Volumetric and Sedimentation Survey of GRANGER LAKE

August 2008 Survey

Prepared by:

The Texas Water Development Board

August 2009

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Executive Summary

In July of 2008, the Texas Water Development Board (TWDB) entered into agreement with the Brazos River Authority for the purpose of performing a volumetric and sedimentation survey of Granger Lake. This survey was performed using a multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder. In addition, sediment core samples were collected in selected locations and were used in interpreting the multi-frequency depth sounder signal returns to derive sediment accumulation estimates.

Granger Lake and Dam are located on the San Gabriel River in Williamson County, seven miles east of Granger, Texas. Bathymetric data collection for Granger Lake occurred on August 26-28, 2008, while the water surface elevation ranged between 502.34 and 502.28 feet above mean sea level (NGVD29). The conservation pool elevation of Granger Lake is 504.0 feet above mean sea level (NGVD29).

The results of the TWDB 2008 Volumetric Survey indicate Granger Lake has a total reservoir capacity of 50,779 acre-feet and encompasses 4,203 acres at conservation pool elevation. Previous estimates of Granger Lake capacities were published in 1968[1,2], 1995[1], and 2002[2,3]. To properly compare current and previous capacity estimates, the TWDB applied current data processing techniques to topographic data available in 1968 and to data collected during the 1995 and 2002 TWDB Granger Lake surveys. Based on these re-assessments, the pre-impoundment (pre-1980) capacity of Granger Lake was between 61,000 acre-feet and 62,000 acre-feet, and post-impoundment capacities were 54,892 acre-feet in 1995 and 52,905 acre-feet in 2002.

The results of the TWDB 2008 Sedimentation Survey indicate Granger Lake has accumulated 6,182 acre-feet of sediment since impoundment in 1980. Based on this measured sediment volume and assuming a constant sediment accumulation rate, Granger Lake loses, on average, approximately 213 acre-feet of capacity per year. Comparisons of capacity estimates from successive surveys, however, suggest that between 1980 and 2008, the sediment accumulation rate in Granger Lake may have increased from 129 acre-feet per year to 304 acre-feet per year.

The TWDB recommends that a similar methodology be used to resurvey Granger Lake in approximately 10 years or after a major flood event. Such a resurvey would provide additional sediment accumulation rate estimates for Granger Lake and would provide direct evidence indicating whether the sediment accumulation rate is increasing or decreasing.

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Granger Lake General Information

Granger Dam and Granger Lake (known as Laneport Dam and Laneport Lake until January 3, 1975[3,4]) are located on the San Gabriel River in the Brazos River Basin, seven miles east of the City of Granger in Williamson County, Texas (Figure 1). Granger Lake is owned by the U.S. Government and operated by the U.S. Army Corps of Engineers, Fort Worth District.[5] Granger Dam was built for flood damage reduction, water conservation, fish and wildlife habitat, and general recreation.[6] Construction of Granger Dam began in October of 1972, with deliberate impoundment beginning on January 21, 1980.[7] Additional pertinent data about Granger Dam and Granger Lake can be found in Table 1.

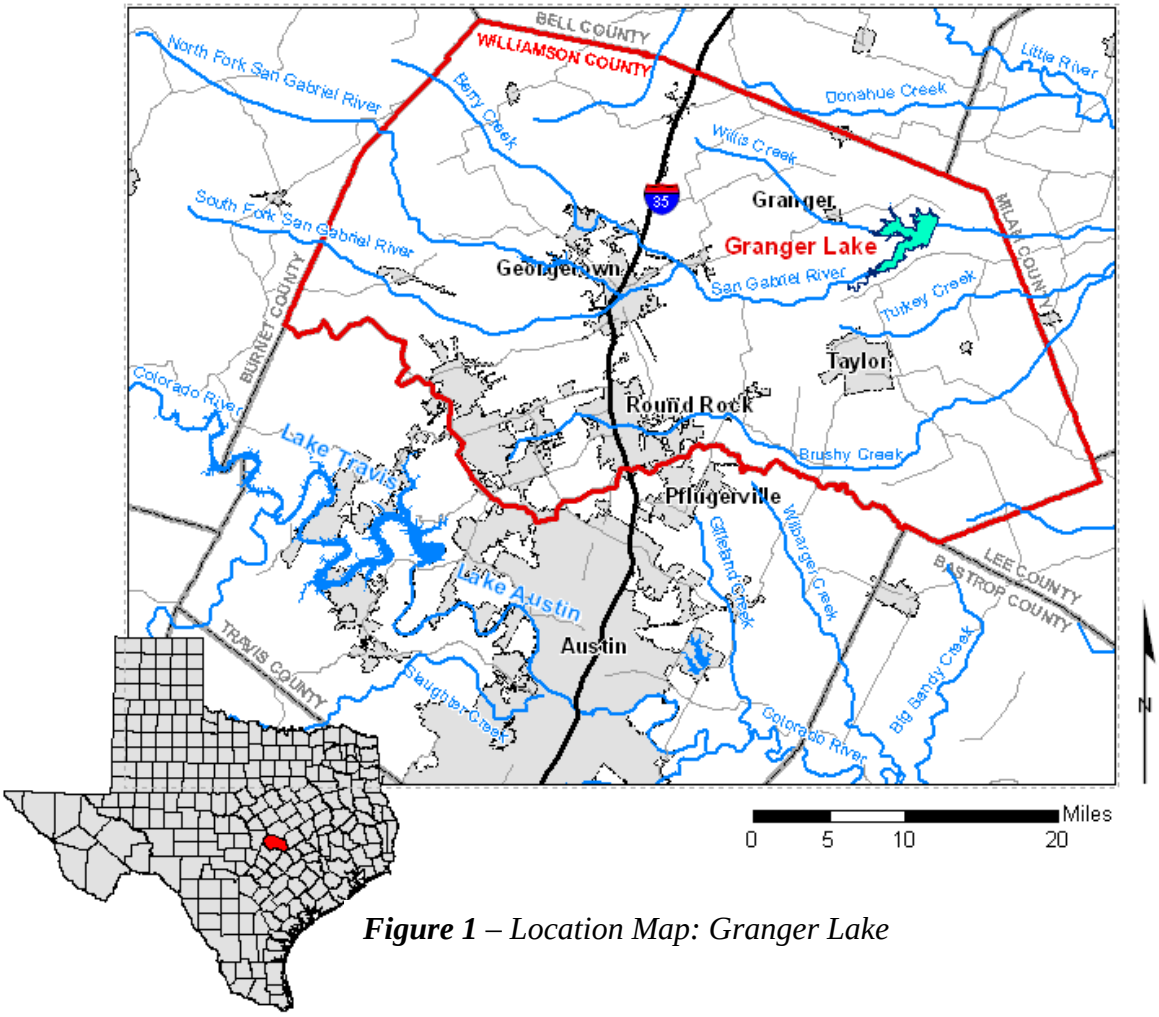


Figure 1 *– Location Map: Granger Lake*

Table 1 - Pertinent Data for Granger Dam and Granger Lake[5]

Owner

The U.S. Government, Operated by the U.S. Army Corps of Engineers, Fort Worth District

Engineer (Design)

U.S. Army Corps of Engineers

Location of Dam

On San Gabriel River in Williamson County, 7 miles east of the City of Granger, and 10 miles northeast of the City of Taylor, Texas

Drainage Area

709 square miles

Dam

Type	Earthfill
Length	16,320 feet including spillway
Maximum height	115 feet
Top width	30 feet

Spillway

Type	Uncontrolled ogee
Length	950
Crest elevation	528.0 feet above mean sea level

Outlet Works

Type	Conduit
Size	18 feet diameter
Control	2 slide gates (8 feet by 18 feet)
Invert elevation	457.0 feet above mean sea level

Low Flow Outlets (discharges to flood control conduit)

Number to wet well	3
Invert elevations	502.0, 494.0, 486.0 feet above mean sea level
Control	3 slide gates, each 3 by 4 feet
Number from wet well	1
Invert elevation	486.0 feet above mean sea level
Control	1 slide gate, 2 by 4 feet

Reservoir Data (Based on TWDB 2008 Volumetric Survey)

Feature	Elevation (ft above msl)	Capacity (Acre-feet)	Area (Acres)
Top of Dam	555.0	N/A	N/A
Maximum design water surface	549.3	N/A	N/A
Spillway Crest	528.0	N/A	N/A
Top of conservation storage space	504.0	50,779	4,203
Invert elevation (Low flow outlets)	486.0	7,351	1,148
Invert elevation (Outlet works)	457.0	0	0
Streambed	440.0	0	0

Water Rights

The water rights for Granger Lake have been appropriated to the Brazos River Authority of Texas through Certificate of Adjudication No. 12-5163. Certificate of Adjudication No. 12-5163 authorizes the Brazos River Authority to maintain an existing dam and reservoir on the San Gabriel River (Granger Lake) and impound therein a maximum of 65,500 acre-feet of water. The Brazos River Authority is authorized to divert and use from Granger Lake a maximum of 19,840 acre-feet of water per year for municipal,

industrial, irrigation, and mining purposes. Granger Lake may also be used for non-consumptive recreation purposes. This certificate has a priority date of February 12, 1968.

The Brazos River Authority optimizes water supply from its reservoirs and run-of-the-river supplies through a coordinated system operation of its water rights.[8] For the purposes of system operation, the Brazos River Authority is authorized by Certificate of Adjudication No. 12-5163 to exceed the priority right and divert a yearly maximum of 30,000 acre-feet of water per year for municipal purposes, 29,800 acre-feet per year for industrial purposes, 5,500 acre-feet per year for irrigation purposes, and 200 acre-feet of water for mining purposes. Any diversions in excess of the 19,840 acre-feet in any calendar year are charged against the sum of the amounts designated as priority rights in the other reservoirs included in the System Operation Order. This system operation is incorporated into the Brazos River Authority's water rights for all lakes in the system: Lake Possum Kingdom, Lake Granbury, Lake Whitney, Lake Aquilla, Lake Proctor, Lake Belton, Lake Stillhouse Hollow, Lake Georgetown, Lake Granger, Lake Limestone, and Lake Somerville.[8]

Certificate of Adjudication No. 12-5167, issued December 14, 1987, authorizes the Brazos River Authority to divert and use a maximum of 30,000 acre-feet of water per year from the reservoirs authorized under Certificates of Adjudication 12-5155 (Possum Kingdom Reservoir), 12-5156 (Lake Granbury), 12-5157 (Lake Whitney), 12-5158 (Lake Aquilla), 12-5159 (Lake Proctor), 12-5160 (Lake Belton), 12-5161 (Stillhouse Hollow Reservoir), 12-5162 (Lake Georgetown), 12-5163 (Lake Granger), 12-5164 (Somerville Lake), and 12-5165 (Lake Limestone) for municipal purposes in the San Jacinto-Brazos Coastal Basin. The Brazos River Authority is also authorized to divert and use a maximum of 170,000 acre-feet per year from the previously listed reservoirs for industrial purposes in the San Jacinto-Brazos Coastal Basin. This certificate may not be construed as authorizing an appropriative right in excess of those rights, above, held by the Brazos River Authority. The complete certificates are on file in the Records Division of the Texas Commission on Environmental Quality.

Volumetric and Sedimentation Survey of Granger Lake

The Texas Water Development Board's (TWDB) Hydrographic Survey Program was authorized by the state legislature in 1991. The Texas Water Code authorizes the TWDB to perform surveys to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, and projected water supply availability.

In July of 2008, the TWDB entered into agreement with the Brazos River Authority for the purpose of performing a volumetric and sedimentation survey of Granger Lake. This survey was performed using a single-beam multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder. The 200 kHz return measures the depth to the current bathymetric surface, while returns from the three frequencies are analyzed in conjunction with sediment core samples to determine sediment accumulation throughout the reservoir.

Datum

The vertical datum used during this survey is that used by the United States Geological Survey (USGS) for the reservoir elevation gage USGS 08105600 Granger Lk nr Granger, TX.[9] The datum for this gage is reported as National Geodetic Vertical Datum 1929 (NGVD29) or mean sea level, thus elevations reported here are in feet above mean sea level. Volume and area calculations in this report are referenced to water levels provided by the USGS gage. The horizontal datum used for this report is the North American Datum of 1983 (NAD83), and the horizontal coordinate system is State Plane Texas Central Zone (feet).

TWDB Bathymetric Data Collection

Bathymetric data collection for Granger Lake occurred on August 26-28, 2008, while the water surface elevation ranged between 502.34 and 502.28 feet above mean sea level (NGVD29). The conservation pool elevation of Granger Lake is 504.0 feet above mean sea level (NGVD29). For data collection, the TWDB used a Specialty Devices, Inc., multi-frequency sub-bottom profiling depth sounder integrated with Differential Global Positioning System (DGPS) equipment. Data collection occurred while navigating along pre-planned range lines oriented perpendicular to the assumed location of the original river

channels and spaced approximately 500 feet apart. These pre-planned range lines were the same range lines used to survey the lake in 1995 and 2002. The depth sounder was calibrated daily using a velocity profiler (for measuring the speed of sound in the water column) and a stadia rod or weighted measuring tape (for depth reading verification). During the survey, team members collected over 40,000 data points over cross-sections totaling nearly 66 miles in length. Figure 2 shows where data points were collected during the TWDB 2008 survey.

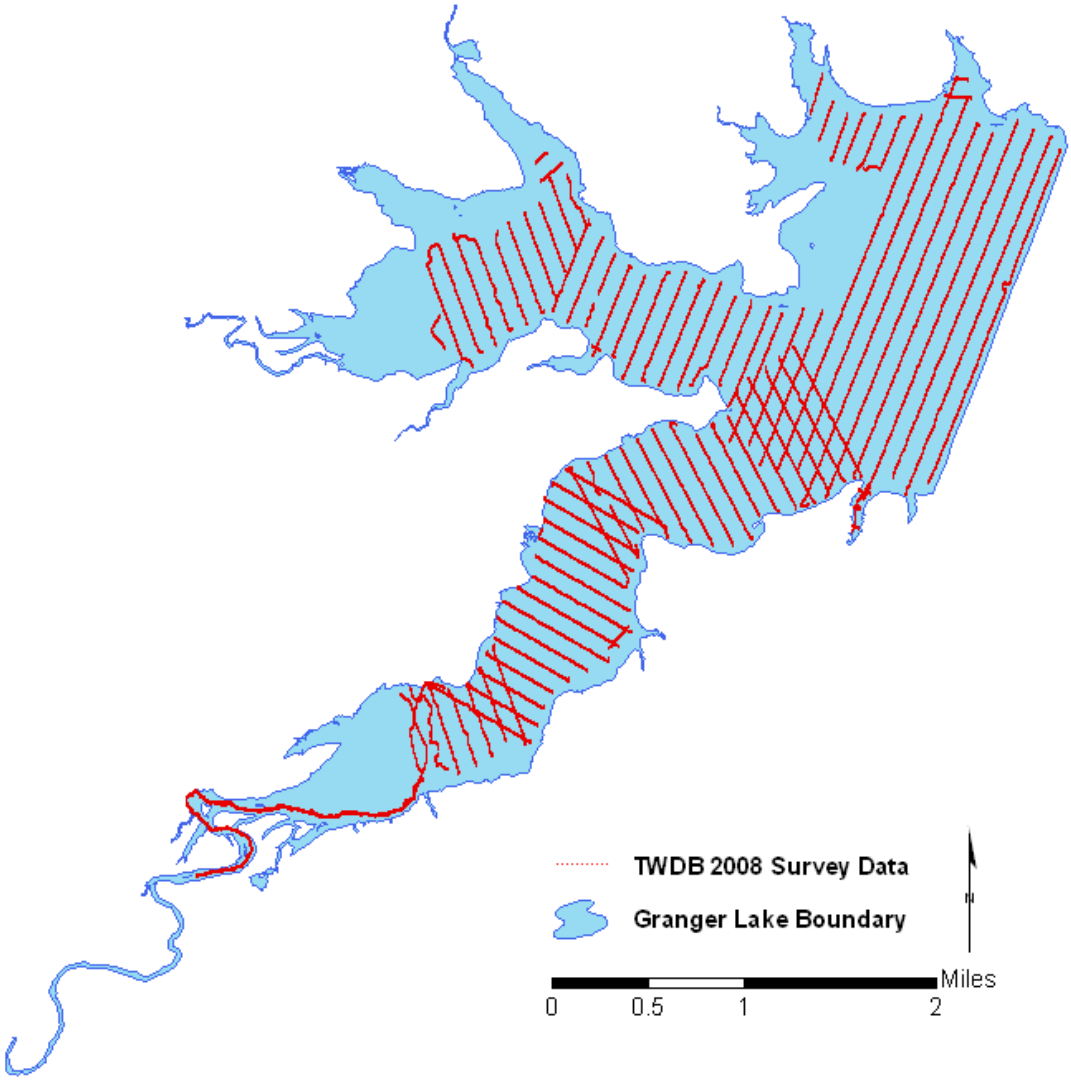


Figure 2 *- Data points collected during TWDB 2008 Survey*

Data Processing

Model Boundaries

The reservoir boundary was digitized from aerial photographs, or digital ortho quarter-quadrangle images (DOQQs)[10,11], using Environmental Systems Research Institute's (ESRI) ArcGIS 9.1 software. 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. As these photographs have a 1-meter resolution; the physical lake boundary may be within ± 1 meter of the location derived from the manual delineation. Therefore, the boundary was digitized at the land water interface visible in the photos and labeled 504.0 feet, or conservation pool elevation, to allow the area-capacity tables to be calculated to conservation pool elevation.

Additional aerial photographs of Granger Lake taken on August 31, 2006 while the water surface elevation in Granger Lake averaged 501.72 feet were used to digitize a 501.72 foot contour. This contour was used to supplement TWDB survey data in locations where the survey data alone was insufficient to properly represent the reservoir bathymetry. The 2006 aerial photos have a 2-meter resolution; therefore, the contour was verified for accuracy against the sounding data collected during the 2008 survey.

Triangulated Irregular Network Model

Upon completion of the bathymetric data collection, the raw data files collected by the TWDB were edited using HydroEdit and DepthPic to remove any data anomalies. HydroEdit is used to automate the editing of the 200 kHz frequency and determine the current bathymetric surface. DepthPic is used to display, interpret, and edit the multi-frequency data, to correct any edits HydroEdit has flagged, and to manually interpret the pre-impoundment surface. The water surface elevations at the times of each sounding are used to convert sounding depths to corresponding bathymetric elevations. For processing outside of DepthPic, the sounding coordinates (X,Y,Z) are exported as a MASS points file. The TWDB also created a MASS points file of interpolated data located in-between surveyed cross sections. This point file is described in the section entitled "Self-Similar Interpolation." To represent reservoir bathymetry in shallow regions, additional points

were added using the "Line Extrapolation" technique.[12] These MASS points files, along with the lake boundary file, are used in creating a Triangulated Irregular Network (TIN) model of the lake bathymetry using the 3D Analyst Extension of ArcGIS. The 3D Analyst algorithms use Delaunay's criteria for triangulation to place a triangle between three non-uniformly spaced points, including the boundary vertices.[13]

Using Arc/Info software, volumes and areas are calculated from the TIN model for the entire reservoir at one-tenth of a foot intervals, from elevation 466.7 feet to elevation 504.0 feet. The Granger Lake Elevation-Capacity Table and Elevation-Area Table, updated for 2008, are presented in Appendix A and B, respectively. The Area-Capacity Curves are presented in Appendix C.

The TIN model was interpolated and averaged using a cell size of 1 foot by 1 foot and converted to a raster. The raster was used to produce an Elevation Relief Map, representing the topography of the reservoir bottom (Figure 3), a map showing shaded depth ranges for Granger Lake (Figure 4), and a 5-foot contour map (Figure 5, attached).

Self-Similar Interpolation

A limitation of the Delaunay method for triangulation when creating TIN models results in artificially-curved contour lines extending into the reservoir where the reservoir walls are steep and the reservoir is relatively narrow. These curved contours are likely a poor representation of the true reservoir bathymetry in these areas. Also, if the surveyed cross sections are not perpendicular to the centerline of the submerged river channel (the location of which is often unknown until after the survey), then the TIN model is not likely to well-represent the true channel bathymetry.

To ameliorate these problems, a Self-Similar Interpolation routine (developed by the TWDB) was used to interpolate the bathymetry in between many survey lines. The Self-Similar Interpolation technique effectively increases the density of points input into the TIN model, and directs the TIN interpolation to better represent the reservoir topography.[12] In the case of Granger Lake, the application of Self-Similar Interpolation helped represent the lake morphology near the banks and improved the representation of the submerged river channel (Figure 6). In areas where obvious geomorphic features indicate a high-probability of cross-section shape changes (e.g. incoming tributaries, significant widening/narrowing of channel, etc.), the assumptions used in applying the

Figure 3

Granger Lake

Elevation Relief Map

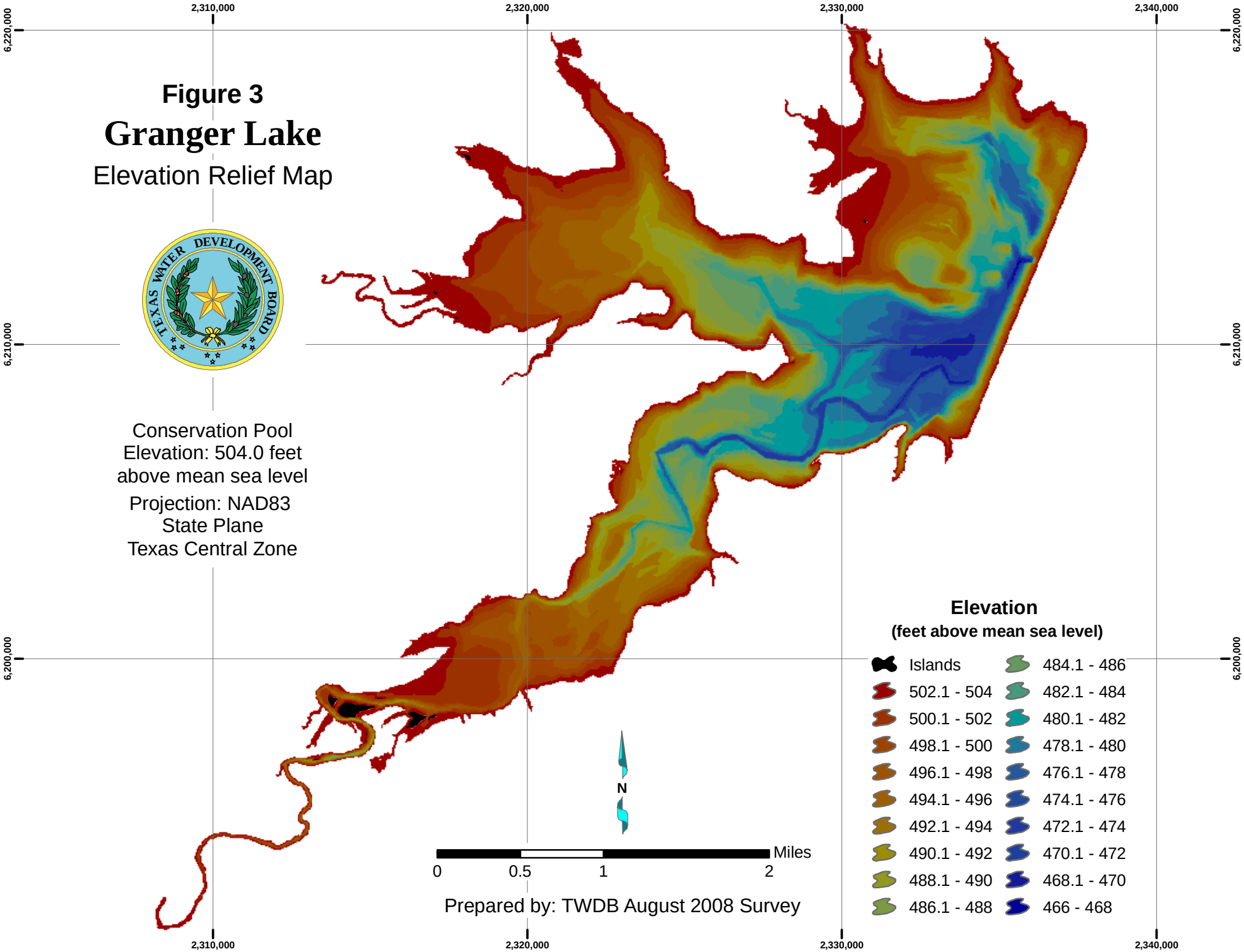
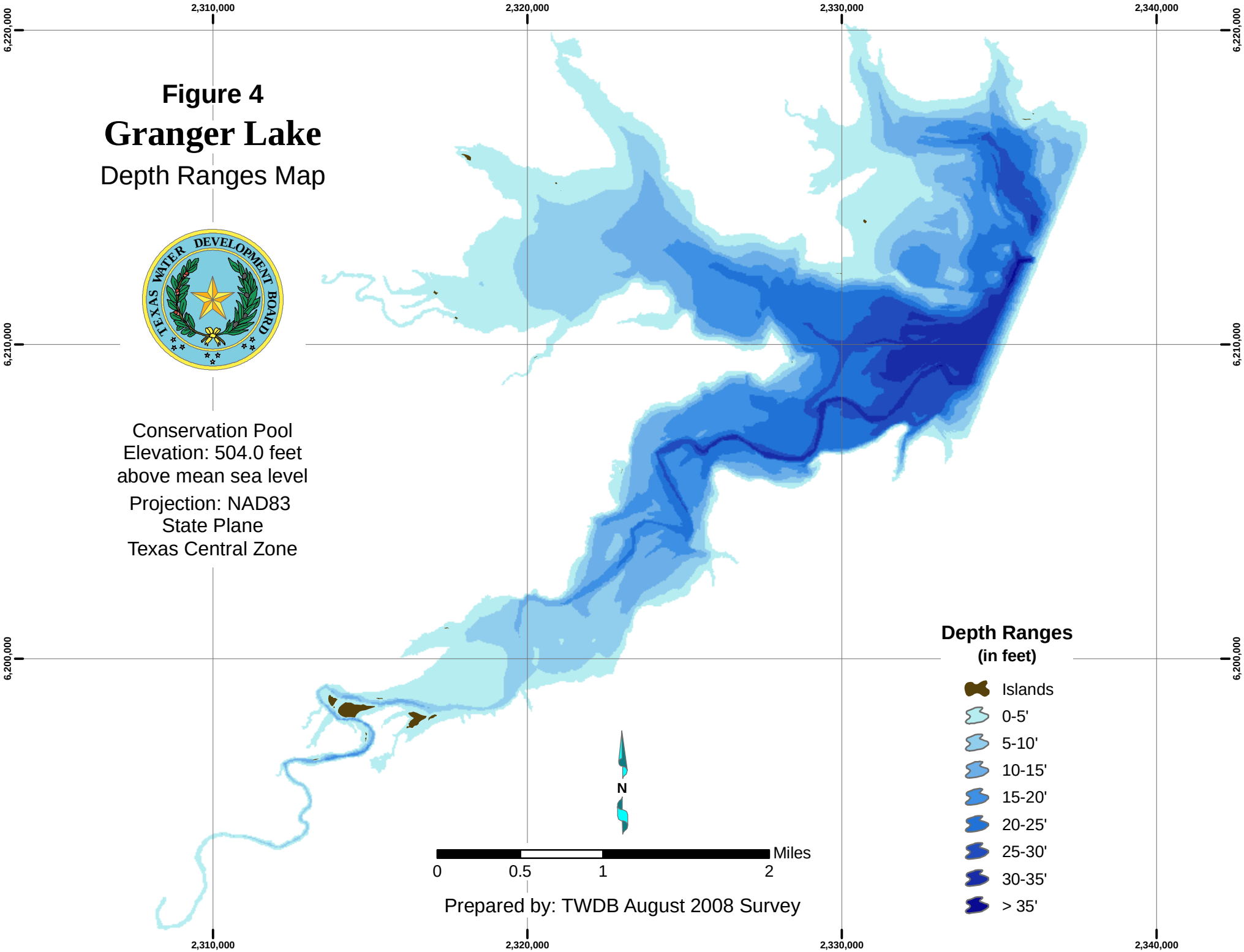


Figure 4

Granger Lake

Depth Ranges Map



Self-Similar Interpolation technique are not likely to be valid. Self-Similar Interpolation was not used in areas of Granger Lake where a high probability of change between cross-sections exists.[12] Figure 6 illustrates typical results of the application of the Self-Similar Interpolation routine in Granger Lake, and the bathymetry shown in Figure 6C was used in computing reservoir capacity and area tables (Appendix A, B).

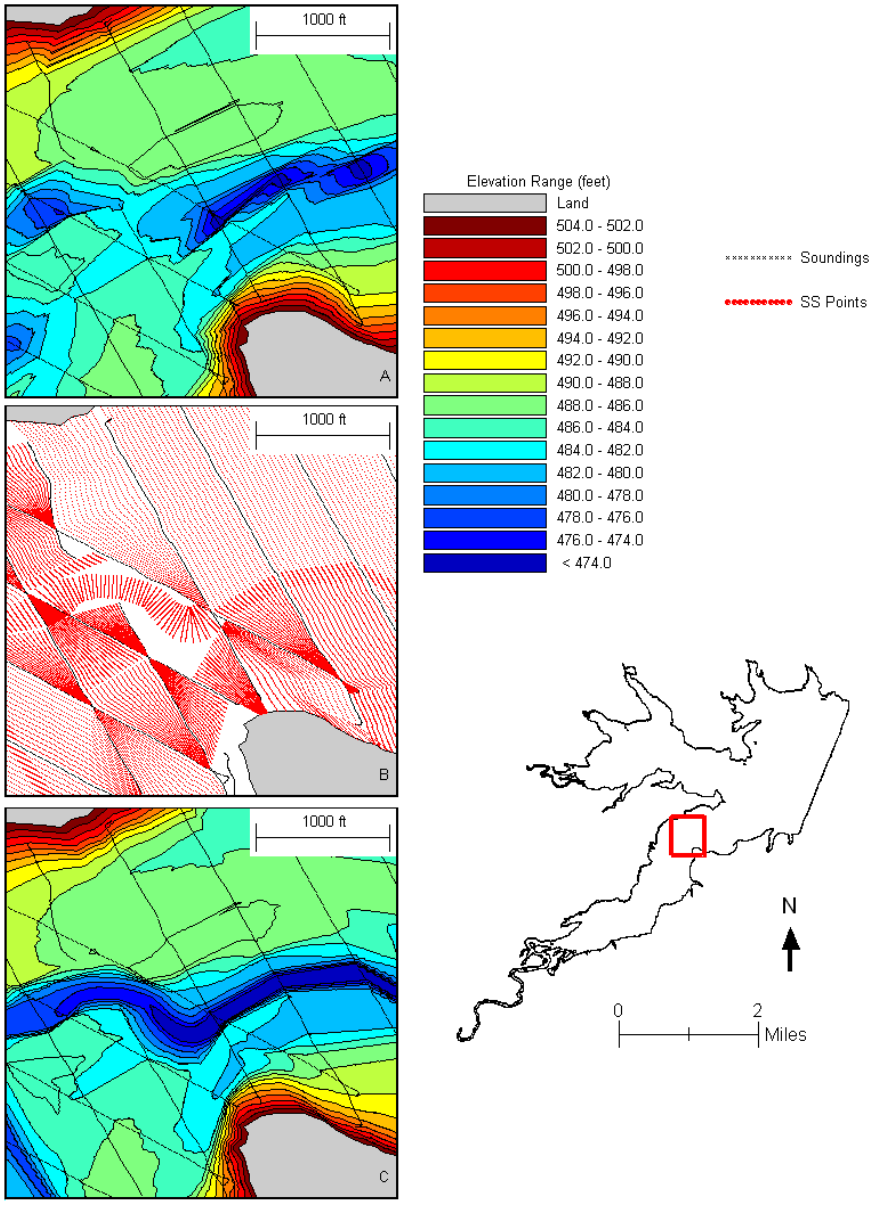


Figure 6 *- Application of the Self-Similar Interpolation technique to Granger Lake sounding data – A) bathymetric contours without interpolated points, B) Sounding points (black) and interpolated points (red) with reservoir boundary shown at elevation 504.0 (black), C) bathymetric contours with the interpolated points. Note: In 6A the submerged river channel indicated by the surveyed cross sections is not represented for the areas in-between the cross sections. This is an artifact of the TIN generation routine. Inclusion of the interpolated points (6C) corrects this and smoothes the bathymetric contours.*

Survey Results

Volumetric Survey

The results of the TWDB 2008 Volumetric Survey indicate Granger Lake has a total reservoir capacity of 50,779 acre-feet and encompasses 4,203 acres at conservation pool elevation (504.0 feet above mean sea level, NGVD29).

The original capacity of Granger Lake at conservation pool elevation was calculated by the U.S. Army Corps of Engineers in 1968[1,2] to be 65,510 acre-feet. The TWDB previously surveyed Granger Lake in October of 1995[1] and March of 2002[2]. The methodology used in deriving the 1968 volume estimate is not identical to those methods currently employed by the TWDB, and the TWDB does not recommend directly comparing results from recent surveys with the original U.S. Army Corps of Engineers capacity estimate. Furthermore, the data collection and processing techniques used by the TWDB have improved significantly over the years and direct comparisons with previous TWDB surveys should be treated with caution (See section titled "Estimating Sediment Accumulation Rates" below).

Sedimentation Survey

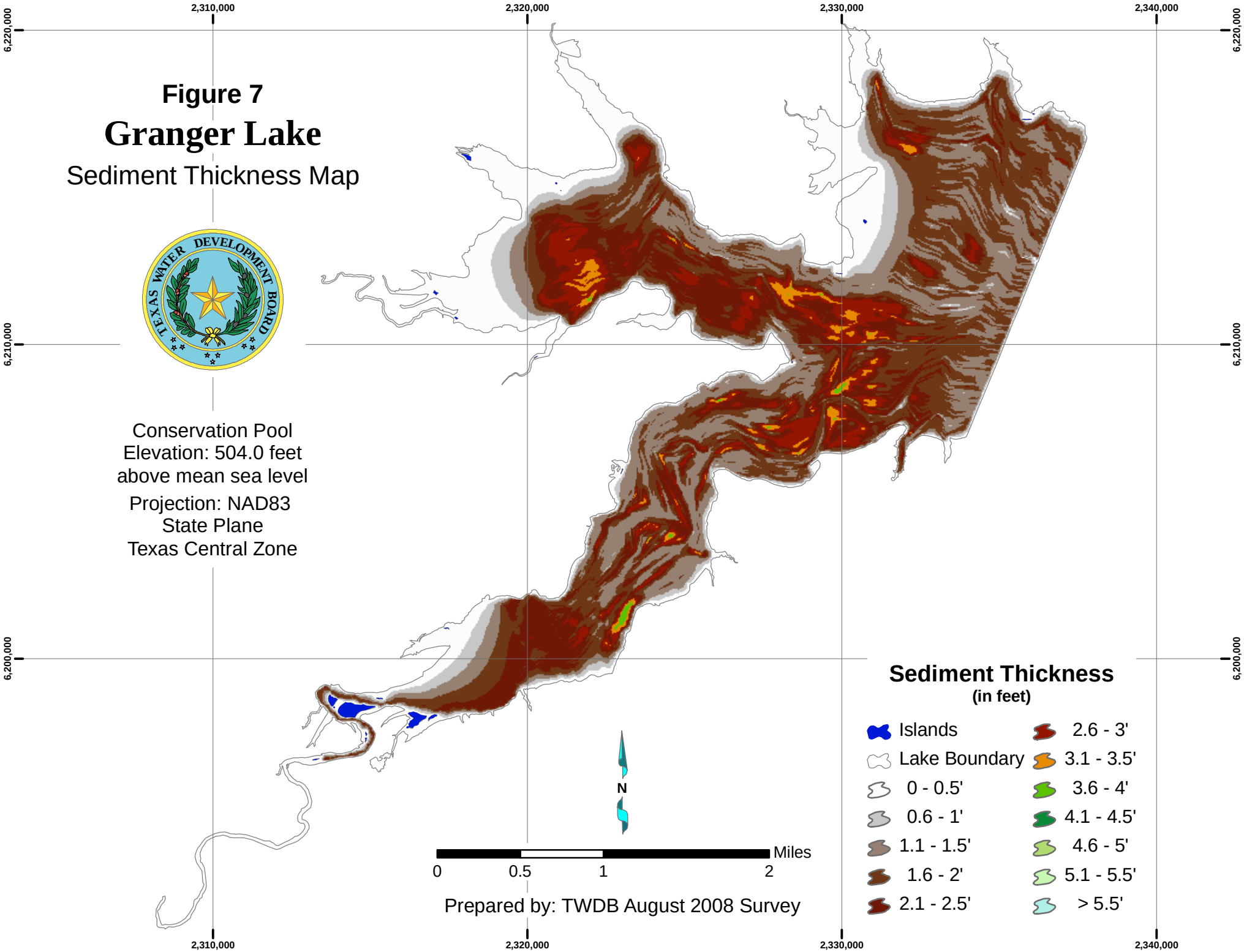
The 200 kHz, 50 kHz, and 24 kHz frequency data were used to interpret sediment distribution and accumulation throughout Granger Lake. Figure 7 shows the thickness of sediment throughout the reservoir. To assist in the interpretation of post-impoundment sediment accumulation, ancillary data was collected in the form of three core samples. All three cores were collected on January 6, 2009 with a custom-coring boat and SDI VibraCore system.

The results of the TWDB 2008 Sedimentation Survey indicate Granger Lake has accumulated 6,182 acre-feet of sediment since impoundment in 1980. The thickest sediment deposits are located within the main body of the lake near the submerged confluence of the San Gabriel River with Willis Creek. The maximum sediment thickness observed in Granger Lake was 5.7 feet. A complete description of the sediment measurement methodology and sample results is presented in Appendix D.

Figure 7

Granger Lake

Sediment Thickness Map



Estimating Sediment Accumulation Rates

In theory, comparing lake volumes from multiple lake surveys allows for the computation of capacity loss rates, which are identical to sediment accumulation rates if all lost capacity is due to sediment accumulation. In practice, however, the differences in methodologies used in each lake survey may yield greater differences in computed lake volumes than physical volume differences due to sediment accumulation over time. For this reason, the TWDB prefers to estimate sediment accumulation rates through sedimentation surveys, which directly measure the sediment layer thicknesses throughout the reservoir. The sediment accumulation rates derived from such surveys reflect the average rate of sediment accrual since the time of impoundment. To estimate temporal trends in sediment accumulation, multiple sedimentation surveys would be beneficial. Comparing results from multiple volumetric surveys, however, would also yield sediment accumulation rate estimates as long as similar methodologies were used when generating each capacity estimate.

To assess the validity of the original capacity estimate of Granger Lake as computed by the U.S. Army Corps of Engineers[5], the TWDB applied current data processing techniques to topographic contour data for the Granger Lake region available in 1968. This contour data is available online from the Texas Natural Resources Information System Strategic Mapping Program (StratMap)[14], which provides digitized contour data derived from 1:24,000 scale U.S. Geological Survey topographic quadrangle maps. The quadrangle maps from which the contours originated are Granger Lake, TX and Granger, TX, dated 1963 (Photo-revised in 1988) and 1964 (Photo-revised in 1988), respectively. The stated accuracy of such contours is to within ± ½ of the contour interval, or to within ± 5 feet of elevation for this data.[15]

The TWDB computed capacity estimates by: 1) using the contour data as hardlines within an ArcGIS TIN model, and 2) by applying the average-area method[16] to contour areas computed in MATLAB. The latter method reproduces the procedures likely to have been used by the U.S. Army Corps of Engineers in deriving their 1968 capacity estimate. Calculations from each of these methods suggest that the pre-impoundment capacity of Granger Lake was between 61,000 acre-feet and 62,000 acre-feet, taking into account the stated accuracy of the contour data. This suggests that the original U.S. Army Corps of Engineers capacity estimate may have over-stated the capacity of Granger Lake.

To properly compare reservoir capacity results from the TWDB surveys of Granger Lake, the TWDB applied the 2008 data processing techniques to the survey data collected in 1995 and 2002. Specifically, the TWDB applied the Self-Similar Interpolation and line extrapolation techniques[17] to the 1995 and 2002 survey datasets. Revised Granger Lake capacities at conservation pool elevation (CPE) are presented in Table 2. The TWDB did not revise the lake areas as the original 1995 and 2002 lake boundaries were used in re-assessing each survey dataset. The TWDB calculated a pre-impoundment (pre-1980) capacity estimate by adding the measured 2008 accumulated sediment volume (6,182 acre-feet) to the measured 2008 Granger Lake volume (50,779 acre-feet). The TWDB calculated pre-impoundment capacity is 8,809 acre-feet (13.4%) less than the original estimate by the U.S. Army Corps of Engineers, and is 4,309-5,309 acre-feet less than the revised estimate calculated by the TWDB using contour data. In assessing sediment accumulation rates, the TWDB only used volume estimates generated from surveys, rather than those derived from contour data.

Table 2 – Revised Capacity Estimates for Granger Lake

	Area @ CPE	Capacity @ CPE (acre-feet)		Capacity Difference	
Year	(acres)	Original	Revised	Acre-Feet	% of Original
1968 (Pre-1980)	4,400	65,510[1]	56,961*	8,809	13.4%
1995	4,009	54,280[2]	54,892	612	1.1%
2002	4,064	52,525[3]	52,905	380	0.7%
2008	4,132	50,779	<>	<>	<>

* 2008 TWDB surveyed capacity of 50,779 acre-feet plus 2008 TWDB surveyed sediment volume of 6,182 acre-feet.

As presented in Table 2, revision of the 1995 and 2002 survey data using current TWDB data processing methods resulted in an increase in reservoir capacity of approximately 1.1% and 0.7%, respectively. Such increases are typical for lakes of similar size and shape as Granger Lake, and are due to the improved representation of the lake bathymetry between adjacent cross sections that is obtained when interpolation is used (see Figure 6 and the section entitled “Self-Similar Interpolation”).

Comparisons of the capacities (at conservation pool elevation) from pre-1980, 1995, 2002, and 2008 (Table 3) suggest Granger Lake looses between 129 acre-feet per year and 304 acre-feet per year, with an average loss rate of 213 acre-feet per year. Analysis of the repeated volumetric surveys suggest that the capacity loss rate for Granger Lake is increasing with time (Figure 8), which may be the result of increased development

within the Granger Lake watershed.[17] Verification of this assertion was not performed for this report. The TWDB notes that the lake areas at conservation pool elevation are different for each of the compared surveys (Table 2), and that some of the reported volume differences are directly attributable to the area differences. The capacity loss rates presented in Table 3 should be considered "best possible estimates."

Table 3 – Capacity/Volume Loss Comparisons for Granger Lake

	Volume Comparisons @ CPE (acre-feet)			
Date	Comparison #1	Comparison #2	Comparison #3	Comparison #4
Pre-1980	56,961*	<>	<>	56,961*
1995	54,892	54,892	<>	<>
2002	<>	52,905	52,905	<>
2008	<>	<>	50,779	50,779
ΔVolume (Acre-Feet)	2,069 (3.6%)	1,987 (3.6%)	2,126 (4.0%)	6,182 (10.9%)
# of Years	16	8	7	29
Capacity Loss Rate (Acre-Feet/Year)	129	248	304	213

* 2008 TWDB surveyed capacity of 50,779 acre-feet plus 2008 TWDB surveyed sediment volume of 6,182 acre-feet.

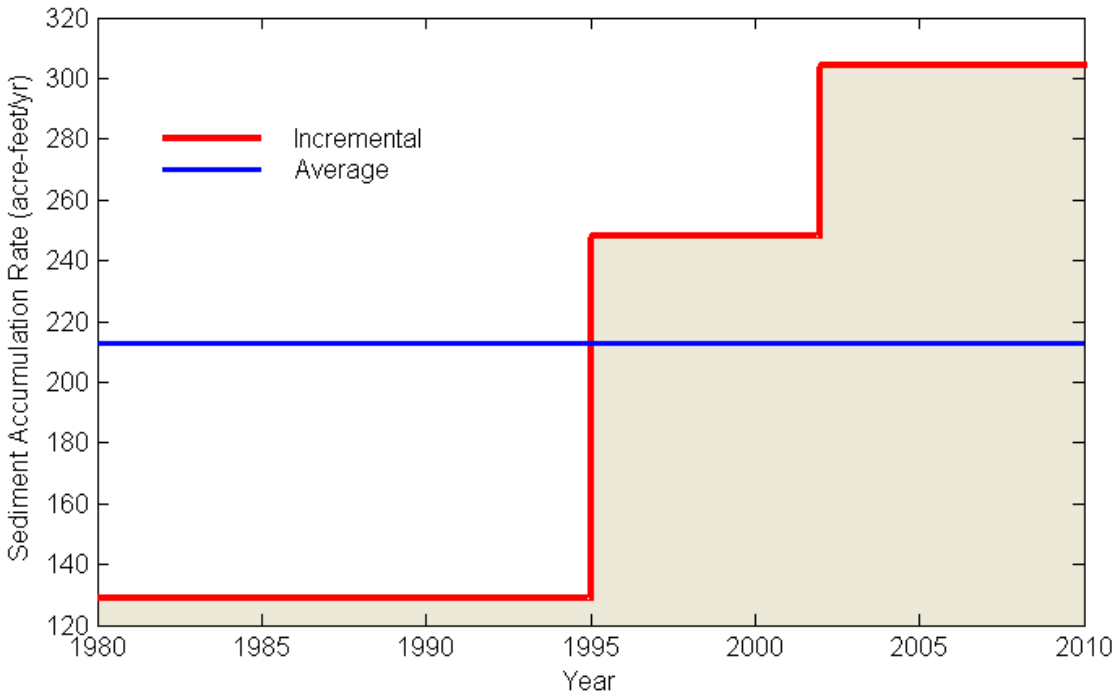


Figure 8 *– Trends in Sediment Accumulation Rates for Granger Lake. Trends are based on volumetric calculations from surveys performed in 1995, 2002, and 2008.*

Sediment Range Lines

In 2002, the TWDB plotted 13 sediment range lines comparing the 2002 survey to the TWDB 1995 survey. It is not clear whether the sediment range lines were defined by the TWDB in 2002, or if they were provided by the Brazos River Authority or other entity. Regardless, the TWDB has plotted the same 13 range lines in Appendix E comparing the 2008 bathymetry, revised 2002 bathymetry, revised 1995 bathymetry, and pre-impoundment bathymetry (as determined by the 2008 survey). Each cross-section was extracted from ArcGIS TIN models of the lake bathymetry using an ArcInfo script developed by the TWDB.

Recommendations

To improve estimates of sediment accumulation rates, the TWDB recommends resurveying Granger Lake in approximately 10 years or after a major flood event. To further improve estimates of sediment accumulation, the TWDB recommends the next survey also be a sedimentation survey. Results from such a re-survey would allow the average sediment accumulation rate for Granger Lake to be quantified with greater accuracy, and a separate rate could be calculated for the time period between 2008 and the date of the future survey. This rate would provide evidence of the temporal trend in sediment accumulation rate for Granger Lake. Additional information detailing sediment accumulation within Granger Lake may be derived through detailed spatial comparisons of survey results from 1995, 2002, and 2008. Such comparisons could provide insight into the locations of active depositional environments and/or locations of scour within Granger Lake. Analysis of the differing lake boundaries from the 1995, 2002 and 2008 surveys would also provide insight on sediment movement within the vicinity of Granger Lake.

TWDB Contact Information

More information about the Hydrographic Survey Program can be found at:

http://www.twdb.state.tx.us/assistance/lakesurveys/volumetricindex.asp

Any questions regarding the TWDB Hydrographic Survey Program may be addressed to:

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Or

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Phone: (512) 463-2465
Email: Jason.Kemp@twdb.state.tx.us

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Appendix A

Granger Lake

RESERVOIR CAPACITY TABLE

TEXAS WATER DEVELOPMENT BOARD — AUGUST 2008 SURVEY

CAPACITY IN ACRE-FEET — Conservation Pool Elevation 504.0 Feet NGVD 29

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
466	0	0	0	0	0	0	0	0	0	0
467	0	0	0	0	0	0	0	0	0	0
468	0	0	0	1	1	1	1	1	1	2
469	2	2	3	3	5	6	8	10	13	16
470	19	22	26	30	34	38	43	48	53	59
471	65	71	78	85	93	101	109	117	126	135
472	145	155	165	176	186	198	209	221	233	246
473	259	272	286	300	315	330	345	361	377	393
474	410	427	444	461	479	497	516	534	553	572
475	592	611	631	651	672	693	714	735	758	780
476	803	826	850	874	899	924	950	976	1,003	1,030
477	1,058	1,087	1,116	1,146	1,176	1,207	1,239	1,271	1,305	1,339
478	1,373	1,409	1,445	1,483	1,521	1,559	1,599	1,640	1,681	1,723
479	1,766	1,810	1,855	1,901	1,947	1,995	2,044	2,093	2,144	2,196
480	2,249	2,303	2,359	2,415	2,473	2,532	2,593	2,654	2,717	2,781
481	2,846	2,913	2,980	3,049	3,119	3,190	3,262	3,335	3,410	3,485
482	3,562	3,639	3,718	3,797	3,877	3,958	4,039	4,122	4,205	4,289
483	4,374	4,460	4,547	4,635	4,724	4,813	4,903	4,994	5,086	5,179
484	5,273	5,367	5,462	5,559	5,656	5,754	5,853	5,953	6,054	6,156
485	6,259	6,363	6,469	6,575	6,682	6,791	6,901	7,012	7,124	7,237
486	7,351	7,466	7,583	7,700	7,819	7,939	8,060	8,182	8,306	8,430
487	8,556	8,683	8,811	8,940	9,070	9,201	9,334	9,467	9,602	9,738
488	9,875	10,012	10,151	10,291	10,432	10,574	10,718	10,862	11,007	11,153
489	11,301	11,450	11,599	11,750	11,902	12,055	12,210	12,365	12,522	12,680
490	12,839	13,000	13,161	13,323	13,487	13,652	13,818	13,985	14,153	14,322
491	14,493	14,664	14,837	15,011	15,186	15,363	15,541	15,720	15,901	16,083
492	16,266	16,450	16,636	16,824	17,012	17,202	17,394	17,586	17,781	17,976
493	18,173	18,371	18,571	18,772	18,975	19,179	19,384	19,591	19,800	20,010
494	20,221	20,434	20,648	20,864	21,081	21,300	21,520	21,743	21,967	22,193
495	22,421	22,650	22,881	23,114	23,349	23,585	23,823	24,063	24,305	24,548
496	24,794	25,041	25,291	25,542	25,795	26,049	26,306	26,564	26,824	27,086
497	27,350	27,616	27,884	28,154	28,427	28,701	28,977	29,255	29,535	29,816
498	30,100	30,385	30,673	30,962	31,254	31,548	31,843	32,141	32,440	32,742
499	33,045	33,350	33,658	33,966	34,277	34,590	34,905	35,221	35,539	35,859
500	36,181	36,505	36,830	37,157	37,486	37,817	38,150	38,485	38,821	39,160
501	39,500	39,842	40,187	40,533	40,881	41,231	41,583	41,938	42,299	42,664
502	43,031	43,400	43,771	44,143	44,517	44,893	45,270	45,650	46,031	46,415
503	46,800	47,188	47,577	47,969	48,362	48,758	49,157	49,557	49,961	50,368
504	50,779									

Appendix B

Granger Lake

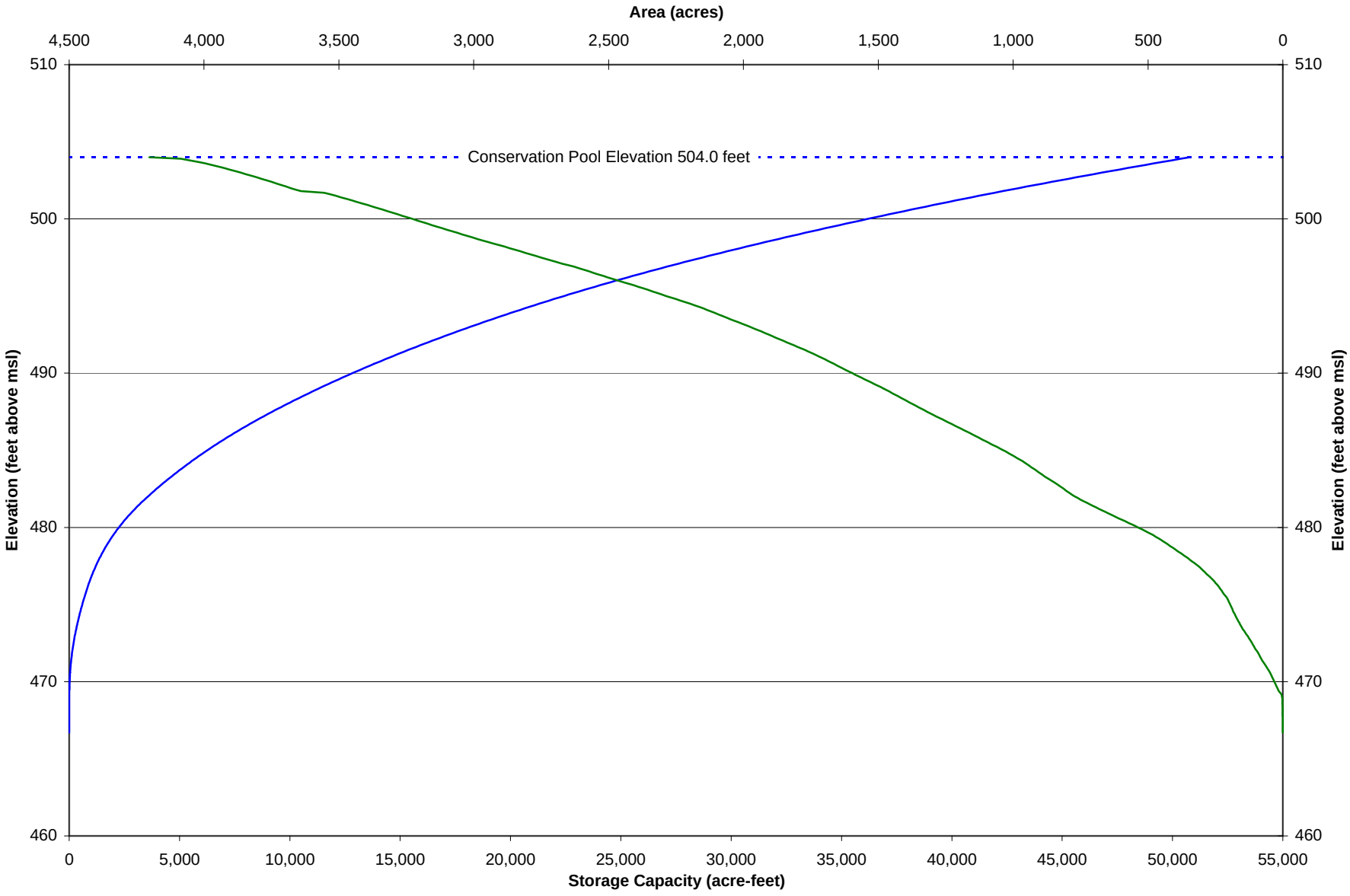
RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — AUGUST 2008 SURVEY

AREA IN ACRES — Conservation Pool Elevation 504.0 Feet NGVD 29

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEVATION in Feet	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
466	0	0	0	0	0	0	0	0	0	0
467	0	0	0	0	0	0	0	0	0	1
468	1	1	1	1	1	1	2	2	2	2
469	2	4	7	11	15	18	20	23	26	29
470	32	35	37	40	43	45	48	52	55	59
471	62	66	70	74	77	81	84	87	90	93
472	97	101	104	108	111	114	117	121	124	128
473	132	136	140	144	148	151	155	158	161	164
474	168	170	173	176	179	182	185	187	190	193
475	195	198	200	203	206	210	215	219	223	227
476	231	235	239	244	249	254	259	265	271	277
477	283	289	295	301	307	313	321	329	337	344
478	352	360	368	376	385	393	401	409	418	426
479	435	443	453	462	471	481	491	503	514	525
480	536	548	560	572	585	597	610	622	634	645
481	657	669	681	693	704	716	727	739	750	760
482	771	780	789	797	805	812	820	829	837	846
483	855	864	874	882	891	899	907	915	923	932
484	940	949	957	966	976	986	996	1,006	1,016	1,026
485	1,036	1,047	1,058	1,070	1,081	1,092	1,103	1,115	1,125	1,137
486	1,148	1,159	1,170	1,182	1,193	1,205	1,216	1,228	1,239	1,251
487	1,262	1,274	1,286	1,297	1,308	1,319	1,330	1,341	1,352	1,362
488	1,373	1,384	1,394	1,405	1,415	1,426	1,437	1,448	1,458	1,469
489	1,480	1,492	1,503	1,515	1,527	1,538	1,550	1,562	1,574	1,585
490	1,597	1,608	1,620	1,631	1,643	1,654	1,664	1,676	1,687	1,698
491	1,710	1,722	1,734	1,747	1,759	1,772	1,785	1,799	1,812	1,826
492	1,839	1,853	1,867	1,880	1,893	1,907	1,920	1,934	1,947	1,962
493	1,976	1,990	2,004	2,019	2,034	2,049	2,063	2,077	2,091	2,106
494	2,120	2,134	2,149	2,165	2,181	2,198	2,215	2,233	2,251	2,268
495	2,286	2,304	2,320	2,337	2,354	2,372	2,390	2,408	2,427	2,446
496	2,465	2,484	2,501	2,520	2,538	2,556	2,573	2,591	2,609	2,628
497	2,650	2,672	2,693	2,712	2,731	2,750	2,770	2,789	2,808	2,827
498	2,846	2,865	2,885	2,905	2,925	2,947	2,967	2,986	3,005	3,024
499	3,043	3,061	3,080	3,099	3,118	3,137	3,155	3,173	3,191	3,209
500	3,227	3,246	3,264	3,282	3,300	3,319	3,337	3,356	3,375	3,394
501	3,413	3,432	3,452	3,471	3,491	3,512	3,532	3,554	3,641	3,661
502	3,679	3,696	3,714	3,731	3,749	3,768	3,786	3,805	3,824	3,844
503	3,864	3,884	3,905	3,926	3,948	3,971	3,995	4,023	4,053	4,086
504	4,203									



Granger Lake
August 2008 Survey
Prepared by: TWDB

Appendix D

Analysis of Sediment Accumulation Data from Granger Lake

Executive Summary

The results of the TWDB 2008 Sedimentation Survey indicate Granger Lake has accumulated 6,182 acre-feet of sediment since impoundment in 1980. Based on this measured sediment volume and assuming a constant sediment accumulation rate, Granger Lake loses approximately 213 acre-feet of capacity per year. The majority of the sediment accumulation has occurred within the main body of the lake, with the thickest deposits in the submerged stream channels. The maximum sediment thickness observed in Granger Lake was 5.7 feet.

Introduction

This appendix includes the results of the sedimentation investigation using multi-frequency depth sounder data collected on August 26-28, 2008 by the Texas Water Development Board (TWDB). Through careful analysis and interpretation of the multi-frequency signal returns, it is possible to discern the pre-impoundment bathymetric surface, as well as the current surface and sediment thickness. Such interpretations are aided and validated through comparisons with sediment core samples which provide independent measurements of sediment thickness. On January 6, 2009 TWDB collected three core samples of the impoundment bottom throughout the reservoir. The remainder of this appendix presents a discussion of the results from and methodology used in the core sampling and multi-frequency data collection efforts, followed by a composite analysis of sediment measured in Granger Lake.

Data Collection & Processing Methodology

TWDB conducted the Granger Lake bathymetric survey on August 26-28, 2008 during which time the water surface elevation ranged between 502.28 feet and 502.34 feet above mean sea level (NGVD29). For all data collection efforts, TWDB used a Specialty Devices, Inc., multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with Differential Global Positioning System (DGPS) equipment. Data collection occurred while navigating along pre-planned range lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. These range lines were the same range lines used to survey the lake in 1995 and 2002. For all data collection efforts, the depth sounder was calibrated daily using a velocity profiler to measure the speed of sound in the water column and a weighted tape or stadia rod for depth reading verification. During the survey, TWDB collected over 40,000 data points over cross-sections totaling nearly 66 miles in length. Figure D1 shows where data points were collected during the TWDB 2008 survey.

Core samples collected by TWDB were collected at locations near where sounding data had been previously collected (Figure D1). The coordinates and a description of each core sample are provided in Table D1. All cores were collected with a custom-coring boat and SDI VibraCore system. Cores were analyzed by TWDB, and both the sediment thickness and the distance the core penetrated the pre-impoundment boundary were recorded.

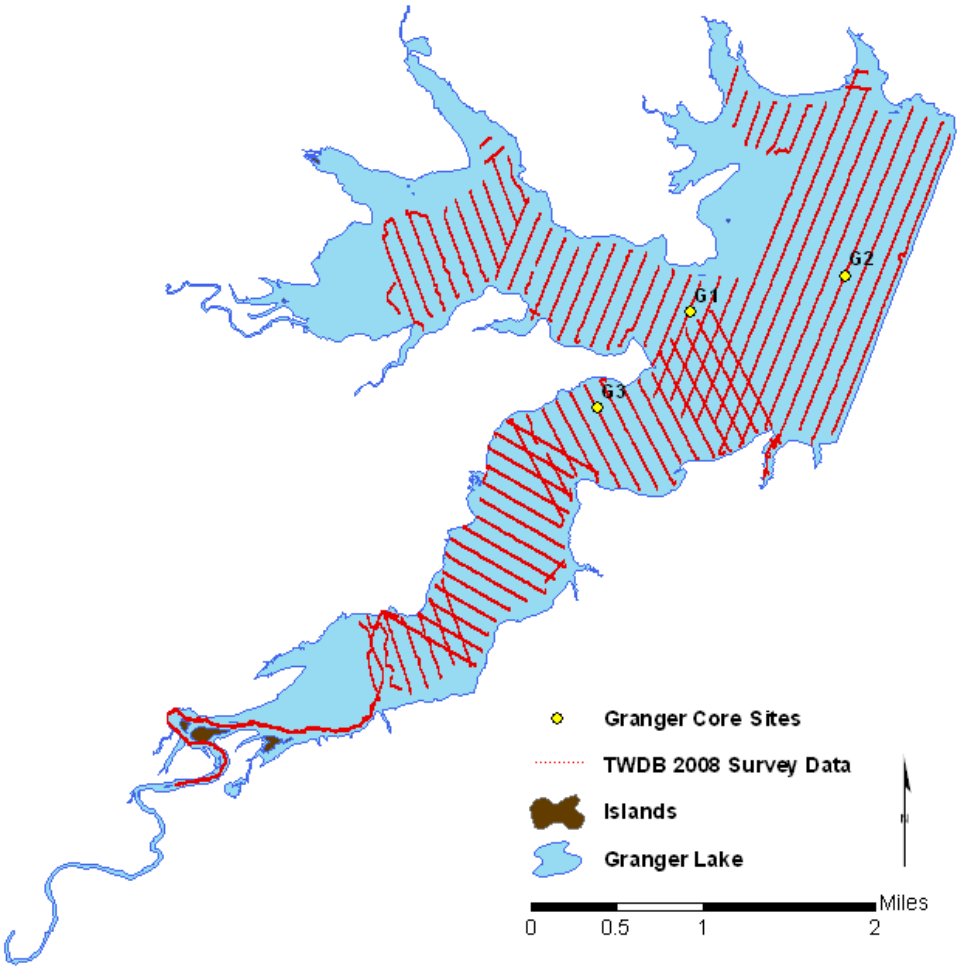


Figure D1 – TWDB 2008 survey data points for Granger Lake

Table D1 – Core Sampling Analysis Data

Core	Easting** (feet)	Northing** (feet)	Description
G1	3233407.9	10230112.4	Surface to 41” consists of muddy sediment. Change of soil structure, color, and content and presence of organic matter at 41”.
G2	3238169.8	10231227.1	Surface to 42” consists of muddy sediment. Change of structure and water content at 42’. No organic matter present.
G3	3230562.2	10227174.2	Surface to 20” consists of muddy/silty sediment. Change of soil structure, color, and water content at 20”. No organic matter present.

** Coordinates are based on NAD83 State Plane Texas Central system

All sounding data is processed using the DepthPic software, within which both the pre-impoundment and current bathymetric surfaces are identified and manually digitized. These surfaces are first identified along cross-sections for which core samples have been collected, thereby allowing the user to identify color bands in the DepthPic display that correspond to the sediment layer(s) observed in the core samples. This process is illustrated in Figure D2 where core sample G2 is shown with its corresponding sounding data. Core sample G2 contained 42 inches of sediment above the pre-impoundment bathymetry, as indicated by the yellow and green boxes. The different box colors indicate changes in soil characteristics and the blue box depicts the pre-impoundment soil identified within the core sample. The pre-impoundment surface is usually identified within the core sample by one of the following methods: (1) a visual examination of the core for in-place terrestrial materials, such as leaf litter, tree bark, twigs, intact roots, etc., concentrations of which tend to occur on or just below the pre-impoundment surface, (2) changes in texture from well sorted, relatively fine-grained sediment to poorly sorted mixtures of coarse and fine-grained materials, and (3) variations in the physical properties of the sediment, particularly sediment water content and penetration resistance with depth.

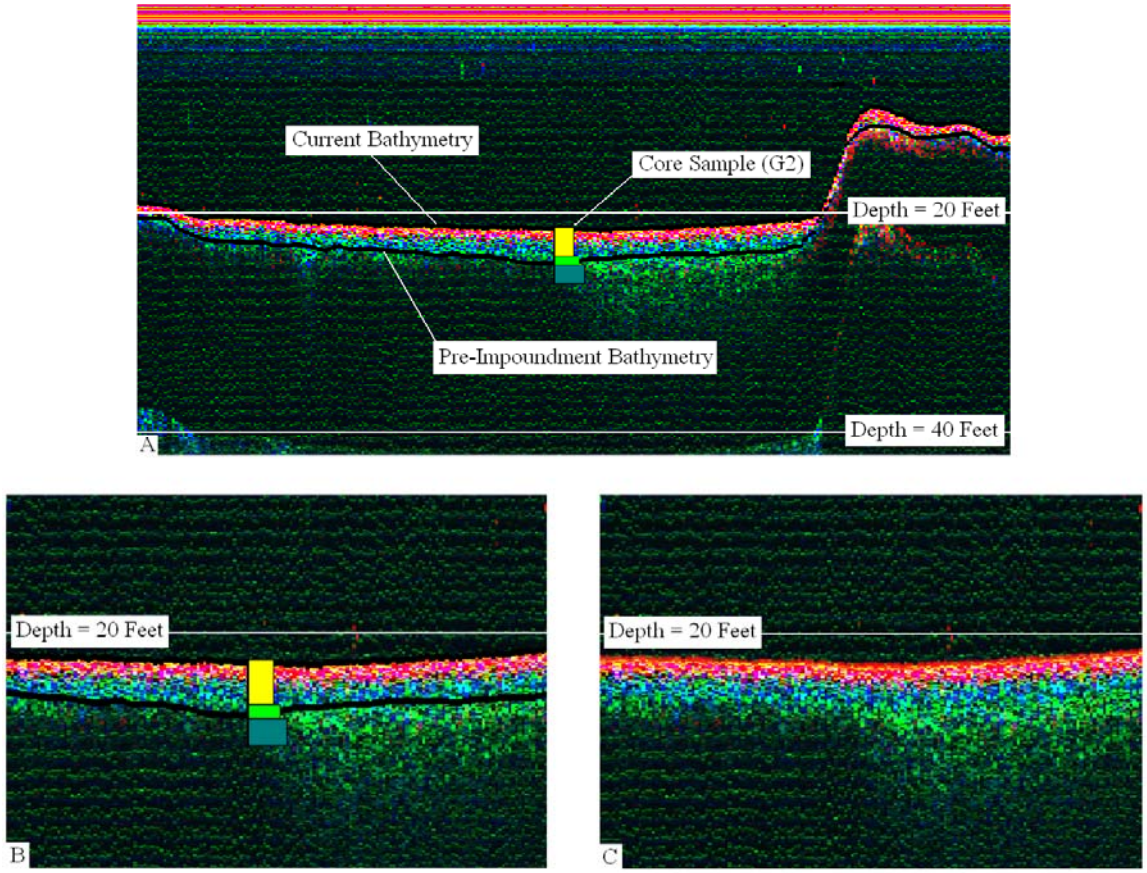


Figure D2 – DepthPic and core sample use in identifying the pre-impoundment bathymetry.

Within DepthPic, the current surface is automatically determined based on the signal returns from the 200 kHz transducer. The pre-impoundment surface must be determined visually based on the pixel color display and any available core sample data. Based on core sample G2, it is clear that the pre-impoundment bathymetric surface for this cross-section may be identified as the base of the blue and teal pixels in the DepthPic display. The pre-impoundment sediment layer is also clearly identifiable as the green pixels (Figure D2).

In analyzing data from cross-sections where core samples were not collected, the assumption is made that sediment layers may be identified in a similar manner as when core sample data is available. To improve the validity of this assumption, core samples are collected at regularly spaced intervals within the lake, or at locations where interpretation of the DepthPic display would be difficult without site-specific core data.

For this reason, all sounding data is collected and reviewed before core sites are selected and cores are collected.

After manually digitizing the pre-impoundment surface from all cross-sections, both the pre-impoundment and current bathymetric surfaces are exported as X-,Y-,Z-coordinates from DepthPic into text files suitable for use in ArcGIS. Within ArcGIS, the sounding points are then processed into TIN models following standard GIS techniques[1].

Results

The results of the TWDB 2008 Sedimentation Survey indicate Granger Lake has accumulated 6,182 acre-feet of sediment since impoundment in 1980. Based on this measured sediment volume and assuming a constant sediment accumulation rate, Granger Lake loses approximately 213 acre-feet of capacity per year. The majority of the sediment accumulation has occurred within the main body of the lake, with the thickest deposits near the submerged confluence of the San Gabriel River with Willis Creek. The maximum sediment thickness observed in Granger Lake was 5.7 feet.

The accumulated sediment volume for Granger Lake was calculated from a sediment thickness TIN model created in ArcGIS. Sediment thicknesses were computed as the difference in elevations between the current and pre-impoundment bathymetric surfaces as determined with the DepthPic software. Sediment thicknesses were interpolated for locations between surveyed cross-sections using the TWDB Self-Similar interpolation technique[2]. For the purposes of the TIN model creation, TWDB assumed 0-foot sediment thicknesses at the model boundaries (defined as the 504.00 foot NGVD29 elevation contour). Figure D3 depicts the sediment thickness in Granger Lake.

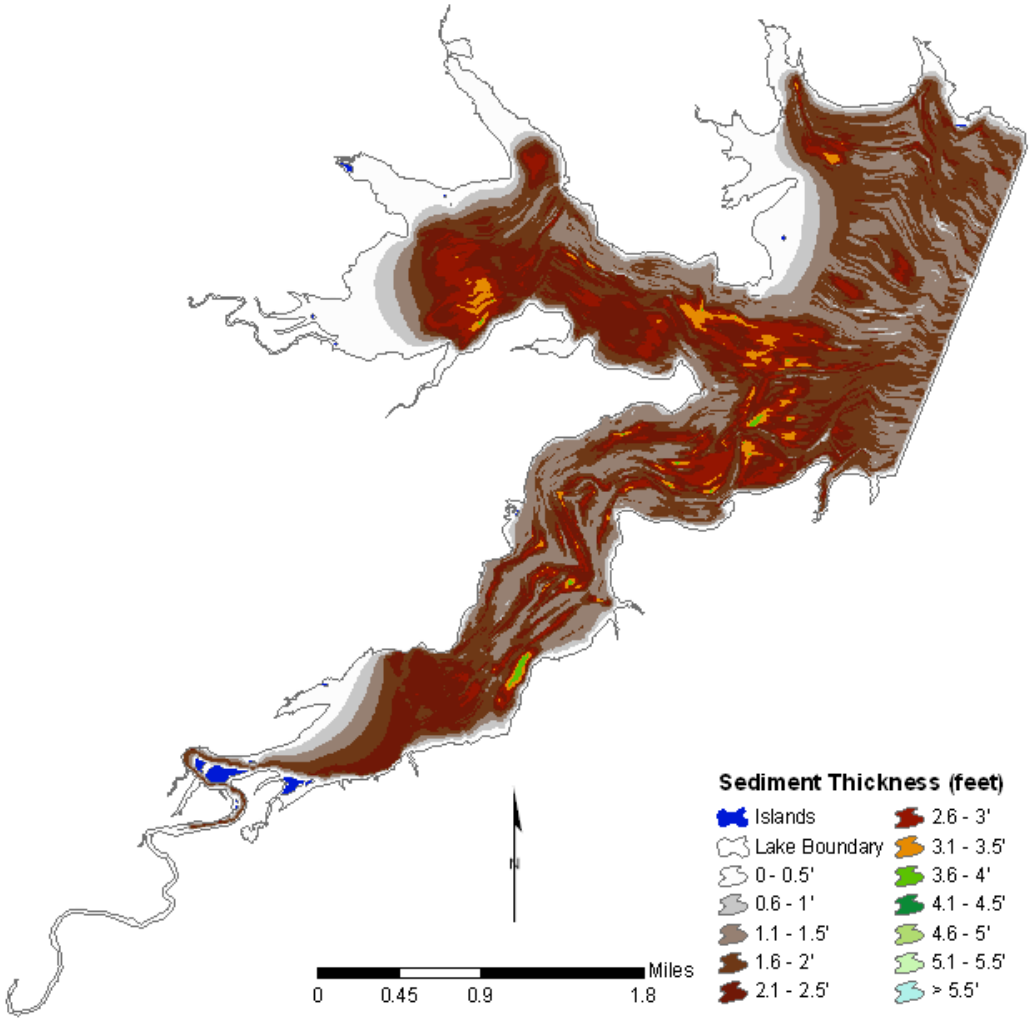
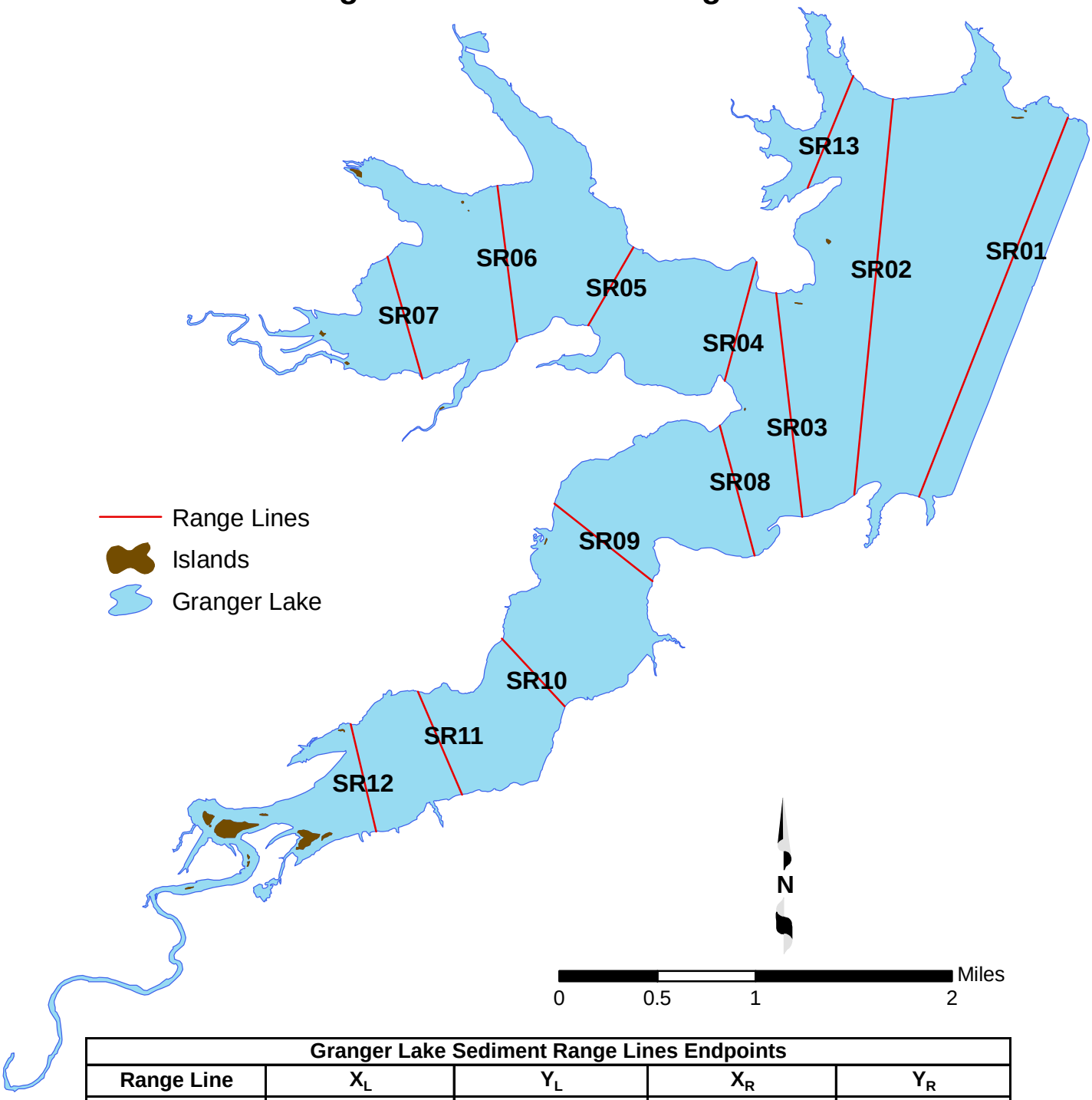


Figure D3 - Sediment thicknesses in Granger Lake derived from multi-frequency sounding data.

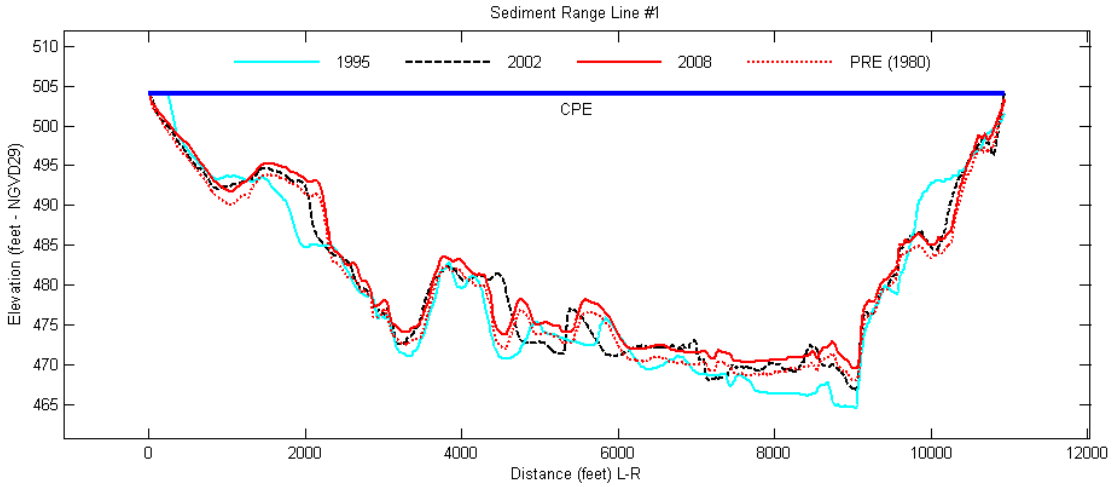
References

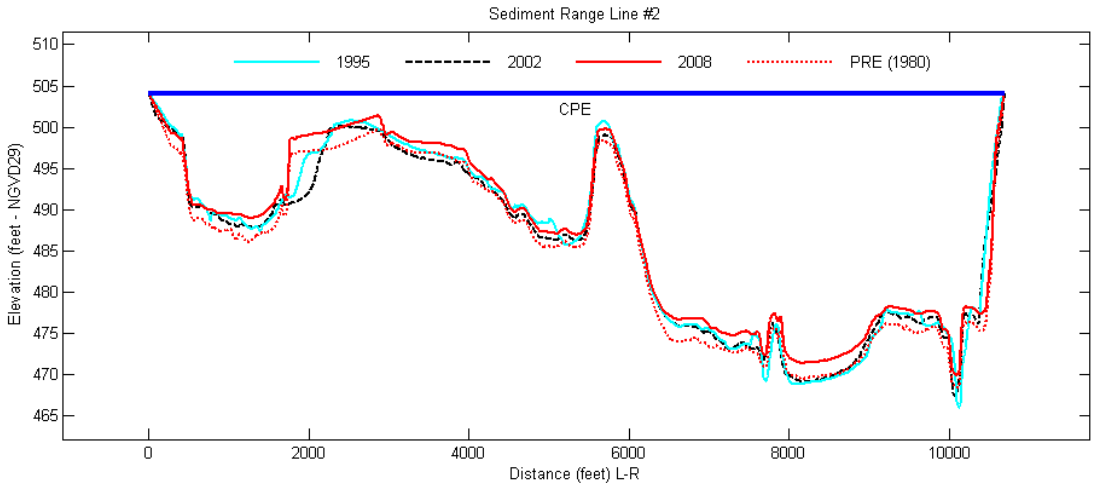
1. Furnans, J., Austin, B., Hydrographic survey methods for determining reservoir volume, Environmental Modelling & Software (2007), doi: 10.1016/j.envsoft.2007.05.011
2. Furnans, Jordan. Texas Water Development Board. 2006. "HydroEdit User's Manual."

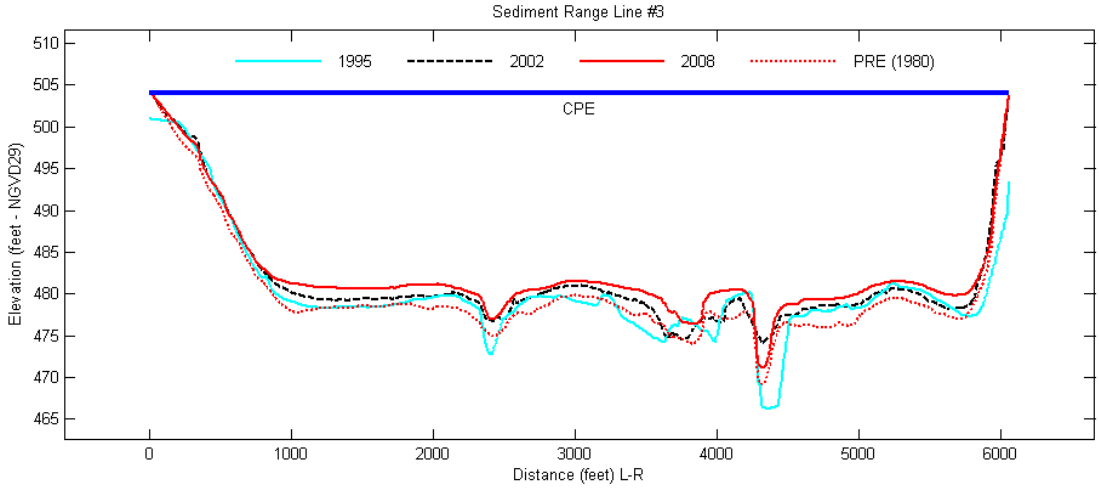
Appendix E
Granger Lake Sediment Range Lines

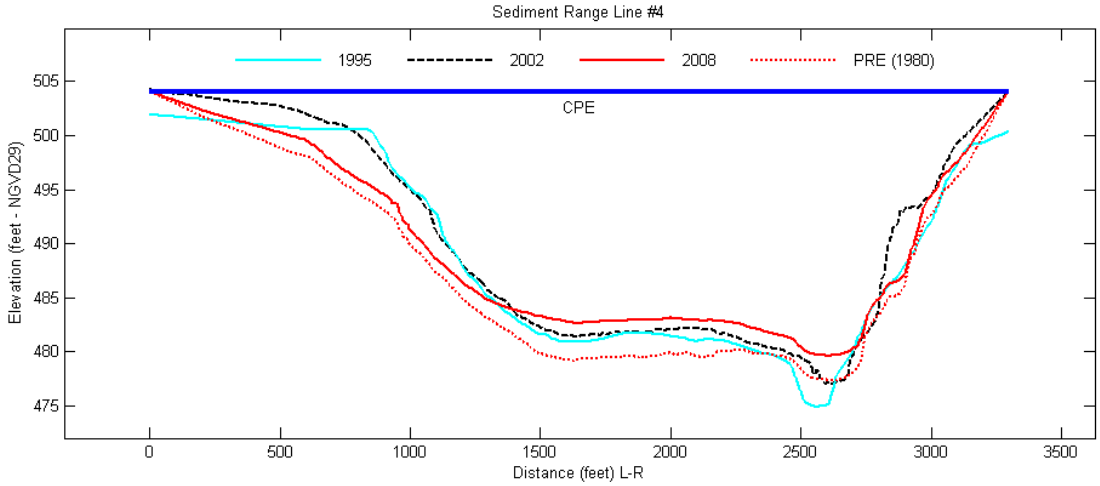


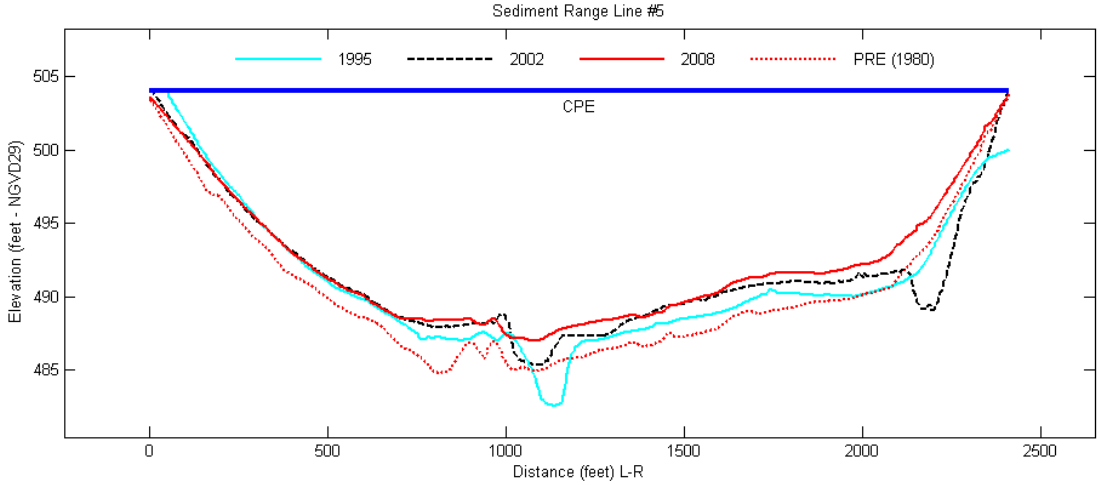
Granger Lake Sediment Range Lines Endpoints				
Range Line	**X_L**	**Y_L**	**X_R**	**Y_R**
SR01	3,241,000.00	10,236,271.00	3,236,996.25	10,226,088.00
SR02	3,236,293.25	10,236,773.00	3,235,257.50	10,226,134.00
SR03	3,233,154.50	10,231,563.00	3,233,857.50	10,225,544.00
SR04	3,232,630.25	10,232,383.00	3,231,772.75	10,229,198.00
SR05	3,229,319.00	10,232,779.00	3,228,111.25	10,230,692.00
SR06	3,225,660.50	10,234,434.00	3,226,189.25	10,230,248.00
SR07	3,222,713.25	10,232,534.00	3,223,650.75	10,229,253.00
SR08	3,231,641.75	10,227,990.00	3,232,572.25	10,224,493.00
SR09	3,227,197.75	10,225,892.00	3,229,830.25	10,223,807.00
SR10	3,225,781.50	10,222,266.00	3,227,466.00	10,220,448.00
SR11	3,223,523.75	10,220,844.00	3,224,710.00	10,218,076.00
SR12	3,221,721.25	10,219,973.00	3,222,405.50	10,217,091.00
SR13	3,235,234.25	10,237,388.00	3,234,005.50	10,234,379.00
Coordinates in NAD83 State Plane Texas Central Zone (feet) $_L$= Left endpoint $_R$= Right endpoint				

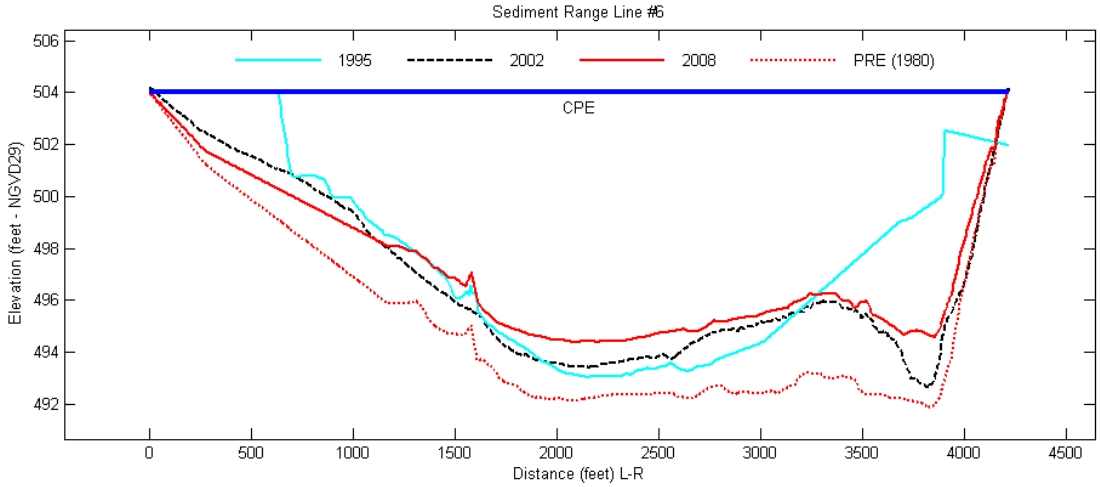

Sediment Range Line #1
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R

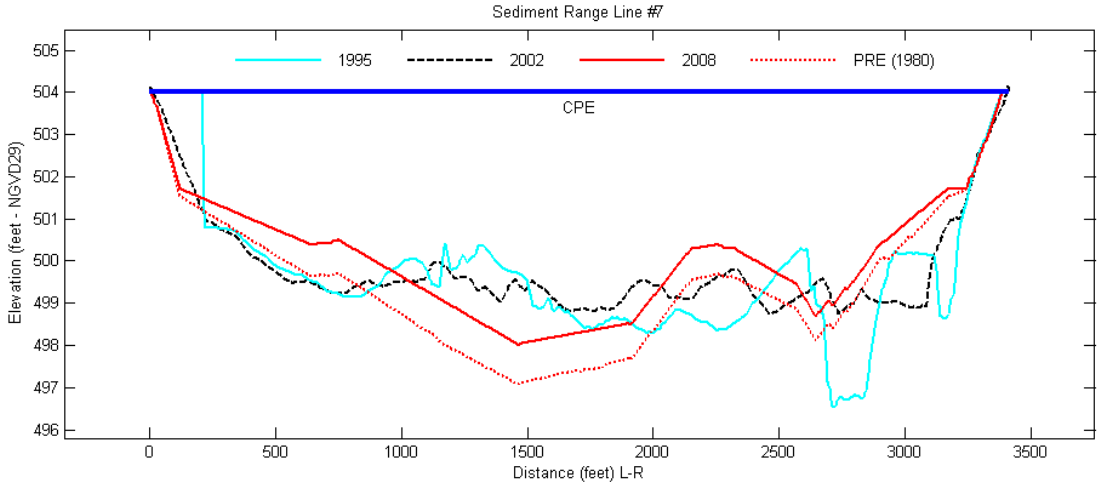

Sediment Range Line #2
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R

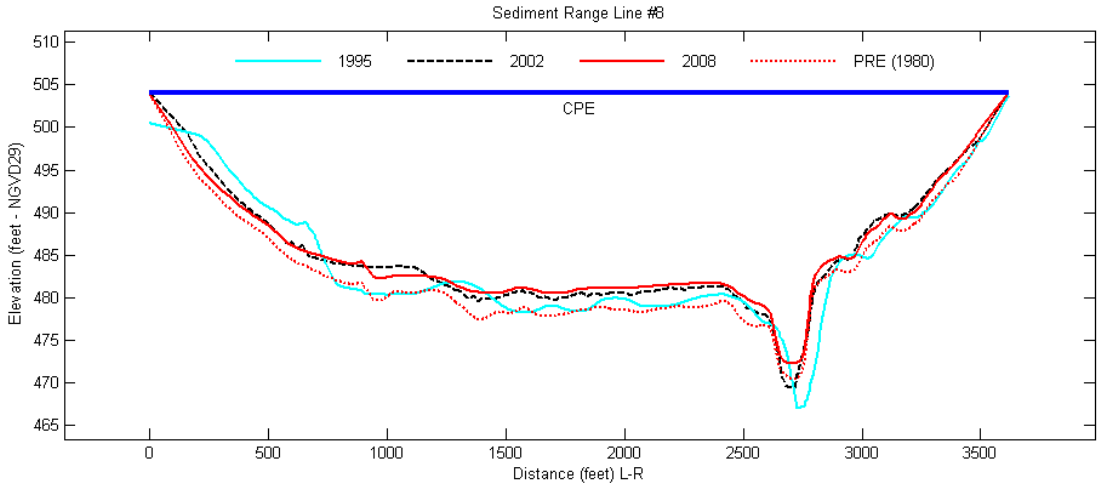

Sediment Range Line #3
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R

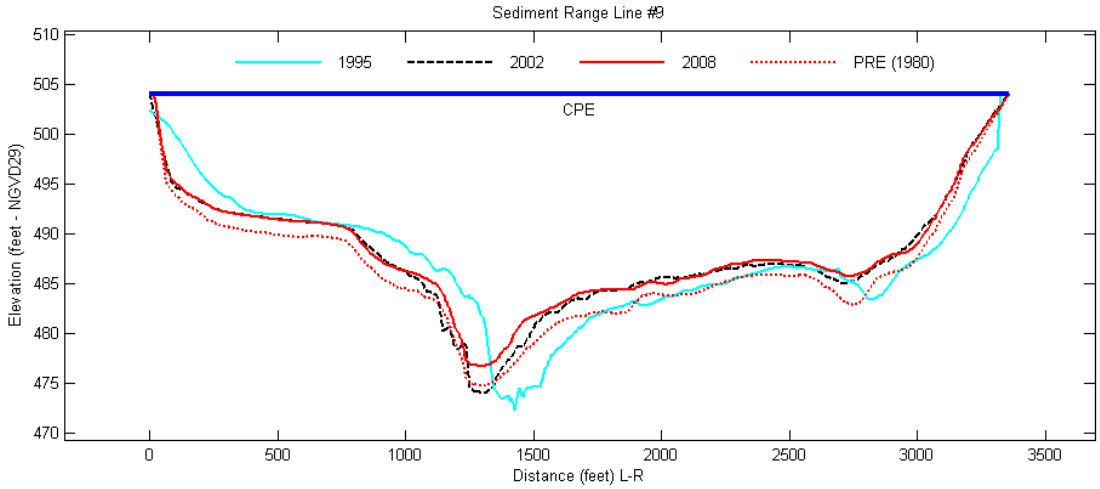

Sediment Range Line #4
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
505
500
495
490
485
480
475
0
500
1000
1500
2000
2500
3000
3500
Distance (feet) L-R

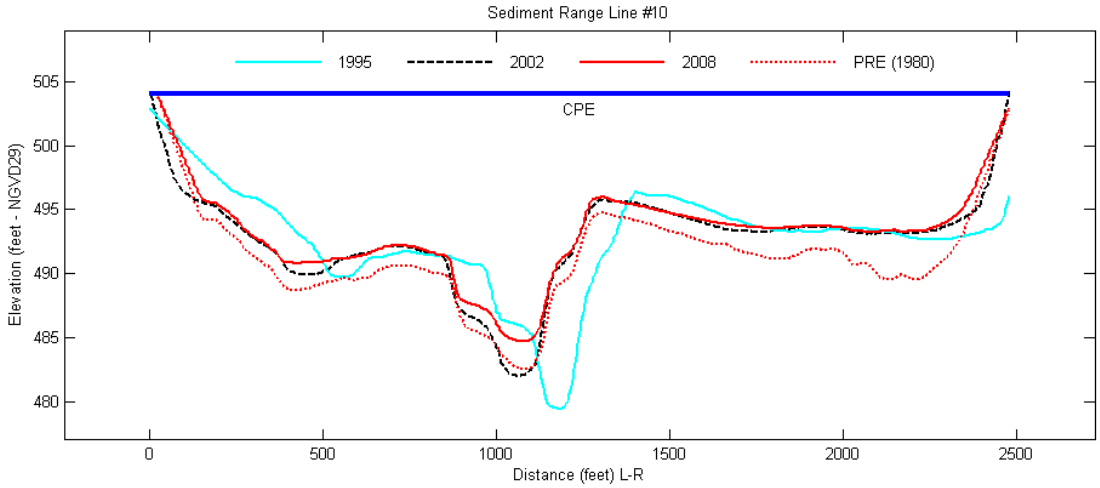

Sediment Range Line #5
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
505
500
495
490
485
0
500
1000
1500
2000
2500
Distance (feet) L-R

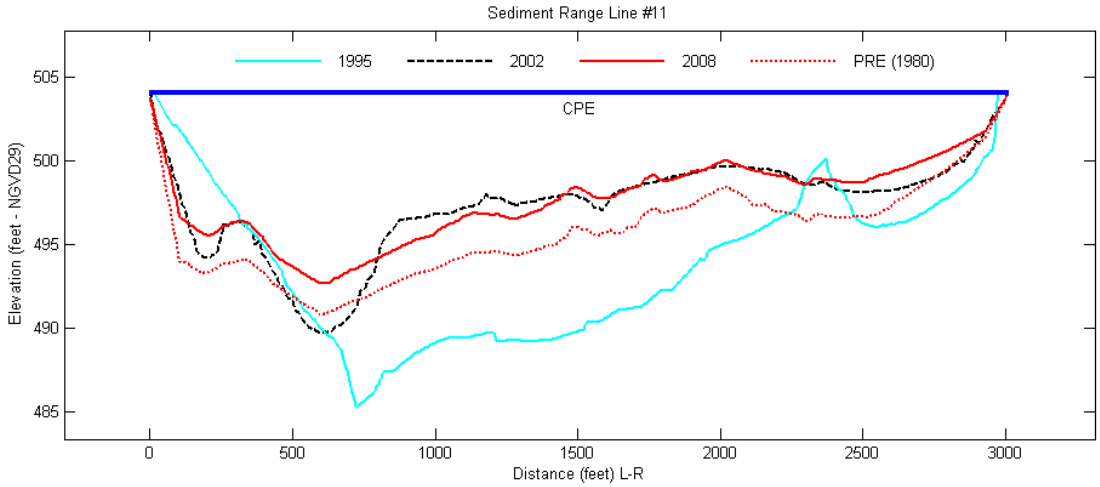

Sediment Range Line #6
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
506
504
502
500
498
496
494
492
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance (feet) L-R

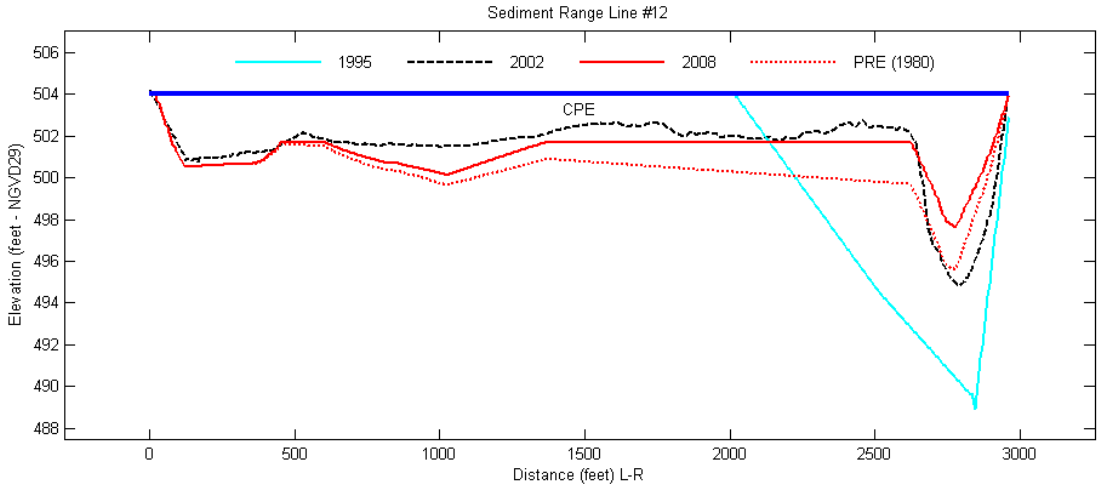

Sediment Range Line #7
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R

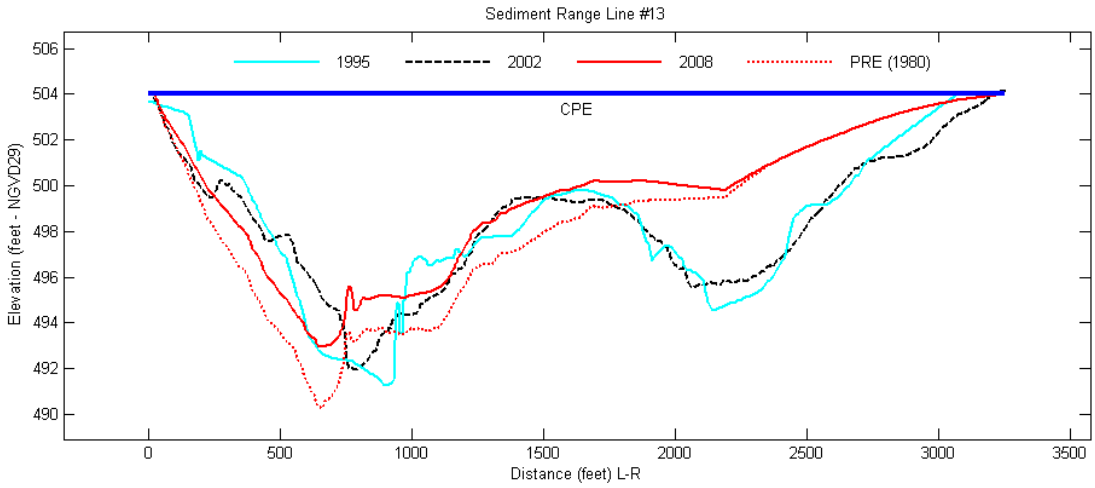

Sediment Range Line #8
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R


Sediment Range Line #9
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R


Sediment Range Line #10
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
505
500
495
490
485
480
0
500
1000
1500
2000
2500
Distance (feet) L-R


Sediment Range Line #11
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
505
500
495
490
485
0
500
1000
1500
2000
2500
3000
Distance (feet) L-R


Sediment Range Line #12
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R


Sediment Range Line #13
1995
2002
2008
PRE (1980)
CPE
Elevation (feet - NGVD29)
Distance (feet) L-R

Appendix F

Granger Lake Intake Study

Executive Summary

The results of the TWDB 2009 Granger Lake intake study indicate the intake structure located on the south bank of the San Gabriel arm in the upper end of Granger Lake may be isolated if the water elevation drops below 496.5 feet above mean sea level. A straight line measurement from the intake structure to a deeper part of the lake (elevation 484 feet above mean sea level), requested by the Brazos River Authority, is approximately 5,900 feet.

Introduction

The Texas Water Development Board conducted a Volumetric and Sedimentation Survey of Granger Lake on August 26-28, 2008. Bathymetric data was collected using a Specialty Devices, Inc., multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder integrated with Differential Global Positioning System (DGPS) equipment. Data collection occurred while navigating along pre-planned range lines oriented perpendicular to the assumed location of the original river channels and spaced approximately 500 feet apart. The water surface elevation of Granger Lake at the time of the survey ranged between 502.34 and 502.28 feet above mean sea level. Conservation Pool Elevation of Granger Lake is 504.0 feet above mean sea level.

This appendix includes the results of additional bathymetric data collection near the intake structure located on the south bank of the San Gabriel arm in the upper end of Granger Lake collected at the request of the Brazos River Authority. Its approximate location is defined by the coordinates: 30°39’50.06” N 97°23’08.03” W. Data was collected on January 6, 2009 while the water surface elevation of Granger Lake averaged 500.51 feet above mean sea level. The additional data was collected with a Knudsen

Engineering Ltd. dual-frequency (200 kHz and 50 kHz) depth sounder integrated with Differential Global Positioning System (DGPS) equipment. Figure 1 shows the data points collected on Granger Lake.

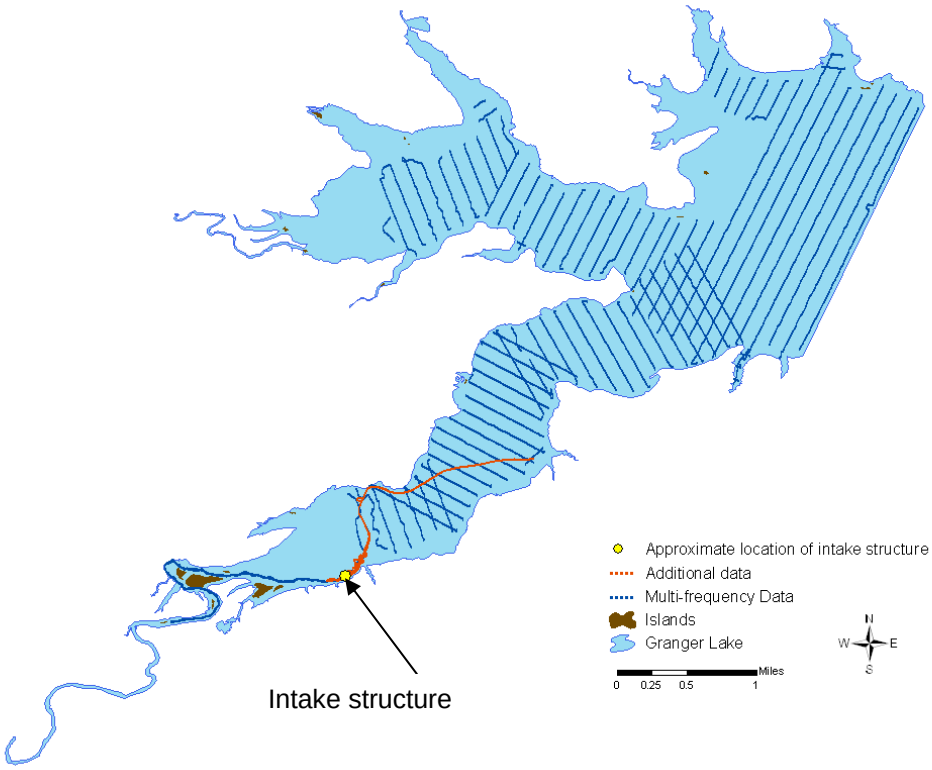


Figure F1 – Data points collected on Granger Lake during TWDB 2008 Survey.

Results

The results of the TWDB 2009 Granger Lake intake study indicate the intake structure located on the south bank of the San Gabriel arm in the upper end of Granger Lake may be isolated if the water elevation drops below 496.5 feet above mean sea level. These results are based on the aforementioned TWDB hydrographic survey data and a Triangulated Irregular Network (TIN) model created from the bathymetric data and interpolated data points in ESRI's ArcGIS 9.2 (procedures are explained in the Volumetric and Sedimentation Survey of Granger Lake report). Figures

2-4 demonstrate these results. Particularly, Figures 2, 3, and 4 illustrate data points with elevations greater than and less than 497.0 feet, 496.5 feet, and 496.0 feet, respectively.

The Brazos River Authority also requested a straight-line measurement, representing a possible pipeline, from the intake structure to a deeper part of the lake. In Figure 5, a straight line was drawn from the center of the deep area that represents the approximate location of the intake structure to a deeper location in the lake. This line represents one possible pipeline solution. The line is approximately 5,900 feet long. The elevation of the lake bottom where the sample pipeline ends is approximately 484 feet above mean sea level. The bathymetry along the sample pipeline was extracted from the TIN model and graphed (Figure 6).

Figure F2

Granger Lake

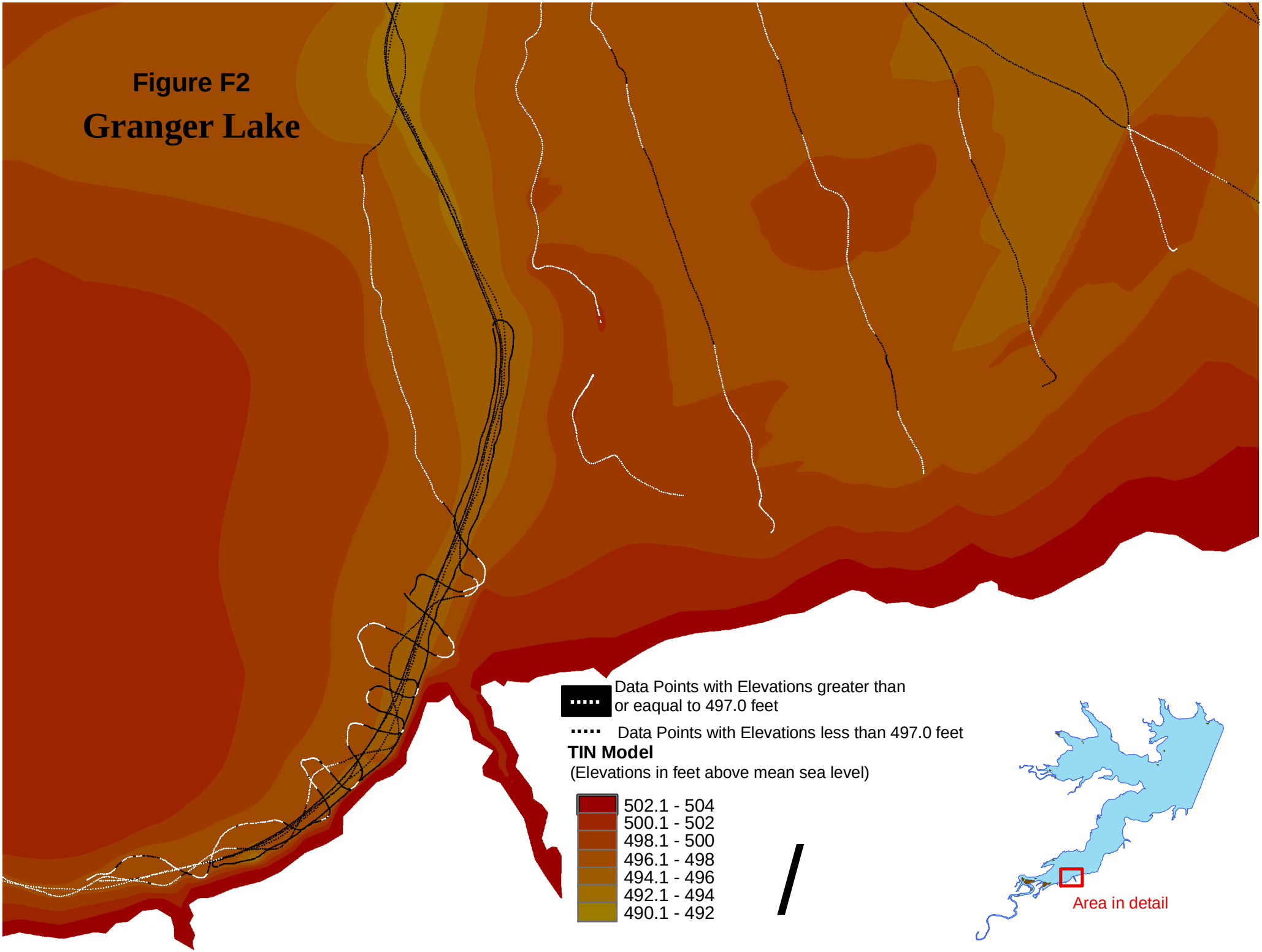


Figure F3

Granger Lake

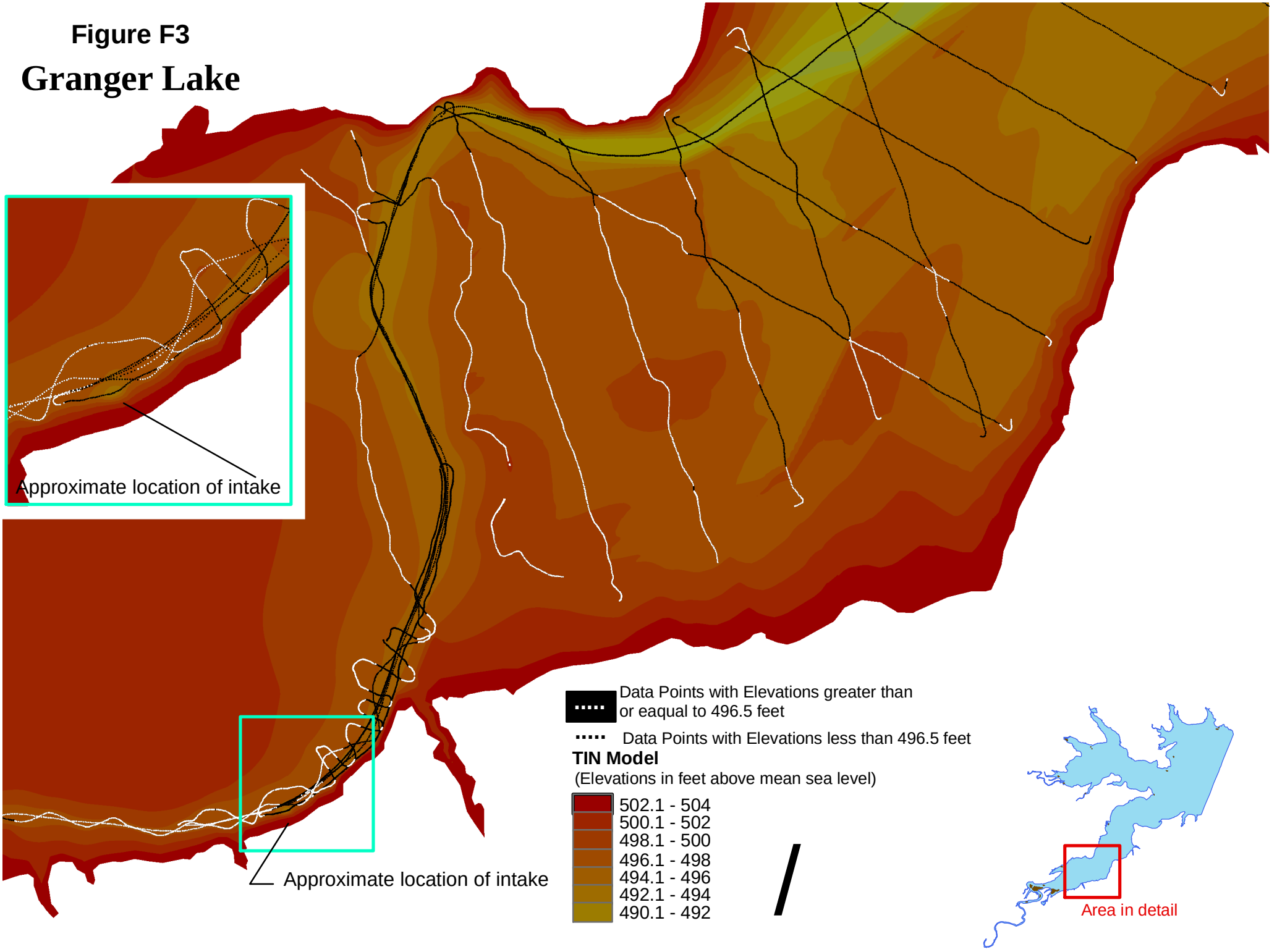


Figure F4

Granger Lake

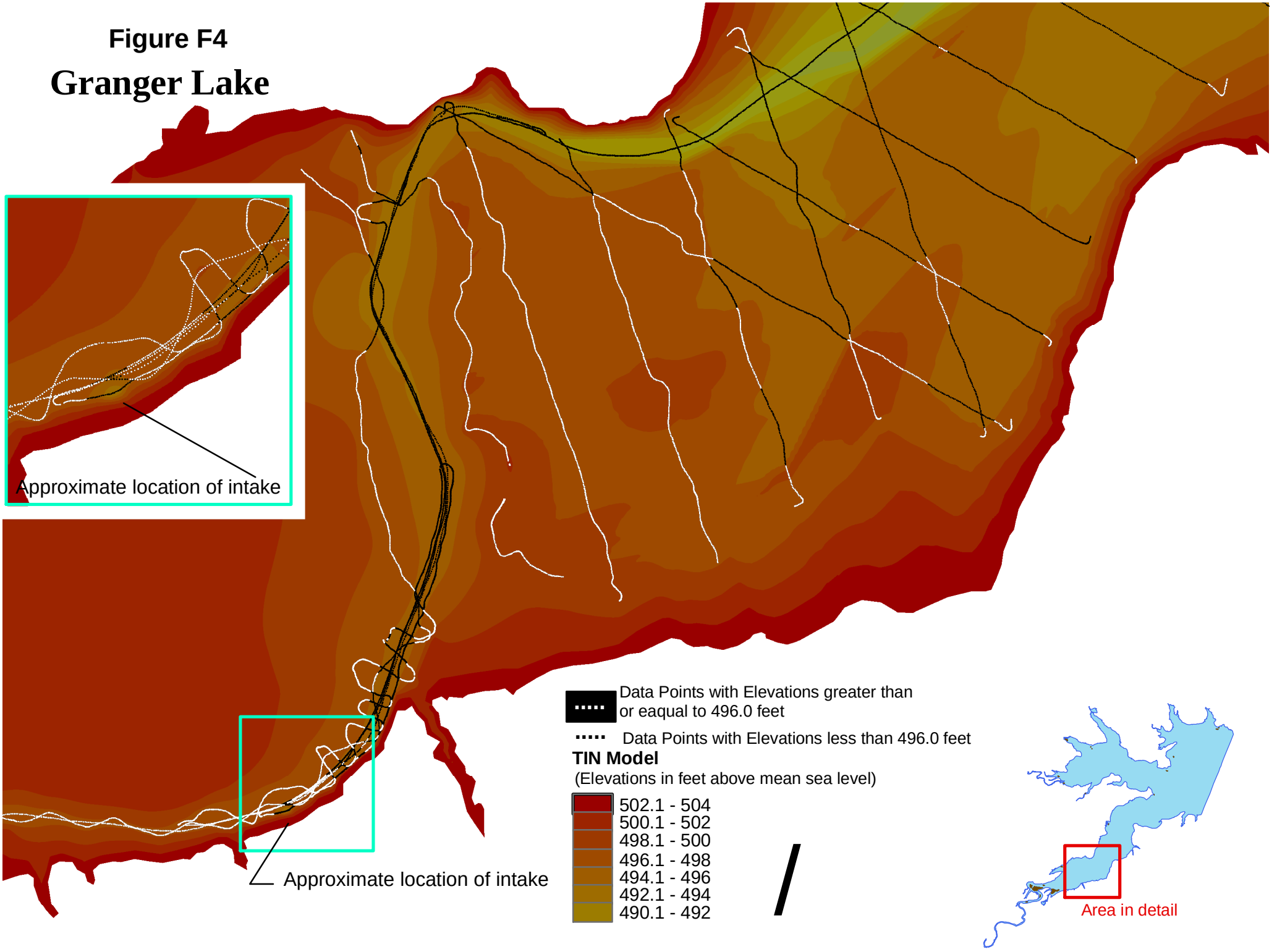
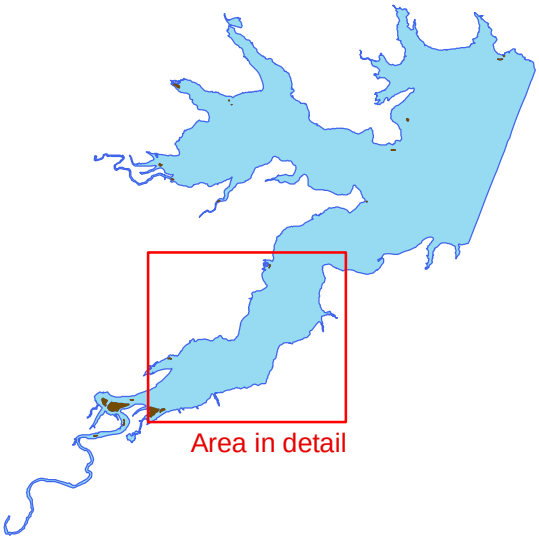


Figure F5

Granger Lake



Sample Pipeline

Elevation

(in feet above mean sea level)

- 502.1 - 504
- 500.1 - 502
- 498.1 - 500
- 496.1 - 498
- 494.1 - 496
- 492.1 - 494
- 490.1 - 492
- 488.1 - 490
- 486.1 - 488
- 484.1 - 486
- 482.1 - 484
- 480.1 - 482
- 478.1 - 480
- 476.1 - 478
- 474.1 - 476
- 472.1 - 474
- 470.1 - 472
- 468.1 - 470
- 466.1 - 468
- 464.1 - 466
- 462.1 - 464
- 460.1 - 462
- 458.1 - 460
- 457.9 - 458

Sample Pipeline

0 0.25 0.5 1 Miles

Figure F6: Sample Pipeline Cross-Section

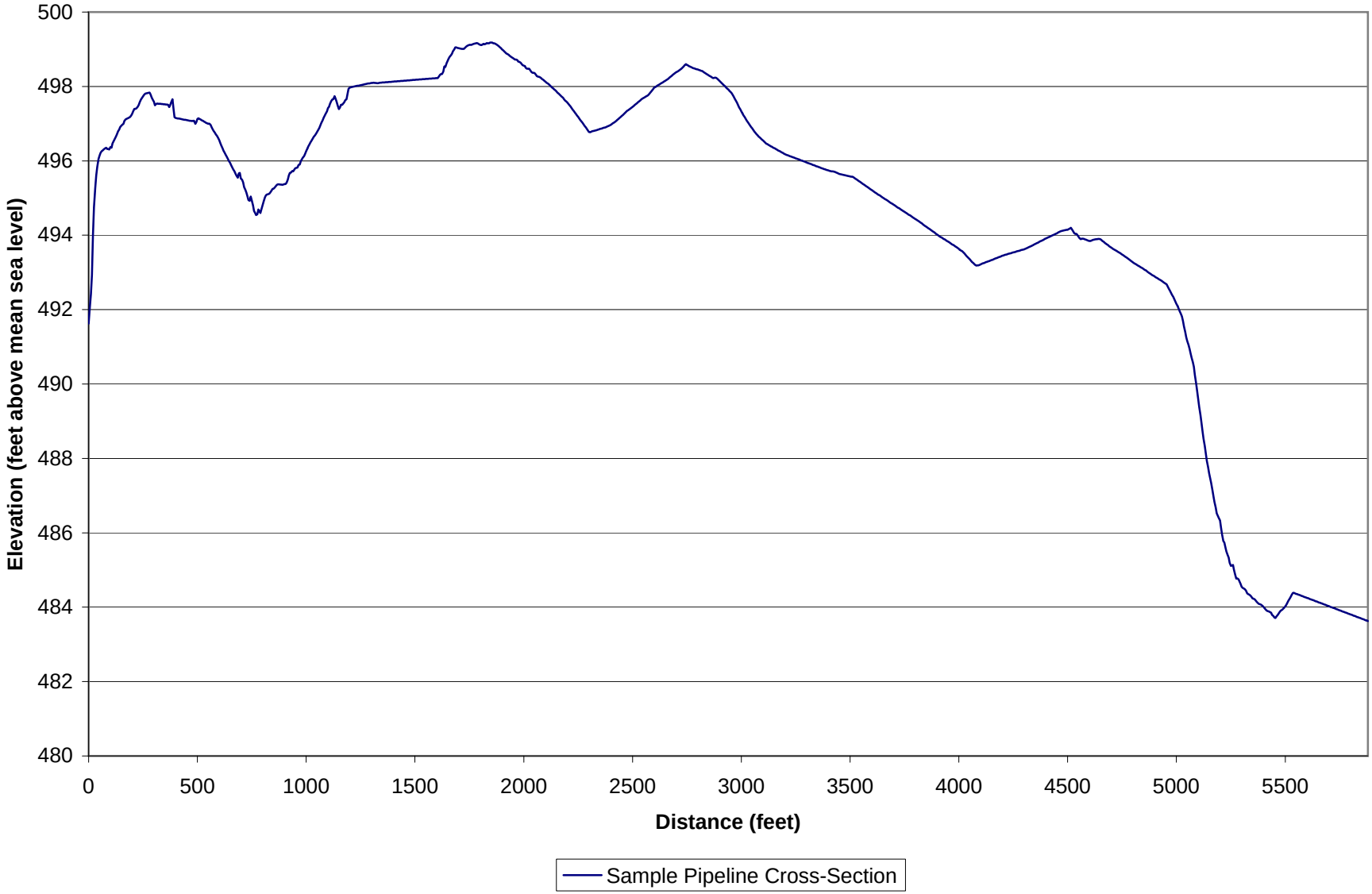


Figure 5

Granger Lake

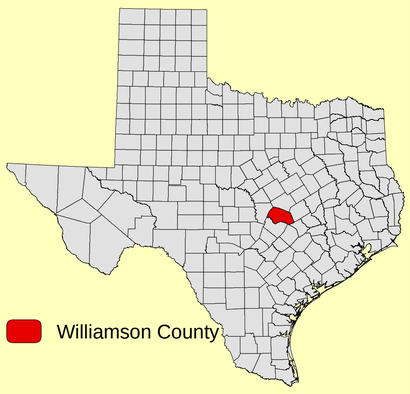
5' - Contour Map

Contours
(in feet above mean sea level)

- 470
- 475
- 480
- 485
- 490
- 495
- 500

Conservation Pool Elevation
504.0 feet above mean sea level

Projection: NAD83
State Plane
Texas Central Zone



This map is a product of a survey conducted by the Texas Water Development Board's Hydrographic Survey Program to determine the capacity of Granger Lake.
The Texas Water Development Board makes no representations nor assumes any liability.

2,310,000
2,320,000
2,330,000
6,220,000
6,210,000
6,200,000

N

0 0.5 1 2 Miles

Prepared by: TEXAS WATER DEVELOPMENT BOARD August 2008 Survey