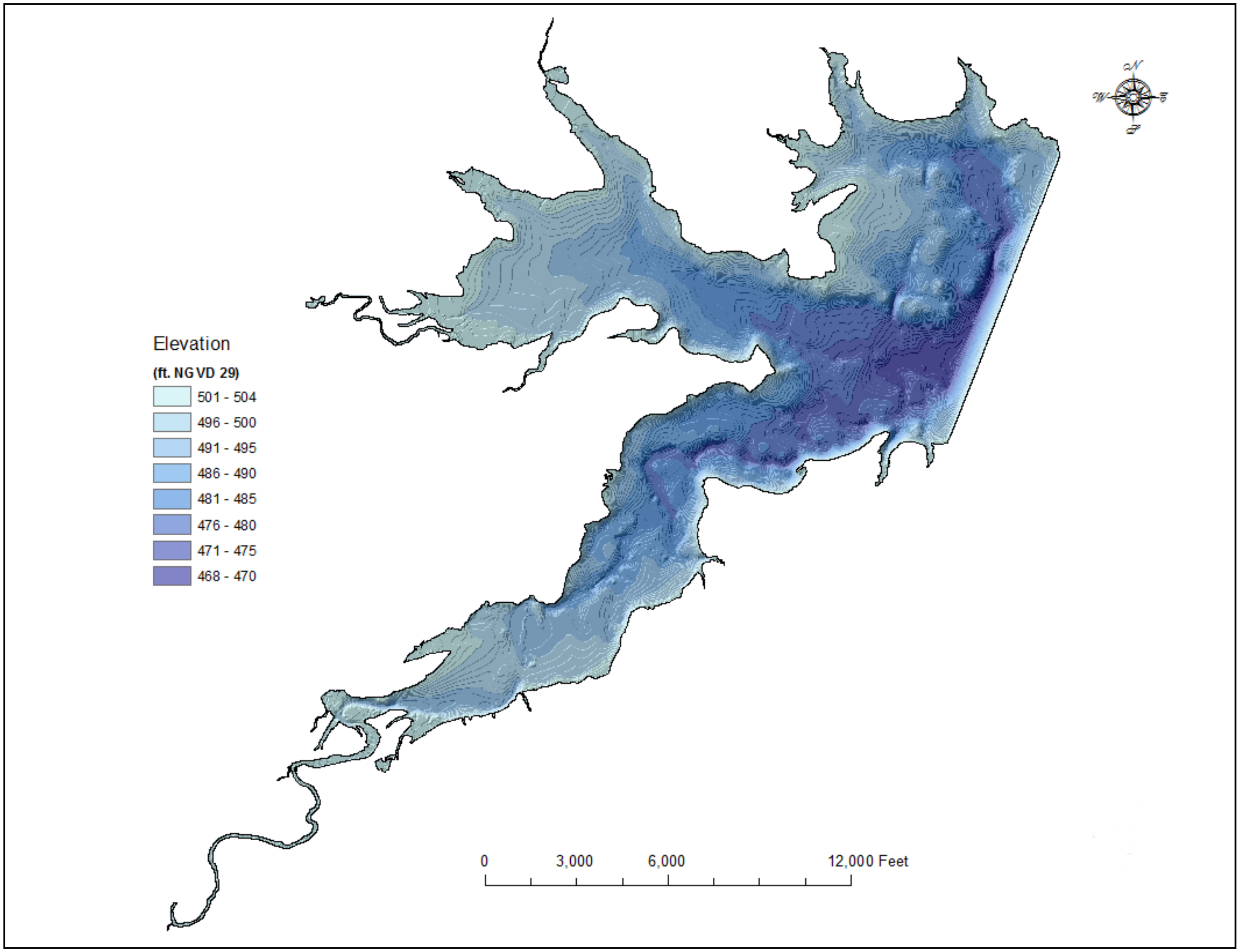

Sediment Range Line #10
Elevation in feet (NAVD 29)
505
500
495
490
485
480
0
500
1000
1500
2000
2500
3000
Distance in Feet L-R
2010
2007
1980


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

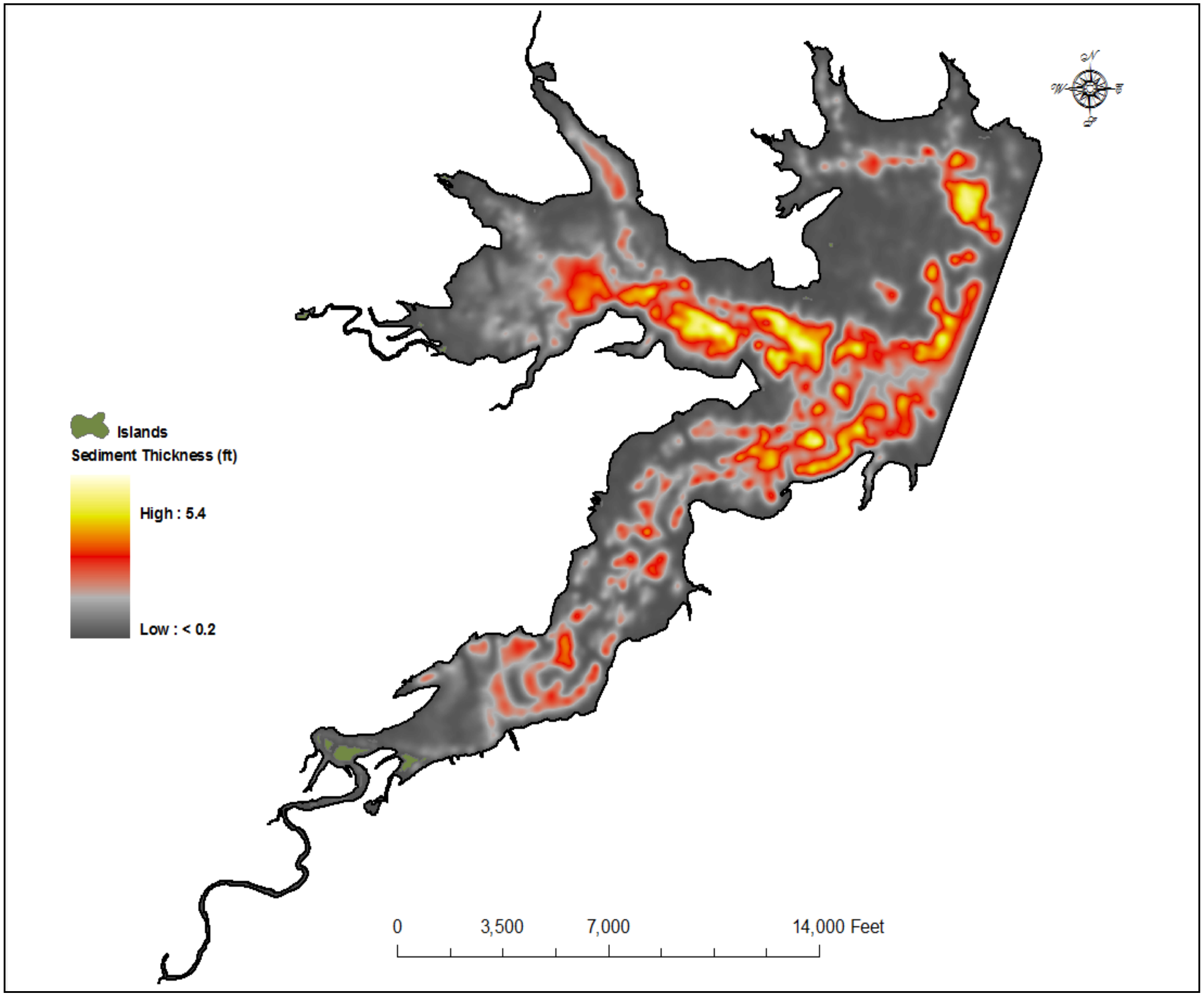

Sediment Range Line #12
Elevation in feet (NAVD 29)
505
500
495
0
500
1000
1500
2000
2500
3000
3500
Distance in Feet L-R
2010
2007
1980


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
N
W
E
S
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
N
W
E
S

VITA

Name: Jason Ross McAlister

Address: Blackland Research and Extension Center
720 East Blackland Road
Temple, Texas 76502

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