# Volumetric and Sedimentation Survey of LAKE BUCHANAN

## March-April 2006 Survey

Prepared by:

The Texas Water Development Board

August 2007

# Texas Water Development Board

J. Kevin Ward, Executive Administrator



Prepared for:

**Lower Colorado River Authority**




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## Executive Summary

In March of 2006, the Texas Water Development Board (TWDB) entered into agreement with the Lower Colorado River Authority (LCRA), Austin, Texas, for the purpose of performing a volumetric and sediment survey of Lake Buchanan while the reservoir was near the top of the conservation pool elevation (1020.5 ft). However, due to continued drought conditions persisting into the spring of 2006, TWDB surveyed the reservoir while the water surface elevation was between 1,011.75 ft and 1,012.2 ft (8.30 ft and 9.25 ft below conservation pool elevation). To augment the survey data collected by TWDB, LCRA provided high-resolution LIDAR data, collected on December 31, 2006 and January 1, 2007 when the water surface elevation in Lake Buchanan was approximately 998 ft. Reservoir capacities were computed based on a combination of the TWDB survey data and the LIDAR data.

The TWDB volumetric and sediment surveys were carried out simultaneously using two separate depth sounders. South of Willow Slough in areas of the reservoir where a majority of water depths exceeded 4.5 ft during the survey, a multi-frequency (200 kHz, 50 kHz, and 24 kHz) sub-bottom profiling depth sounder was used to collect data. While north of Willow Slough in the shallower riverine reaches of the reservoir, a single frequency (200 kHz) sounder was use to collect data. The 200 kHz signal from both sounders determined the current reservoir bathymetry, while the multi-frequency data was used to identify the pre-impoundment surface throughout most of the reservoir.

**The results of the TWDB 2006 Volumetric Survey indicate Lake Buchanan has a total reservoir capacity of 886,626 acre-ft and encompasses 22,137 acres at conservation pool elevation (gauge datum 1,020.5 ft NGVD 29).**

**The results of the TWDB 2006 Sedimentation Survey indicate Lake Buchanan contains at least 34,275 acre-ft of sediment. This volume is likely an underestimate of the true sediment volume above the pre-impoundment surface, as portions of the reservoir were unsurveyable using the multi-frequency depth sounder because the water was too shallow.**

Lake Buchanan was originally impounded in May of 1937 and per the Texas Department of Water Resources, the original reservoir capacity and area at elevation 1,020.5 ft was estimated to have been 992,000 acre-ft and 23,060 acres. The current daily allocation table of values for capacity and area used by the LCRA were developed from a combination of 1991 LCRA survey data and 1997 aerial photographs. Values interpolated from this table indicate a capacity and area at elevation 1,020.5 ft of 888,865 acre-ft and 22,387 acres, respectively. When compared to the TWDB 2006 survey results, these numbers indicate the reservoir has experienced a 105,374 acre-ft (10.6%) decrease in capacity since impoundment and a 2,239 acre-ft (0.3%) decrease in capacity from the current daily allocation table numbers. The TWDB 2006 survey indicates a 923 acre (4.0%) decrease in surface area at the conservation pool elevation since impoundment and a 250 acre (1.1%) decrease in area when compared to the area listed in the current daily allocation table. It is important to remember that area and volumes calculated by different methodologies can easily vary within the differences stated above and comparisons are presented here for informational purposes only.

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## Lake Buchanan General Information

Lake Buchanan is located on the Colorado River between Burnet and Llano Counties, 414 river miles from the Gulf of Mexico.[1]

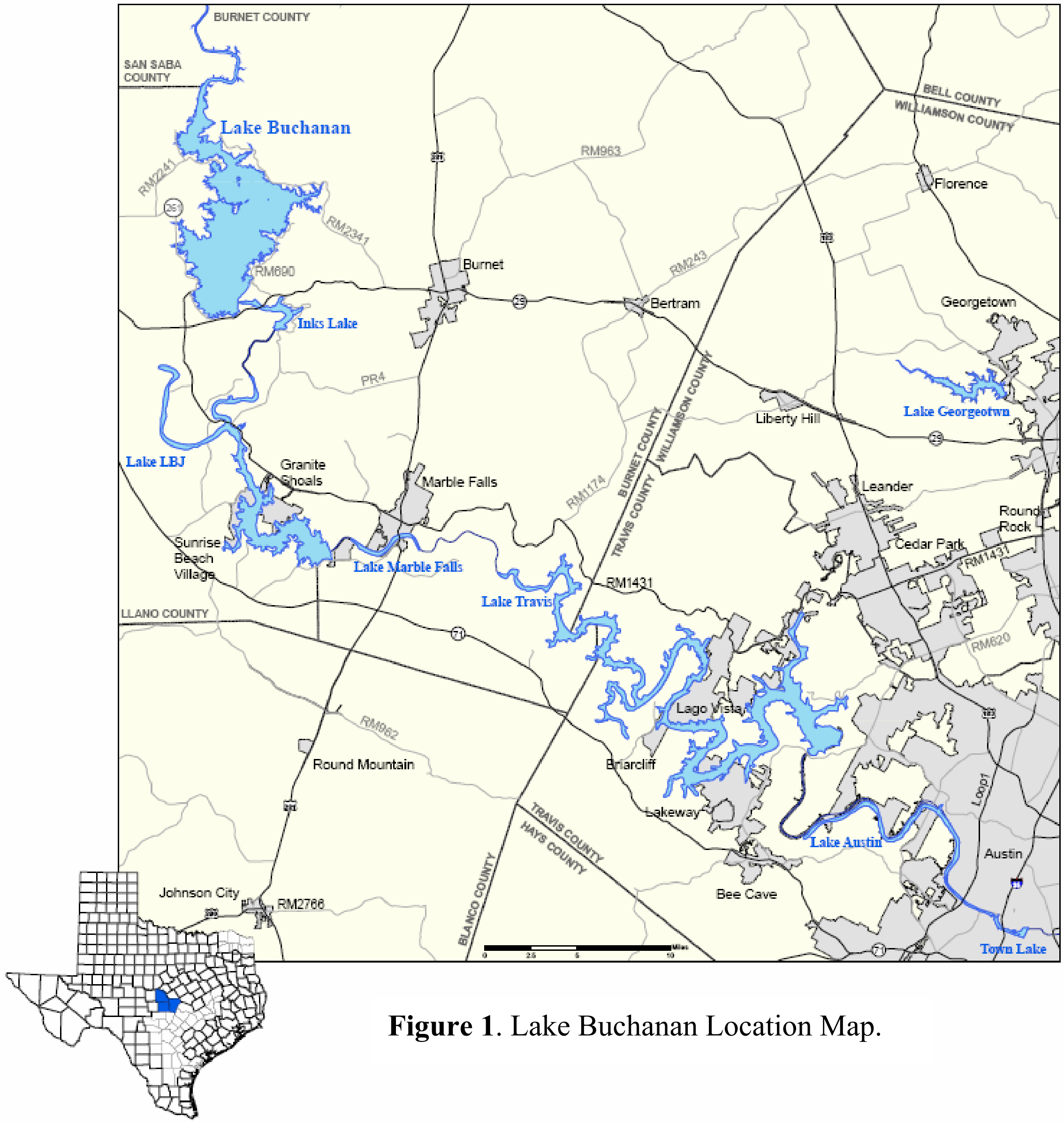



**Figure 1**. Lake Buchanan Location Map.

With recurring drought and devastating flooding, early-day residents of the area recognized the value of building dams on the Colorado River. The site of Buchanan Dam was originally identified by Adam Johnson, a Burnet County surveyor and stage driver, who sketched a dam for this location in the 1850's. But it wasn't until April 1931 that construction of a dam at this location began, when a Texas subsidiary of the Chicago-based Insull utility company began construction on Hamilton Dam. A year and a half later, the utility went bankrupt, leaving the dam less than half-built. Alvin Wirtz became receiver of the bankrupt utility company's assets, and found funding to finish the dam from the federal government, provided one condition: that the money go to a public agency created and owned by the State of Texas. In 1933, Wirtz drafted legislation creating a Colorado River Authority; however, pressure from private utilities and West Texas water interests caused the bill to fail in the Texas Legislature three times before Gov. Miriam A "Ma" Ferguson arranged a compromise for the authority to control only the lower portion of the river. Hence, through the passage of the LCRA Act, the Lower Colorado River Authority (LCRA) was created on November 13, 1934, with authority to store and sell water, generate electricity, prevent flood damages, and implement reforestation and soil-conservation programs. The LCRA began reconstruction on the dam on February 19, 1935.[2,3] Deliberate impoundment began on May 20, 1937 and the dam was completed in 1938. The first generator began operation in January of 1938.[3] In 1934, Hamilton Dam was renamed Buchanan Dam after U.S. Rep. J.P. Buchanan.[1]

By 1951, the LCRA had completed six dams on the Colorado River. The string of resulting lakes is known as the Highland Lakes. Lake Buchanan is the most upstream lake in the system, and is used to store drinking water and supply hydroelectricity. The Highland Lakes System also includes Lake Travis (used for water supply and hydroelectricity generation), and several pass-through lakes with hydroelectric generation capabilities: Inks Lake, Lake Lyndon Baines Johnson, and Lake Marble Falls. All of these lakes are owned and operated by the LCRA. The sixth (and most downstream) lake in the system, Lake Austin, is owned by the City of Austin but operated by the LCRA.[4]

## Water Rights

The complete certificates of adjudication and amendments described below are on file in the Records Department of the Texas Commission on Environmental Quality. Through these certificates of adjudication and amendments, the LCRA was granted the following water rights for Lake Buchanan:

### Certificate of Adjudication: 14-5478

Issued: June 28, 1989.

Certificate of Adjudication 14-5478 authorizes the LCRA to maintain an existing dam on the Colorado River (Buchanan Dam and Lake Buchanan) and to impound therein not to exceed 992,475 acre-ft of water. LCRA is authorized to use the water for recreation purposes with no right of diversion or release for this purpose. LCRA is authorized to divert and use not to exceed 1,500,000 acre-ft of water per annum from Lake Buchanan and Lake Travis (COA 14-5482) for municipal, industrial, irrigation, and mining purposes, subject to several conditions, including: that the LCRA prepare a Management Plan that includes recognition of the necessity of beneficial inflows from the Colorado River into the Lavaca-Tres Palacios Estuary, protection of fish and wildlife habitats, consideration of the effects on existing instream uses and water quality, mitigation of adverse impacts on wildlife habitats inundated by new reservoir construction, mitigation of adverse environmental impacts caused by new projects taking, storing or diverting in excess of 5,000 acre-ft per year, and recognition of the Texas Commission on Environmental Quality's (TCEQ) statutory authority to require water conservation; LCRA shall not commit to supply water on a firm uninterruptible basis in excess of the Combined Firm Yield of Lakes Travis and Buchanan; LCRA shall not impose its priority under this certificate or COA 14-5482 against any junior permanent water right with a priority date senior to November 1, 1987; and LCRA shall supply water under this certificate or under COA 14-5482 to or for the benefit of any downstream water right with a priority date junior to December 1, 1900 and senior to November 1, 1987 that authorizes the diversion of not more than 3,000 acre-ft of water per annum. The LCRA is authorized to use the bed and banks of the Colorado River, below Buchanan Dam, to convey water released from Lake Buchanan for use by LCRA or others entitled to use such water in the amounts and for the purposes authorized. The LCRA is authorized to divert and use water through Buchanan Dam for the purpose of hydroelectric power generation subject to conditions including the fact that LCRA can not release water solely for the purpose of hydroelectric generation, except during emergency shortages of electricity, and to the extent that such releases will not impair LCRA's ability to satisfy all existing and projected demands for water from Lakes Travis and Buchanan.

**Amendment to Certificate of Adjudication: 14-5478A**

Issued: October 12, 1989

Per amendment A to Certificate of Adjudication 14-5478, in addition to the authorizations included in paragraph 2.B., USE of Certificate No. 14-5478 to divert and use water from Lake Buchanan for municipal, industrial, irrigation and mining purposes, the LCRA is authorized to divert, use and release waters from Lake Buchanan for domestic, recreation, instream flows and bay and estuary purposes. The water used for recreation purposes is limited to that quantity of water actually sold for that purpose whether used in, or released or diverted from, Lakes Buchanan and Travis. The LCRA is also required to follow the provisions of the Water Management Plan as approved by Order of the Commission on September 7, 1989, and the terms and conditions of the Order.

**Amendment to Certificate of Adjudication: 14-5478B**
Issued: March 8, 1990

Per amendment B to Certificate of Adjudication 14-5478, in addition to the authorizations included in Certificate No. 14-5478, as amended, to divert and use water from Lake Buchanan for municipal, industrial, irrigation, mining, domestic, recreation, instream flows, and bay and estuary purposes, the LCRA is authorized to divert, use and release the waters in Lake Buchanan for livestock and recharge purposes.

**Amendment to Certificate of Adjudication: 14-5478C**
Issued: March 29, 1996

Per amendment C to Certificate of Adjudication 14-5478, a 532 acre-foot portion of water rights authorized by Certificate No. 14-2564, to be severed from said Certificate and combined with the water rights authorized by Certificate 14-5478, as amended. All other terms of Certificate 14-5478, as amended, remain in full force and effect. The priority date of this amendment as it relates to all other water rights is December 31, 1929. The priority date for impoundment of water in Lake Buchanan, the use of impounded water for recreation, and the use of released water for hydroelectric generation is March 29, 1926. The priority date for all other diversions and uses of water for authorized purposes is March 7, 1938.

**Lake Management by LCRA**

Through the passage of the LCRA Act by the Texas Legislature in 1934, the LCRA was established as a "conservation and reclamation district" responsible for harnessing the Colorado River and its tributaries and making them productive for the people within its water service area. Originally, the service area consisted of the ten counties that comprise the watershed of the lower Colorado River: Blanco, Burnet, Fayette, Colorado, Llano, Travis, Bastrop, Wharton, San Saba, and Matagorda. Several amendments to the LCRA Act expanded the service area to its current extent (Figure 2).

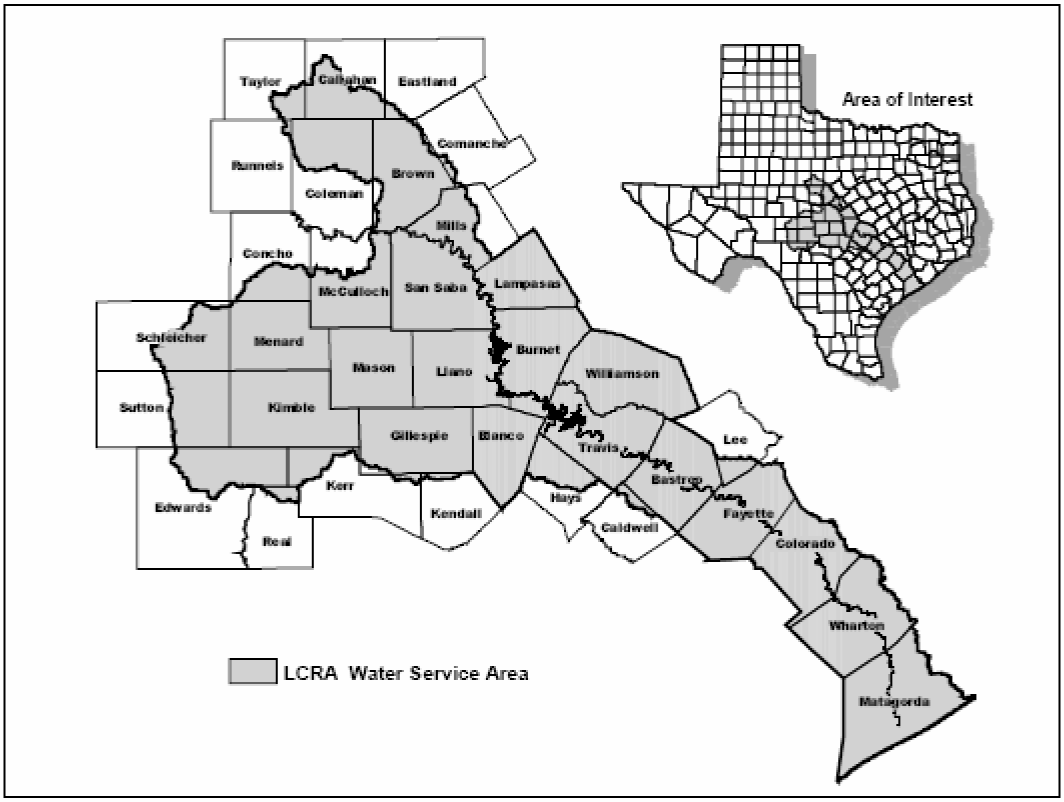



**Figure 2.** LCRA Water Service Areas as of January 1, 2003.
Source: LCRA Water Management Plan 2003.

The LCRA operates Lake Buchanan as part of a system of the Highland Lakes. Lakes Buchanan and Travis are water storage reservoirs, while Lakes Inks, LBJ, Marble Falls, and Austin are pass-through reservoirs. The LCRA maintains a Water Management Plan as a blueprint for how it will operate the Highland Lakes System. Water availability is based on the Combined Firm Yield of Lakes Buchanan and Travis. The Combined Firm Yield is the annual dependable water supply that can be supplied from Lakes Buchanan and Travis during a repetition of the Drought of Record. Any water available for use in excess of the Combined Firm Yield is considered interruptible water, used mainly for irrigation, and is sold on an interruptible basis subject to annual availability. Availability of interruptible water is projected by the LCRA each November. The projected supply depends on the amount of expected combined water storage in Lakes Buchanan and Travis on January 1, anticipated inflows for the subsequent months through the irrigation season, and the current demands for firm water.[5] Final supply and availability decisions are made in January based on actual contents, inflows, and demands for firm water.

The ultimate goal of the systems operation is to maximize the beneficial uses of the water stored in Lakes Buchanan and Travis, as well as the flows of water below the Highland Lakes. The systems operation process minimizes the impacts of losses due to evaporation and spills, and in combination with the Water Management Plan, allows the LCRA to optimize and conserve available water to meet existing and future water needs while being a steward of the water and land of the lower Colorado River basin.[6] The complete LCRA Water Management Plan is available through the LCRA website at http://www.lcra.org/water/wmp.html.

Table 1 provides pertinent data about Buchanan Dam and Lake Buchanan.[1,2]

**Table 1: Pertinent Data for Buchanan Dam and Lake Buchanan**

**Owner**: Lower Colorado River Authority
**Engineer: (Design):** Fargo Engineering Company, U.S. Bureau of Reclamation, LCRA
**Location:** On the Colorado River in Burnet County, 13 miles west of Burnet. Lake shoreline is in Burnet, Llano, and San Saba Counties.
**Drainage Area:** 31,250 square miles of 11,900 square miles is probably noncontributing
**Dam:**

| | |
|---|---|
| Type | Multiple concrete arch, gated and gravity sections |
| Length | 10,987 ft plus 1,700 ft of natural ground |
| Height | 145.5 ft |
| Top Width | Varies, with the maximum 33.8 ft |
| Base Width | 215.11 ft |
| Type | 3 sections with tainter gates |
| **Section 1** (near left or north end) | |
| Crest Elevation | 1,005.5 ft above msl |
| Control | 16 gates, each 33 by 15.5 ft |
| Discharge Capacity | 7,250 cfs each |
| **Section 2** (center) | |
| Crest Elevation | 1,005.5 ft above msl |
| Control | 14 gates, each 33 by 15.5 ft |
| Discharge Capacity | 7,250 cfs each |
| **Section 3** (nearest powerhouse) | |
| Crest Elevation | 995.5 ft above msl |
| Control | 7 gates, each 40 by 25.5 ft |
| Discharge Capacity | 19,000 cfs each |
| **Section 4** (overflow no control far left or north end) | |
| Crest Elevation | 1,020.5 ft above msl |
| Crest length | 1,100 ft |
| Total Flood Gates | 37 |
| Total Discharge Capacity | 355,000 cfs |

**Outlet Works:** None. Water is released through turbines. 3 turbines with a discharge capacity of 1,500 cfs each.
**Power Features:** 3 generating units, each 12,667 kw, or 51.3 megawatts, capacity
**Special Features:** A pump-back unit with a capacity of 840 cfs returns water from Inks Lake to Lake Buchanan during off-peak power demand periods. The vertical pump is driven by a 13,500 hp motor.
**Reservoir Data** (Based on current TWDB 2006 Survey)

| FEATURE | ELEVATION (feet above msl) | CAPACITY (acre-ft) | AREA (acres) |
|---|---|---|---|
| Top of gravity overflow | 1,020.5 | 886,626 | 22,137 |
| Sill of 15-ft gates | 1,005.5 | 583,272 | 17,559 |
| Sill of 25-ft gates | 995.5 | 425,201 | 14,221 |
| Invert to penstocks | 937.5 | 15,186 | 1,549 |
| Usable Capacity | - | 871,440 | - |

# Volumetric and Sediment Survey of Lake Buchanan

## Introduction

The TWDB Hydrographic Survey Program was authorized by the state legislature in 1991. The Texas Water Code authorizes the TWDB, at the request of a political subdivision, to perform a survey to determine reservoir storage capacity, sedimentation levels, rates of sedimentation, projected water supply availability, or potential mitigative measures, and to conduct other bathymetric studies.

In March of 2006, the Texas Water Development Board entered into agreement with the Lower Colorado River Authority, Austin, Texas, for the purpose of performing a volumetric and sediment survey of Lake Buchanan while the reservoir was near the top of the conservation pool. However, due to continued drought conditions persisting into the spring of 2006, TWDB surveyed the reservoir while the water surface elevation was between 1,011.75 ft and 1,012.2 ft (8.30 ft and 9.25 ft below conservation pool elevation). To augment the survey data collected by TWDB, LCRA provided high-resolution LIDAR data, collected on December 31, 2006 and January 1, 2007 when the water surface elevation in Lake Buchanan was approximately 998 ft. Elevation-Capacity and Elevation-Area Tables were computed based on a combination of the TWDB survey data and the LIDAR data. TWDB processing of the LCRA-provided LIDAR data is detailed in Appendix J.

## Datum

The vertical datum used during this survey is that used by the United States Geological Survey (USGS) for the reservoir elevation gauge TX071 08148000 LCRA Lk Buchanan nr Burnet, TX.[7] Capacity and area calculations in this report are referenced to water levels provided by the USGS gauge. The datum for this gauge is reported as 0.48 ft above National Geodetic Vertical Datum 1929 (NGVD29)[8] or mean sea level (msl), **thus elevations reported here are referenced to the NGVD 1929 datum**. The horizontal datum used for this report is North American Datum of 1983 (NAD83), and the horizontal coordinate system used is the State Plane - Texas Central Zone (feet).

### Bathymetric Survey

Bathymetric data collection for Lake Buchanan occurred between March 10th and April 10th of 2006, while the water surface elevation was below the conservation pool elevation of 1,020.5 ft (gauge datum). The water surface elevation varied between 1,012.20 ft and 1,011.25 ft during the TWDB survey.

For data collection, the survey team used two boats equipped with depth sounders integrated with Differential Global Positioning System (DGPS) equipment while navigating along pre-planned range lines. The pre-planned range lines were oriented in a perpendicular fashion to the original stream channels and spaced approximately 500 feet apart. The depth sounders were calibrated each day using a velocity profiler to measure the speed of sound in the water column and a modified bar check using a weighted tape or stadia rod to verify the depth reading. The average speed of sound through the water column varied between 4,793 and 4,853 feet per second during the survey.

The depth sounders used to survey Lake Buchanan included a Specialty Devices, Inc, (SDI) multi-frequency depth sounder and an Odom Hydrotrac single frequency depth sounder. The multi-frequency depth sounder uses 200 kHz, 50 kHz, and 24 kHz sound waves to collect bathymetry and sediment thickness data, and was used primarily in regions of the reservoir where water depths exceeded 4.5 ft. The Odom Hydrotrac depth sounder uses a single 200 kHz sound wave to measure water depths, and was used in areas where water depths were less than 4.5 ft (primarily north of Willow Slough). During the survey, team members collected nearly 512,500 data points. Figure 3 shows the locations of all data points collected during the survey.

## Data Processing

### Model Boundary

At the request of the LCRA, surface areas and capacities were calculated to elevation 1,035 ft, or 14.5 ft above CPE. In order to estimate surface areas and capacities above pool elevation 1,020.5 ft, an upper model boundary was developed from a combination of the 1,040 ft contour from the digital hypsography (1:24,000 scale) and LCRA-provided LIDAR data (See Appendix J). For modeling purposes only, the 1,040 ft contour was closed across the top of the dam, and therefore does not reflect the true

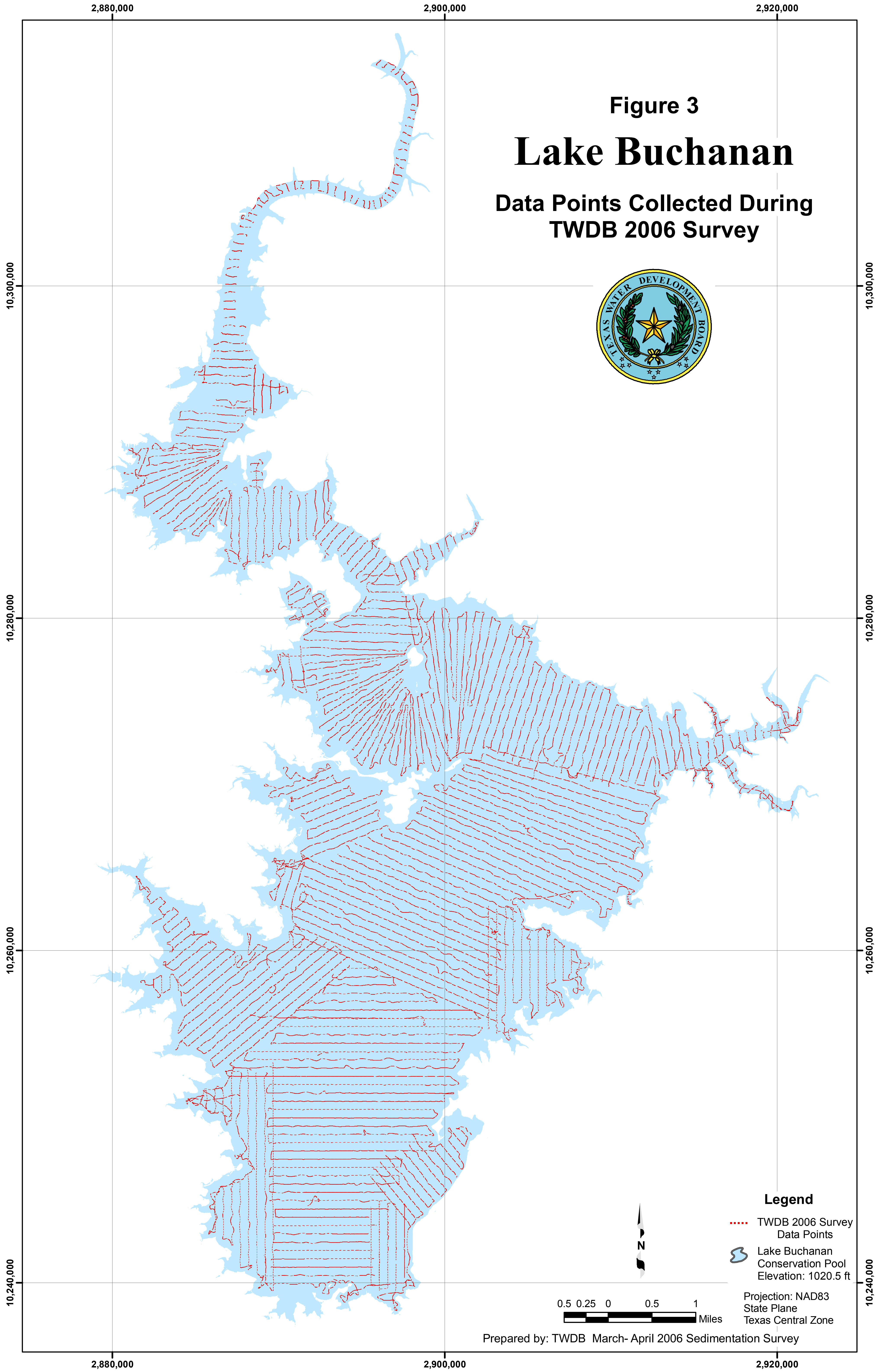


Figure 3
Lake Buchanan
Data Points Collected During
TWDB 2006 Survey
TEXAS WATER DEVELOPMENT BOARD
2,880,000
2,900,000
2,920,000
10,300,000
10,280,000
10,260,000
10,240,000
Legend
TWDB 2006 Survey Data Points
Lake Buchanan Conservation Pool Elevation: 1020.5 ft
Projection: NAD83
State Plane
Texas Central Zone
N
0.5 0.25 0 0.5 1
Miles
Prepared by: TWDB March- April 2006 Sedimentation Survey

elevations near the dam crest. These incorrect elevations near the dam crest will not affect the final TIN model, which is computed only to elevation 1,035 ft.

**Triangular Irregular Network (TIN) Model**

Upon completion of data collection, the raw data files are edited using DepthPic and HypackMAX to remove any data anomalies. DepthPic is used to display, interpret, and edit the multi-frequency data, while HypackMAX is used to edit the single-frequency data collected in the shallower upper reaches of the reservoir. 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 and HypackMAX, the sounding coordinates (X,Y,Z) are exported as a MASS points file.

To create a surface representation of the Lake Buchanan bathymetry, the 3D Analyst Extension of ArcGIS (ESRI, Inc.) is used. This extension creates a triangulated irregular network (TIN) model of the bathymetry, where each MASS point and boundary node becomes the vertex of a triangular portion of the reservoir bottom surface.[9] From the TIN model, reservoir capacities and areas are calculated at one-tenth of a foot (0.1 ft) intervals, from elevation 906.0 ft to elevation 1,035.0 ft. TWDB surveyed data was used in creating surfaces with elevations less than 999.0 ft, whereas LCRA-provided LIDAR data and TWDB surveyed data was used for areas with elevations greater than 999.0 ft.

The Elevation-Capacity and Elevation-Area Tables, updated for 2006, are presented in Appendices A and B, respectively. An Elevation-Capacity graph and an Elevation-Area graph are presented in Appendices C and D, respectively.

The TIN model was interpolated and averaged using a cell size of 10 ft by 10 ft and converted to a raster. The raster was used to produce an Elevation Relief Map representing the topography of the reservoir bottom (Figure 4), a map showing shaded depth ranges for Lake Buchanan (Figure 5), and a 10-ft contour map (Figure 6). The reservoir extent depicted in these figures is that corresponding to the conservation-pool elevation (1,020.5 ft).

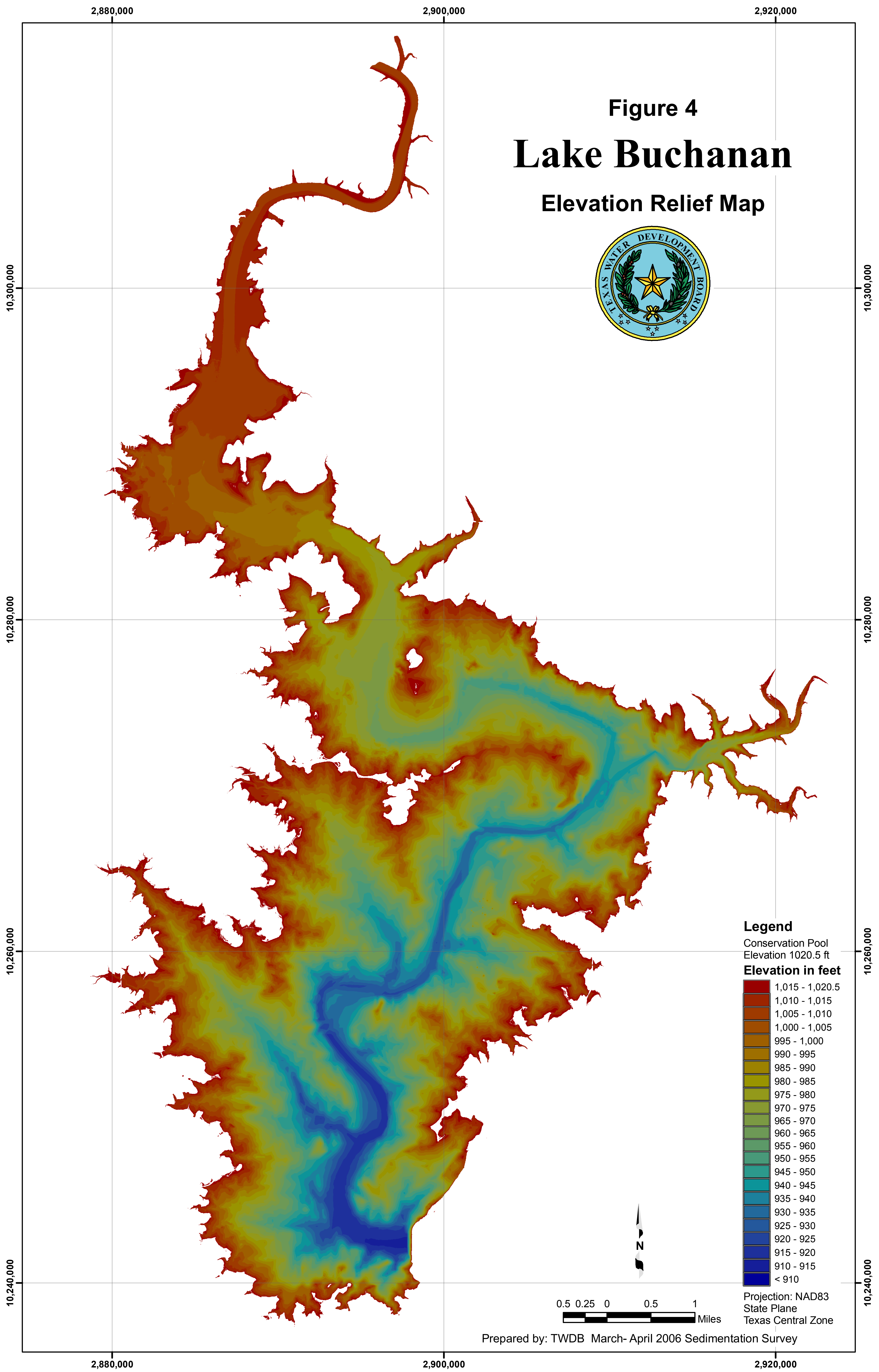


Figure 4
Lake Buchanan
Elevation Relief Map
TEXAS WATER DEVELOPMENT BOARD
2,880,000
2,900,000
2,920,000
10,300,000
10,280,000
10,260,000
10,240,000
Legend
Conservation Pool
Elevation 1020.5 ft
Elevation in feet
1,015 - 1,020.5
1,010 - 1,015
1,005 - 1,010
1,000 - 1,005
995 - 1,000
990 - 995
985 - 990
980 - 985
975 - 980
970 - 975
965 - 970
960 - 965
955 - 960
950 - 955
945 - 950
940 - 945
935 - 940
930 - 935
925 - 930
920 - 925
915 - 920
910 - 915
< 910
N
0.5 0.25 0 0.5 1
Miles
Projection: NAD83
State Plane
Texas Central Zone
Prepared by: TWDB March- April 2006 Sedimentation Survey

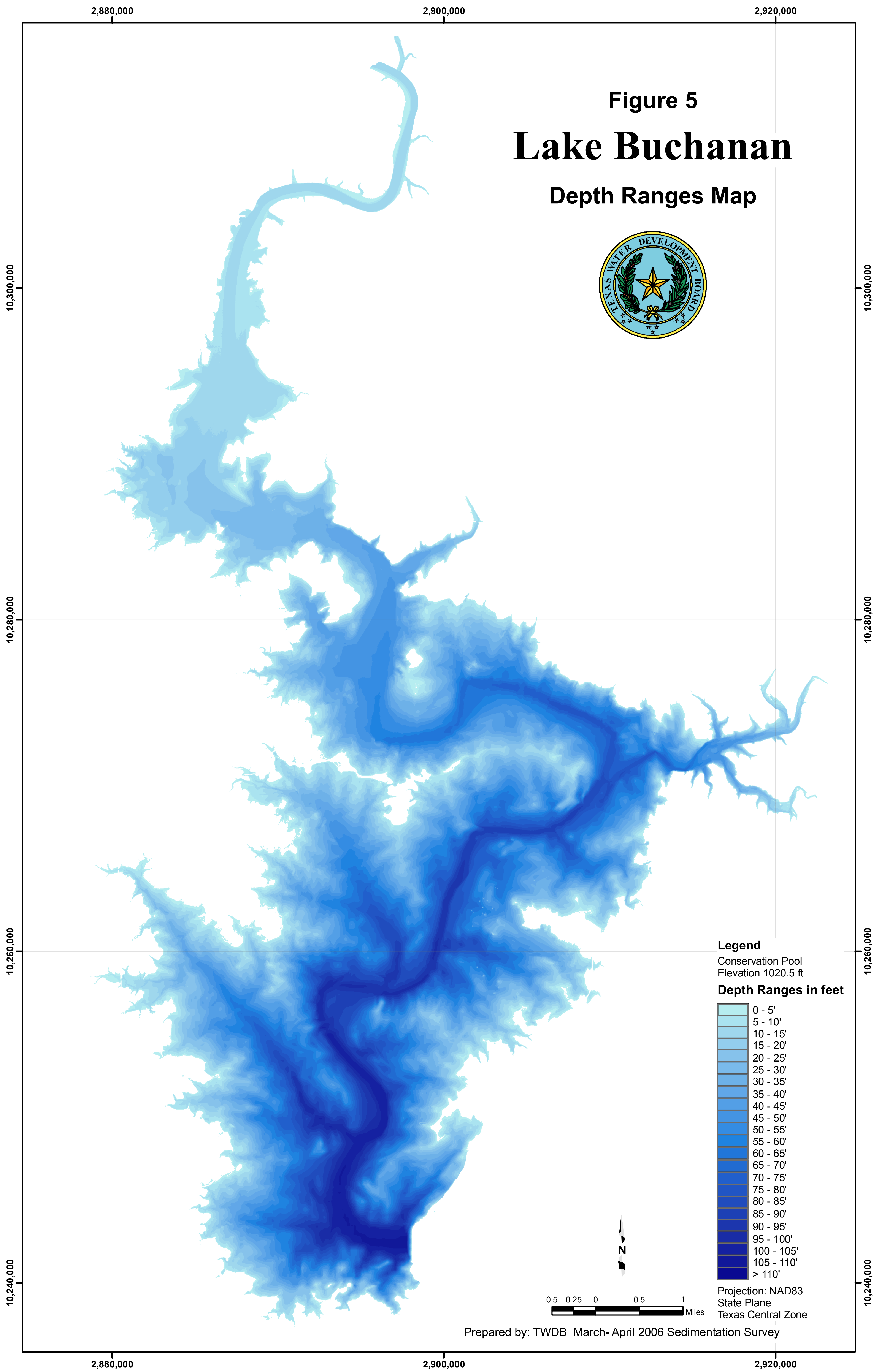


Figure 5
Lake Buchanan
Depth Ranges Map
TEXAS WATER DEVELOPMENT BOARD
2,880,000
2,900,000
2,920,000
10,300,000
10,280,000
10,260,000
10,240,000
Legend
Conservation Pool
Elevation 1020.5 ft
Depth Ranges in feet
0 - 5'
5 - 10'
10 - 15'
15 - 20'
20 - 25'
25 - 30'
30 - 35'
35 - 40'
40 - 45'
45 - 50'
50 - 55'
55 - 60'
60 - 65'
65 - 70'
70 - 75'
75 - 80'
80 - 85'
85 - 90'
90 - 95'
95 - 100'
100 - 105'
105 - 110'
> 110'
Projection: NAD83
State Plane
Texas Central Zone
N
0.5 0.25 0 0.5 1
Miles
Prepared by: TWDB March- April 2006 Sedimentation Survey

## 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 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 (SSI) routine (developed by the TWDB) was used to interpolate the bathymetry in between many 500 ft-spaced survey lines. The SSI technique effectively increases the density of points input into the TIN model, as well directs the TIN interpolation to better represent the submerged river channels.[10] In the case of Lake Buchanan, the application of SSI helped define the river channel where the survey line pattern missed a meander and helped define the steep topology of the reservoir banks (as in the vicinity of the Council Creek arm of the reservoir). 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 SSI technique are not likely to be valid; therefore, self-similar interpolation was not used in areas of Lake Buchanan where a high probability of change between cross-sections exists.[10] Figure 7 illustrates typical results of the application of the SSI routine in Lake Buchanan, and the bathymetry shown in Figure 7C was used in computing reservoir capacity and area tables (Appendix A, B).

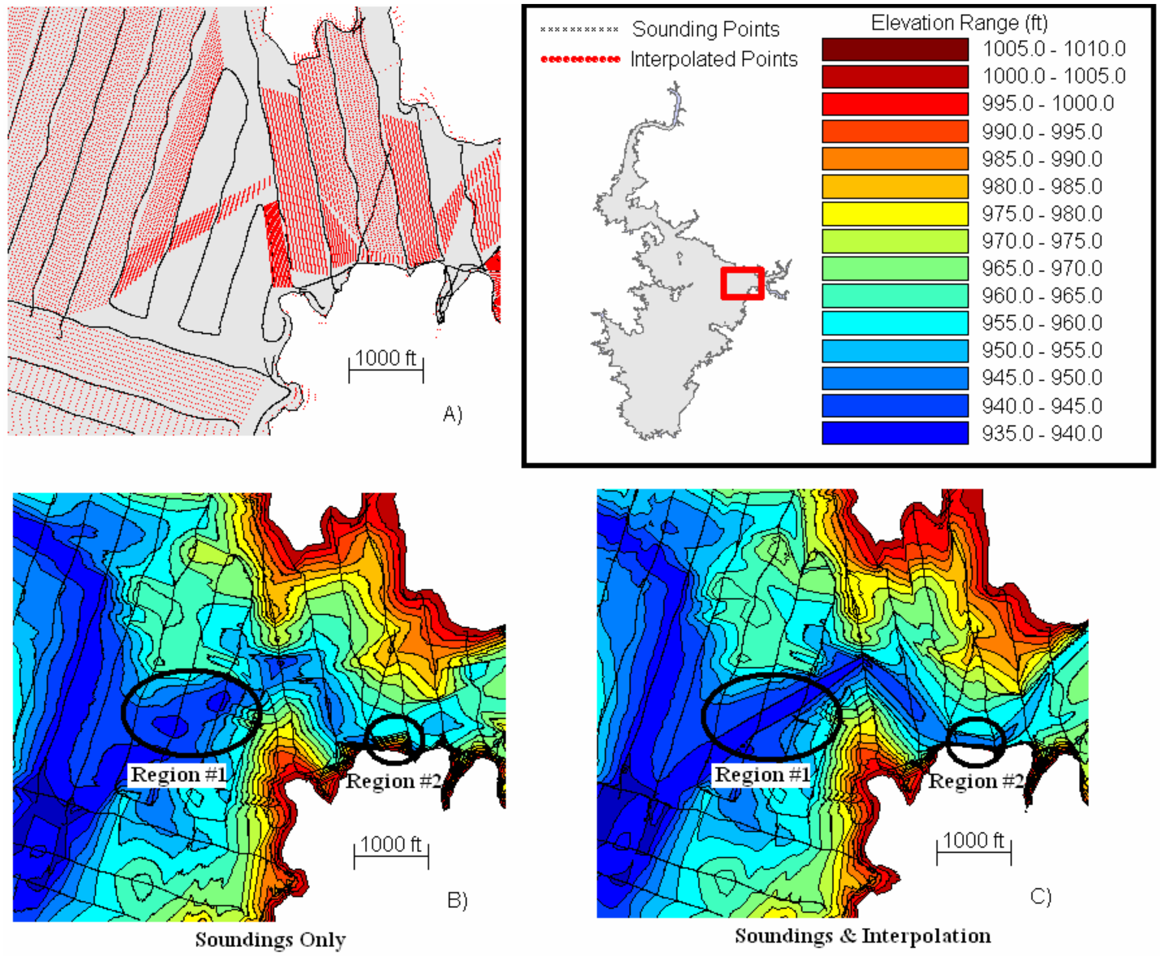



***Figure** 7 - Application of the Self-Similar Interpolation technique to Lake Buchanan sounding data – A) Sounding (black) points and interpolated points (red) with reservoir boundary shown at elevation 1,010 (grey), B) bathymetric contours without interpolated points, C) bathymetric contours with the interpolated points. Note: inclusion of the interpolated points created a noticeable submerged river channel (Region #1) and eliminated artificial curving contours near reservoir boundaries (Region #2).*

## Sediment Range Lines

Cross-sections developed for the Lake Buchanan Survey closely coincided with the positions of the HEC-RAS cross-sections provided by the LCRA. “HEC-RAS is a one-dimensional steady flow hydraulic model designed to aid hydraulic engineers in channel flow analysis and floodplain determination.”[11] Twenty-eight cross-sections, falling within the reservoir, are plotted in Appendix E. The plots were extracted from the TIN model and are plotted as distance from endpoint verses elevation. Positional coordinates for the endpoints of each range line are provided in Appendix F along with a map showing their location in the reservoir.

**Volumetric Survey and Results**

During data processing, the 200 kHz frequency data from both depth sounders was used to calculate the capacity of Lake Buchanan. The results of the TWDB 2006 Volumetric Survey indicate Lake Buchanan has a total capacity of 886,626 acre-ft and encompasses 22,137 acres at conservation pool elevation (gauge datum 1,020.5 ft).

Lake Buchanan was originally impounded in May of 1937 and per the Texas Department of Water Resources,[12] original reservoir capacity and area at elevation 1,020.5 ft was estimated to have been 992,000 acre-ft and 23,060 acres. These original estimates are based on 1925 USGS topographical 20-ft contour maps, 1939 LCRA survey data, and a 1965 USGS[3] datum adjustment to mean sea level. No datum adjustments were made in the comparisons in this report.

The current daily allocation table of values for capacity and area used by the LCRA was developed from a combination of 1991 LCRA survey data and 1997 aerial photographs (Appendix I). Values interpolated from this table indicate a capacity and area at elevation 1,020.5 ft of 888,865 acre-ft and 22,387 acres, respectively. When compared to the TWDB 2006 survey results, these numbers indicate the reservoir has experienced a 105,374 acre-ft (10.6%) decrease in capacity since impoundment and a 2,239 acre-ft (0.3%) decrease in capacity from the current daily allocation table numbers. The TWDB 2006 survey indicates a 923 acre (4.0%) decrease in surface area at the conservation pool elevation since impoundment and a 250 acre (1.1%) decrease in area when compared to the area listed in the current daily allocation table.

Due to differences in the methodologies used to calculate the reservoir's original impoundment capacity, the 1997 capacity, and 2006 TWDB survey capacity, comparison of these values is not recommended and is presented here for informational purposes only.[13] The TWDB considers the 2006 survey to be a significant improvement over previous methods and recommends that the same methodology be used to resurvey Lake Buchanan in 5 to 10 years or after 3 to 4 major flood events (similar to the flood events in the summer of 2007).

### Sediment Survey & Results

Multi-frequency depth soundings were collected throughout the reservoir starting just south of Willow Slough (Figure 3). The 200 kHz, 50 kHz, and 24 kHz frequency data from the SDI depth sounder were used to interpret sediment distribution and accumulation throughout Lake Buchanan. Ancillary data was collected in the form of six core samples to assist in the interpretation of post-impoundment sediment accumulation.

Based on multi-frequency depth sounding data, Lake Buchanan contains at least 34,275 acre-ft of sediment. This volume is likely an underestimate of the true sediment volume above the pre-impoundment surface, as portions of the reservoir were un-surveyable using the multi-frequency depth sounder. Figure 8 shows the locations in which sediment has accumulated. A complete description of the sediment measurement & calculation process is presented in Appendix G of this report.

## 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 Barney Austin, Director of the Surface Water Resources Division, at 512-463-8856, or by email at: Barney.Austin@twdb.state.tx.us.

## References


1. Lower Colorado River Authority, LCRA: Water: Buchanan Dam, viewed 18 October 2006, http://www.lcra.org/water/buchanan.html.

2. Lower Colorado River Authority, LCRA: About LCRA: History, viewed 18 October 2006, http://www.lcra.org/about/history.html#birth.

3. Texas Water Development Board, Report 126, Engineering Data on Dams and Reservoirs in Texas, Part III, February 1971.

4. Lower Colorado Regional Water Planning Group, Region K, 2006, LCWPG Water Plan, Chapter 3, http://www.twdb.state.tx.us/rwpg/2006_RWP/RegionK/Chapter%203.pdf

5. Lower Colorado River Authority, Water Management Plan for the Lower Colorado River Basin, Effective September 20, 1989 Including Amendments Through May 14, 2003, http://www.lcra.org/docs/water_RevisedWMP.pdf.

6. Lower Colorado Regional Water Planning Group, Region K, 2006, LCWPG Water Plan, Chapter 4, http://www.twdb.state.tx.us/rwpg/2006_RWP/RegionK/Chapter%204.pdf

7. United States Geological Survey. http://tx.usgs.gov/ 07 June 2006.

8. United States Geological Survey. Water Resources Data Texas Water Year 2002. Vol. 4, Water-Data Report TX-02-4, March 2003.

9. ESRI, Environmental Systems Research Institute. 1995. ARC/INFO Surface Modeling and Display, TIN Users Guide.

10. Furnans, Jordan. Texas Water Development Board. 2006. "HydroEdit User's Manual."

11. University of Texas, Center for Research in Water Resources, April 1999. http://www.ce.utexas.edu/prof/maidment/grad/tate/research/RASExercise/webfiles/hecras.html, accessed 01/30/2007.

12. Texas Department of Water Resources, LP-60. "Present and Future Surface-Water Availability in the Colorado River Basin, Texas, Appendices." September 1978.

13. United States Department of Agriculture, Natural Resource Conservation Service, National Engineering Handbook, Section 3, Sedimentation, Chapter 7, Field Investigations and Surveys, December 1983.

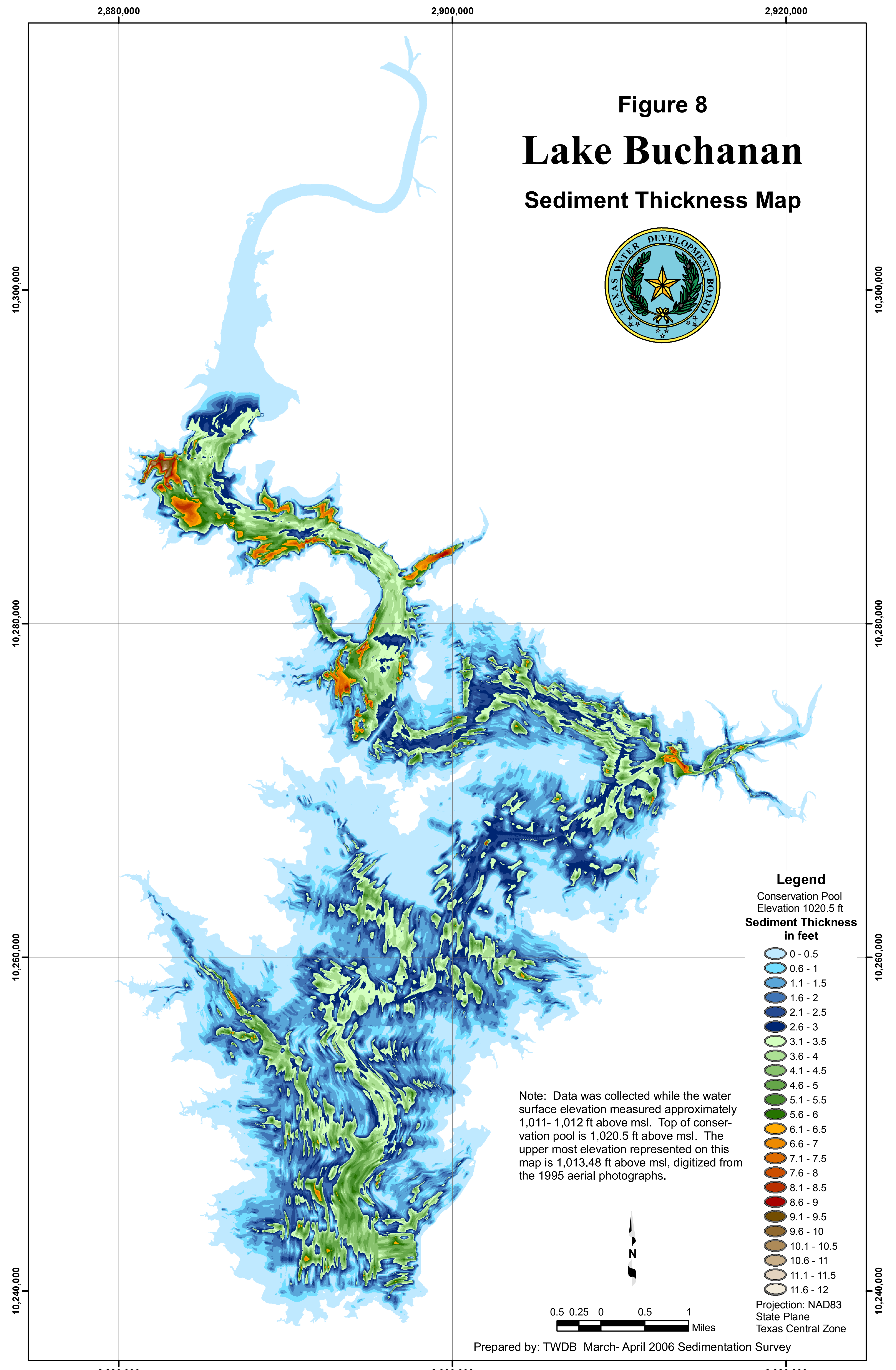


Figure 8
Lake Buchanan
Sediment Thickness Map
TEXAS WATER DEVELOPMENT BOARD
2,880,000
2,900,000
2,920,000
10,300,000
10,280,000
10,260,000
10,240,000
Legend
Conservation Pool
Elevation 1020.5 ft
Sediment Thickness
in feet
0 - 0.5
0.6 - 1
1.1 - 1.5
1.6 - 2
2.1 - 2.5
2.6 - 3
3.1 - 3.5
3.6 - 4
4.1 - 4.5
4.6 - 5
5.1 - 5.5
5.6 - 6
6.1 - 6.5
6.6 - 7
7.1 - 7.5
7.6 - 8
8.1 - 8.5
8.6 - 9
9.1 - 9.5
9.6 - 10
10.1 - 10.5
10.6 - 11
11.1 - 11.5
11.6 - 12
Projection: NAD83
State Plane
Texas Central Zone
Note: Data was collected while the water surface elevation measured approximately 1,011- 1,012 ft above msl. Top of conservation pool is 1,020.5 ft above msl. The upper most elevation represented on this map is 1,013.48 ft above msl, digitized from the 1995 aerial photographs.
N
0.5 0.25 0 0.5 1
Miles
Prepared by: TWDB March- April 2006 Sedimentation Survey

Appendix A

## Lake Buchanan

### RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD

March 2006 SURVEY

Conservation Pool Elevation 1020.5 ft

VOLUME IN ACRE-FEET

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 |
|---|---|---|---|---|---|---|---|---|---|---|
| 906 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 907 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 908 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 909 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 910 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 911 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 912 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 913 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 914 | 1 | 1 | 2 | 3 | 4 | 5 | 7 | 9 | 11 | 13 |
| 915 | 16 | 18 | 21 | 24 | 28 | 32 | 37 | 42 | 48 | 55 |
| 916 | 62 | 69 | 77 | 86 | 95 | 104 | 114 | 124 | 135 | 146 |
| 917 | 158 | 170 | 183 | 196 | 210 | 224 | 240 | 255 | 272 | 289 |
| 918 | 307 | 325 | 344 | 363 | 384 | 404 | 426 | 448 | 470 | 493 |
| 919 | 517 | 541 | 565 | 591 | 616 | 642 | 669 | 696 | 723 | 751 |
| 920 | 779 | 808 | 837 | 867 | 897 | 927 | 957 | 989 | 1,020 | 1,052 |
| 921 | 1,084 | 1,117 | 1,150 | 1,183 | 1,217 | 1,251 | 1,286 | 1,321 | 1,356 | 1,392 |
| 922 | 1,428 | 1,465 | 1,502 | 1,540 | 1,578 | 1,616 | 1,655 | 1,694 | 1,733 | 1,773 |
| 923 | 1,813 | 1,854 | 1,896 | 1,937 | 1,979 | 2,022 | 2,065 | 2,109 | 2,152 | 2,197 |
| 924 | 2,242 | 2,287 | 2,333 | 2,379 | 2,427 | 2,474 | 2,522 | 2,571 | 2,620 | 2,670 |
| 925 | 2,721 | 2,772 | 2,824 | 2,877 | 2,931 | 2,986 | 3,041 | 3,097 | 3,154 | 3,212 |
| 926 | 3,270 | 3,329 | 3,389 | 3,450 | 3,511 | 3,573 | 3,636 | 3,699 | 3,764 | 3,829 |
| 927 | 3,895 | 3,962 | 4,029 | 4,097 | 4,166 | 4,236 | 4,306 | 4,377 | 4,448 | 4,521 |
| 928 | 4,594 | 4,667 | 4,742 | 4,817 | 4,893 | 4,969 | 5,046 | 5,124 | 5,203 | 5,282 |
| 929 | 5,362 | 5,443 | 5,524 | 5,606 | 5,689 | 5,772 | 5,856 | 5,941 | 6,027 | 6,113 |
| 930 | 6,200 | 6,288 | 6,377 | 6,466 | 6,556 | 6,647 | 6,739 | 6,832 | 6,925 | 7,019 |
| 931 | 7,114 | 7,209 | 7,305 | 7,403 | 7,501 | 7,599 | 7,699 | 7,800 | 7,901 | 8,003 |
| 932 | 8,106 | 8,210 | 8,315 | 8,421 | 8,527 | 8,635 | 8,744 | 8,854 | 8,964 | 9,076 |
| 933 | 9,188 | 9,301 | 9,415 | 9,530 | 9,646 | 9,762 | 9,880 | 9,998 | 10,117 | 10,238 |
| 934 | 10,359 | 10,481 | 10,604 | 10,728 | 10,853 | 10,978 | 11,105 | 11,233 | 11,361 | 11,490 |
| 935 | 11,621 | 11,752 | 11,884 | 12,017 | 12,151 | 12,286 | 12,422 | 12,559 | 12,697 | 12,835 |
| 936 | 12,975 | 13,115 | 13,257 | 13,399 | 13,543 | 13,687 | 13,833 | 13,979 | 14,126 | 14,275 |
| 937 | 14,424 | 14,574 | 14,726 | 14,878 | 15,032 | 15,186 | 15,341 | 15,498 | 15,655 | 15,814 |
| 938 | 15,974 | 16,134 | 16,296 | 16,459 | 16,623 | 16,788 | 16,954 | 17,121 | 17,289 | 17,459 |
| 939 | 17,629 | 17,801 | 17,973 | 18,147 | 18,322 | 18,497 | 18,674 | 18,853 | 19,032 | 19,213 |
| 940 | 19,394 | 19,577 | 19,761 | 19,947 | 20,133 | 20,321 | 20,510 | 20,700 | 20,891 | 21,083 |
| 941 | 21,277 | 21,472 | 21,668 | 21,865 | 22,064 | 22,263 | 22,464 | 22,666 | 22,869 | 23,074 |
| 942 | 23,280 | 23,486 | 23,695 | 23,904 | 24,115 | 24,327 | 24,540 | 24,755 | 24,970 | 25,188 |
| 943 | 25,406 | 25,626 | 25,847 | 26,070 | 26,294 | 26,519 | 26,746 | 26,974 | 27,204 | 27,435 |
| 944 | 27,667 | 27,901 | 28,136 | 28,373 | 28,611 | 28,851 | 29,092 | 29,334 | 29,578 | 29,823 |
| 945 | 30,070 | 30,318 | 30,567 | 30,818 | 31,071 | 31,325 | 31,580 | 31,837 | 32,095 | 32,355 |
| 946 | 32,616 | 32,878 | 33,143 | 33,408 | 33,675 | 33,944 | 34,214 | 34,486 | 34,759 | 35,034 |
| 947 | 35,311 | 35,589 | 35,869 | 36,151 | 36,434 | 36,719 | 37,005 | 37,293 | 37,583 | 37,874 |
| 948 | 38,167 | 38,461 | 38,757 | 39,055 | 39,354 | 39,654 | 39,956 | 40,260 | 40,566 | 40,873 |
| 949 | 41,181 | 41,491 | 41,803 | 42,116 | 42,431 | 42,747 | 43,065 | 43,384 | 43,705 | 44,028 |
| 950 | 44,352 | 44,678 | 45,005 | 45,334 | 45,665 | 45,997 | 46,331 | 46,667 | 47,004 | 47,343 |
| 951 | 47,683 | 48,025 | 48,369 | 48,714 | 49,062 | 49,410 | 49,760 | 50,112 | 50,466 | 50,821 |
| 952 | 51,178 | 51,536 | 51,897 | 52,258 | 52,622 | 52,987 | 53,353 | 53,722 | 54,092 | 54,463 |
| 953 | 54,837 | 55,212 | 55,588 | 55,967 | 56,347 | 56,729 | 57,112 | 57,497 | 57,884 | 58,272 |
| 954 | 58,663 | 59,054 | 59,448 | 59,844 | 60,241 | 60,640 | 61,040 | 61,443 | 61,847 | 62,253 |
| 955 | 62,662 | 63,072 | 63,484 | 63,899 | 64,315 | 64,734 | 65,154 | 65,577 | 66,001 | 66,428 |
| 956 | 66,856 | 67,286 | 67,719 | 68,153 | 68,590 | 69,029 | 69,469 | 69,912 | 70,357 | 70,804 |
| 957 | 71,253 | 71,704 | 72,157 | 72,613 | 73,070 | 73,530 | 73,991 | 74,455 | 74,921 | 75,389 |
| 958 | 75,858 | 76,331 | 76,805 | 77,281 | 77,760 | 78,241 | 78,724 | 79,209 | 79,696 | 80,185 |
| 959 | 80,677 | 81,170 | 81,666 | 82,164 | 82,664 | 83,167 | 83,671 | 84,177 | 84,686 | 85,197 |
| 960 | 85,710 | 86,225 | 86,742 | 87,261 | 87,783 | 88,306 | 88,832 | 89,360 | 89,890 | 90,423 |
| 961 | 90,957 | 91,493 | 92,032 | 92,573 | 93,116 | 93,661 | 94,208 | 94,757 | 95,308 | 95,862 |

Appendix A (continued)

## Lake Buchanan

### RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD — March 2006 SURVEY

Conservation Pool Elevation 1020.5 ft

VOLUME IN ACRE-FEET — 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| 962 | 96,418 | 96,976 | 97,536 | 98,098 | 98,663 | 99,229 | 99,798 | 100,369 | 100,942 | 101,518 |
| 963 | 102,096 | 102,676 | 103,258 | 103,843 | 104,430 | 105,020 | 105,611 | 106,206 | 106,802 | 107,401 |
| 964 | 108,001 | 108,604 | 109,210 | 109,818 | 110,428 | 111,041 | 111,655 | 112,272 | 112,892 | 113,513 |
| 965 | 114,137 | 114,763 | 115,392 | 116,023 | 116,656 | 117,291 | 117,929 | 118,570 | 119,212 | 119,858 |
| 966 | 120,505 | 121,155 | 121,807 | 122,462 | 123,119 | 123,779 | 124,440 | 125,105 | 125,771 | 126,441 |
| 967 | 127,112 | 127,786 | 128,462 | 129,140 | 129,821 | 130,504 | 131,189 | 131,877 | 132,567 | 133,260 |
| 968 | 133,955 | 134,652 | 135,353 | 136,055 | 136,760 | 137,467 | 138,177 | 138,889 | 139,604 | 140,321 |
| 969 | 141,040 | 141,762 | 142,487 | 143,214 | 143,943 | 144,675 | 145,409 | 146,146 | 146,884 | 147,626 |
| 970 | 148,370 | 149,116 | 149,866 | 150,617 | 151,372 | 152,129 | 152,888 | 153,651 | 154,416 | 155,184 |
| 971 | 155,955 | 156,728 | 157,504 | 158,282 | 159,063 | 159,847 | 160,633 | 161,422 | 162,213 | 163,007 |
| 972 | 163,804 | 164,603 | 165,406 | 166,210 | 167,018 | 167,827 | 168,640 | 169,455 | 170,273 | 171,094 |
| 973 | 171,917 | 172,743 | 173,572 | 174,403 | 175,237 | 176,073 | 176,912 | 177,753 | 178,598 | 179,445 |
| 974 | 180,294 | 181,146 | 182,001 | 182,859 | 183,720 | 184,583 | 185,449 | 186,318 | 187,190 | 188,065 |
| 975 | 188,943 | 189,823 | 190,706 | 191,592 | 192,482 | 193,373 | 194,267 | 195,165 | 196,065 | 196,968 |
| 976 | 197,873 | 198,781 | 199,692 | 200,605 | 201,522 | 202,440 | 203,361 | 204,286 | 205,212 | 206,142 |
| 977 | 207,074 | 208,009 | 208,947 | 209,887 | 210,830 | 211,776 | 212,724 | 213,675 | 214,629 | 215,586 |
| 978 | 216,545 | 217,507 | 218,472 | 219,439 | 220,410 | 221,382 | 222,358 | 223,336 | 224,317 | 225,302 |
| 979 | 226,288 | 227,277 | 228,270 | 229,264 | 230,263 | 231,263 | 232,266 | 233,272 | 234,281 | 235,292 |
| 980 | 236,306 | 237,322 | 238,342 | 239,363 | 240,388 | 241,415 | 242,445 | 243,478 | 244,514 | 245,552 |
| 981 | 246,593 | 247,636 | 248,683 | 249,732 | 250,784 | 251,838 | 252,895 | 253,955 | 255,018 | 256,084 |
| 982 | 257,152 | 258,223 | 259,297 | 260,373 | 261,453 | 262,535 | 263,620 | 264,708 | 265,798 | 266,891 |
| 983 | 267,986 | 269,083 | 270,184 | 271,287 | 272,393 | 273,501 | 274,611 | 275,725 | 276,841 | 277,960 |
| 984 | 279,080 | 280,204 | 281,330 | 282,459 | 283,591 | 284,724 | 285,861 | 287,001 | 288,142 | 289,287 |
| 985 | 290,434 | 291,584 | 292,736 | 293,891 | 295,049 | 296,209 | 297,372 | 298,538 | 299,706 | 300,877 |
| 986 | 302,050 | 303,225 | 304,404 | 305,585 | 306,769 | 307,955 | 309,144 | 310,336 | 311,529 | 312,726 |
| 987 | 313,925 | 315,126 | 316,330 | 317,536 | 318,745 | 319,956 | 321,169 | 322,386 | 323,604 | 324,826 |
| 988 | 326,049 | 327,275 | 328,504 | 329,735 | 330,970 | 332,206 | 333,444 | 334,686 | 335,930 | 337,177 |
| 989 | 338,426 | 339,677 | 340,932 | 342,188 | 343,448 | 344,709 | 345,973 | 347,240 | 348,508 | 349,780 |
| 990 | 351,054 | 352,329 | 353,609 | 354,889 | 356,173 | 357,459 | 358,747 | 360,038 | 361,331 | 362,627 |
| 991 | 363,924 | 365,224 | 366,528 | 367,833 | 369,141 | 370,451 | 371,764 | 373,079 | 374,397 | 375,718 |
| 992 | 377,041 | 378,367 | 379,695 | 381,026 | 382,361 | 383,698 | 385,039 | 386,384 | 387,732 | 389,084 |
| 993 | 390,438 | 391,795 | 393,156 | 394,520 | 395,887 | 397,256 | 398,628 | 400,003 | 401,381 | 402,763 |
| 994 | 404,146 | 405,532 | 406,921 | 408,313 | 409,707 | 411,103 | 412,502 | 413,904 | 415,307 | 416,714 |
| 995 | 418,122 | 419,532 | 420,946 | 422,362 | 423,780 | 425,201 | 426,624 | 428,050 | 429,478 | 430,909 |
| 996 | 432,342 | 433,778 | 435,217 | 436,657 | 438,101 | 439,546 | 440,993 | 442,444 | 443,896 | 445,352 |
| 997 | 446,808 | 448,268 | 449,730 | 451,193 | 452,660 | 454,129 | 455,599 | 457,073 | 458,548 | 460,027 |
| 998 | 461,507 | 462,989 | 464,475 | 465,962 | 467,453 | 468,946 | 470,442 | 471,942 | 473,447 | 474,966 |
| 999 | 476,493 | 478,023 | 479,558 | 481,095 | 482,636 | 484,179 | 485,725 | 487,275 | 488,827 | 490,383 |
| 1,000 | 491,941 | 493,502 | 495,068 | 496,636 | 498,210 | 499,786 | 501,366 | 502,951 | 504,540 | 506,133 |
| 1,001 | 507,730 | 509,331 | 510,938 | 512,547 | 514,161 | 515,778 | 517,399 | 519,025 | 520,653 | 522,287 |
| 1,002 | 523,922 | 525,561 | 527,205 | 528,851 | 530,501 | 532,153 | 533,808 | 535,468 | 537,129 | 538,795 |
| 1,003 | 540,462 | 542,133 | 543,808 | 545,485 | 547,167 | 548,851 | 550,538 | 552,230 | 553,924 | 555,622 |
| 1,004 | 557,324 | 559,029 | 560,738 | 562,451 | 564,168 | 565,887 | 567,610 | 569,337 | 571,066 | 572,800 |
| 1,005 | 574,537 | 576,276 | 578,020 | 579,767 | 581,518 | 583,272 | 585,029 | 586,791 | 588,556 | 590,326 |
| 1,006 | 592,098 | 593,874 | 595,655 | 597,438 | 599,227 | 601,019 | 602,816 | 604,619 | 606,426 | 608,238 |
| 1,007 | 610,053 | 611,872 | 613,696 | 615,523 | 617,354 | 619,188 | 621,025 | 622,868 | 624,712 | 626,562 |
| 1,008 | 628,414 | 630,271 | 632,133 | 633,998 | 635,868 | 637,742 | 639,620 | 641,504 | 643,392 | 645,284 |
| 1,009 | 647,180 | 649,080 | 650,985 | 652,893 | 654,805 | 656,720 | 658,638 | 660,561 | 662,485 | 664,415 |
| 1,010 | 666,347 | 668,282 | 670,222 | 672,164 | 674,112 | 676,062 | 678,015 | 679,974 | 681,935 | 683,902 |
| 1,011 | 685,871 | 687,844 | 689,823 | 691,805 | 693,793 | 695,784 | 697,778 | 699,778 | 701,781 | 703,789 |
| 1,012 | 705,799 | 707,814 | 709,833 | 711,854 | 713,881 | 715,910 | 717,943 | 719,980 | 722,019 | 724,063 |
| 1,013 | 726,109 | 728,158 | 730,211 | 732,266 | 734,324 | 736,385 | 738,448 | 740,515 | 742,584 | 744,658 |
| 1,014 | 746,732 | 748,810 | 750,893 | 752,977 | 755,065 | 757,156 | 759,249 | 761,346 | 763,446 | 765,549 |
| 1,015 | 767,654 | 769,761 | 771,872 | 773,985 | 776,101 | 778,219 | 780,339 | 782,462 | 784,586 | 786,715 |
| 1,016 | 788,844 | 790,975 | 793,110 | 795,245 | 797,385 | 799,525 | 801,668 | 803,814 | 805,961 | 808,112 |

Appendix A (continued)

## Lake Buchanan

### RESERVOIR VOLUME TABLE

TEXAS WATER DEVELOPMENT BOARD — March 2006 SURVEY

Conservation Pool Elevation 1020.5 ft

VOLUME IN ACRE-FEET — 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,017 | 810,264 | 812,418 | 814,575 | 816,733 | 818,894 | 821,056 | 823,219 | 825,385 | 827,551 | 829,720 |
| 1,018 | 831,889 | 834,059 | 836,232 | 838,405 | 840,581 | 842,757 | 844,934 | 847,114 | 849,295 | 851,478 |
| 1,019 | 853,661 | 855,846 | 858,034 | 860,222 | 862,413 | 864,604 | 866,796 | 868,992 | 871,189 | 873,388 |
| 1,020 | 875,588 | 877,791 | 879,996 | 882,203 | 884,414 | 886,626 | 888,840 | 891,059 | 893,279 | 895,504 |
| 1,021 | 897,730 | 899,960 | 902,194 | 904,430 | 906,670 | 908,912 | 911,158 | 913,408 | 915,661 | 917,918 |
| 1,022 | 920,173 | 922,431 | 924,694 | 926,958 | 929,228 | 931,499 | 933,774 | 936,053 | 938,334 | 940,619 |
| 1,023 | 942,906 | 945,196 | 947,491 | 949,787 | 952,087 | 954,389 | 956,694 | 959,004 | 961,315 | 963,630 |
| 1,024 | 965,946 | 968,266 | 970,588 | 972,916 | 975,243 | 977,574 | 979,907 | 982,244 | 984,585 | 986,927 |
| 1,025 | 989,271 | 991,618 | 993,968 | 996,323 | 998,678 | 1,001,036 | 1,003,396 | 1,005,759 | 1,008,128 | 1,010,496 |
| 1,026 | 1,012,867 | 1,015,241 | 1,017,617 | 1,019,999 | 1,022,381 | 1,024,765 | 1,027,152 | 1,029,541 | 1,031,936 | 1,034,331 |
| 1,027 | 1,036,728 | 1,039,128 | 1,041,531 | 1,043,939 | 1,046,346 | 1,048,757 | 1,051,170 | 1,053,585 | 1,056,006 | 1,058,427 |
| 1,028 | 1,060,851 | 1,063,277 | 1,065,706 | 1,068,140 | 1,070,574 | 1,073,010 | 1,075,450 | 1,077,891 | 1,080,339 | 1,082,786 |
| 1,029 | 1,085,235 | 1,087,687 | 1,090,142 | 1,092,602 | 1,095,062 | 1,097,524 | 1,099,989 | 1,102,457 | 1,104,930 | 1,107,402 |
| 1,030 | 1,109,877 | 1,112,355 | 1,114,835 | 1,117,321 | 1,119,806 | 1,122,294 | 1,124,785 | 1,127,278 | 1,129,776 | 1,132,274 |
| 1,031 | 1,134,775 | 1,137,278 | 1,139,784 | 1,142,295 | 1,144,806 | 1,147,319 | 1,149,835 | 1,152,353 | 1,154,877 | 1,157,401 |
| 1,032 | 1,159,927 | 1,162,455 | 1,164,986 | 1,167,523 | 1,170,059 | 1,172,598 | 1,175,140 | 1,177,684 | 1,180,234 | 1,182,783 |
| 1,033 | 1,185,335 | 1,187,889 | 1,190,446 | 1,193,009 | 1,195,571 | 1,198,136 | 1,200,703 | 1,203,273 | 1,205,849 | 1,208,424 |
| 1,034 | 1,211,002 | 1,213,582 | 1,216,165 | 1,218,754 | 1,221,342 | 1,223,933 | 1,226,527 | 1,229,123 | 1,231,725 | 1,234,326 |
| 1,035 | 1,236,930 | | | | | | | | | |

Appendix B

# Lake Buchanan

## RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — March 2006 SURVEY

Conservation Pool Elevation 1020.5 ft

AREA IN ACRES — 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| 906 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 907 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 908 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 909 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 910 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 911 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 912 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 913 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| 914 | 3 | 5 | 8 | 10 | 13 | 15 | 18 | 20 | 22 | 24 |
| 915 | 25 | 27 | 30 | 33 | 39 | 45 | 51 | 57 | 63 | 69 |
| 916 | 74 | 79 | 83 | 88 | 92 | 96 | 100 | 104 | 109 | 115 |
| 917 | 120 | 125 | 130 | 135 | 141 | 147 | 154 | 161 | 168 | 174 |
| 918 | 180 | 186 | 193 | 199 | 205 | 211 | 217 | 222 | 227 | 233 |
| 919 | 238 | 244 | 249 | 254 | 259 | 263 | 268 | 272 | 277 | 281 |
| 920 | 285 | 289 | 293 | 297 | 301 | 305 | 309 | 313 | 317 | 321 |
| 921 | 324 | 328 | 332 | 336 | 340 | 344 | 348 | 352 | 357 | 361 |
| 922 | 365 | 369 | 373 | 377 | 381 | 385 | 389 | 393 | 397 | 402 |
| 923 | 406 | 411 | 415 | 419 | 424 | 428 | 432 | 437 | 442 | 446 |
| 924 | 451 | 457 | 462 | 467 | 473 | 479 | 484 | 490 | 497 | 503 |
| 925 | 510 | 517 | 525 | 534 | 542 | 550 | 558 | 565 | 573 | 580 |
| 926 | 587 | 594 | 602 | 609 | 617 | 625 | 633 | 641 | 648 | 656 |
| 927 | 663 | 671 | 678 | 685 | 692 | 699 | 706 | 713 | 720 | 727 |
| 928 | 733 | 740 | 748 | 755 | 761 | 768 | 775 | 782 | 789 | 796 |
| 929 | 803 | 810 | 817 | 824 | 831 | 838 | 845 | 852 | 859 | 867 |
| 930 | 875 | 882 | 890 | 898 | 906 | 914 | 921 | 929 | 936 | 944 |
| 931 | 952 | 959 | 967 | 976 | 984 | 993 | 1,002 | 1,010 | 1,018 | 1,026 |
| 932 | 1,034 | 1,042 | 1,053 | 1,064 | 1,074 | 1,083 | 1,092 | 1,101 | 1,110 | 1,119 |
| 933 | 1,127 | 1,136 | 1,144 | 1,153 | 1,161 | 1,170 | 1,179 | 1,188 | 1,198 | 1,207 |
| 934 | 1,216 | 1,225 | 1,234 | 1,243 | 1,253 | 1,262 | 1,271 | 1,280 | 1,289 | 1,298 |
| 935 | 1,307 | 1,317 | 1,326 | 1,335 | 1,345 | 1,355 | 1,364 | 1,373 | 1,382 | 1,392 |
| 936 | 1,401 | 1,410 | 1,420 | 1,429 | 1,439 | 1,449 | 1,459 | 1,469 | 1,479 | 1,489 |
| 937 | 1,499 | 1,509 | 1,519 | 1,529 | 1,539 | 1,549 | 1,560 | 1,570 | 1,581 | 1,591 |
| 938 | 1,602 | 1,612 | 1,623 | 1,634 | 1,645 | 1,655 | 1,666 | 1,677 | 1,688 | 1,698 |
| 939 | 1,709 | 1,720 | 1,731 | 1,742 | 1,754 | 1,765 | 1,776 | 1,788 | 1,800 | 1,812 |
| 940 | 1,823 | 1,835 | 1,847 | 1,859 | 1,871 | 1,882 | 1,894 | 1,906 | 1,918 | 1,930 |
| 941 | 1,942 | 1,954 | 1,967 | 1,979 | 1,991 | 2,003 | 2,015 | 2,027 | 2,039 | 2,051 |
| 942 | 2,063 | 2,075 | 2,088 | 2,101 | 2,114 | 2,126 | 2,139 | 2,152 | 2,165 | 2,178 |
| 943 | 2,191 | 2,204 | 2,219 | 2,233 | 2,247 | 2,261 | 2,275 | 2,289 | 2,304 | 2,318 |
| 944 | 2,332 | 2,346 | 2,360 | 2,374 | 2,388 | 2,402 | 2,417 | 2,431 | 2,445 | 2,460 |
| 945 | 2,474 | 2,488 | 2,503 | 2,517 | 2,532 | 2,546 | 2,560 | 2,575 | 2,589 | 2,604 |
| 946 | 2,619 | 2,634 | 2,649 | 2,664 | 2,679 | 2,694 | 2,710 | 2,726 | 2,742 | 2,758 |
| 947 | 2,775 | 2,791 | 2,808 | 2,824 | 2,840 | 2,857 | 2,873 | 2,889 | 2,905 | 2,920 |
| 948 | 2,936 | 2,951 | 2,967 | 2,982 | 2,998 | 3,014 | 3,030 | 3,046 | 3,061 | 3,077 |
| 949 | 3,093 | 3,109 | 3,124 | 3,140 | 3,155 | 3,171 | 3,186 | 3,202 | 3,218 | 3,234 |
| 950 | 3,250 | 3,266 | 3,282 | 3,298 | 3,315 | 3,332 | 3,348 | 3,364 | 3,380 | 3,397 |
| 951 | 3,413 | 3,429 | 3,446 | 3,462 | 3,478 | 3,495 | 3,511 | 3,527 | 3,544 | 3,560 |
| 952 | 3,577 | 3,593 | 3,609 | 3,626 | 3,642 | 3,658 | 3,675 | 3,692 | 3,709 | 3,725 |
| 953 | 3,742 | 3,759 | 3,776 | 3,792 | 3,809 | 3,826 | 3,843 | 3,859 | 3,876 | 3,894 |
| 954 | 3,911 | 3,928 | 3,945 | 3,963 | 3,980 | 3,998 | 4,016 | 4,034 | 4,053 | 4,072 |
| 955 | 4,092 | 4,113 | 4,135 | 4,155 | 4,175 | 4,195 | 4,214 | 4,234 | 4,254 | 4,274 |
| 956 | 4,295 | 4,315 | 4,336 | 4,356 | 4,377 | 4,397 | 4,418 | 4,438 | 4,459 | 4,479 |
| 957 | 4,500 | 4,522 | 4,543 | 4,564 | 4,585 | 4,605 | 4,626 | 4,647 | 4,668 | 4,689 |
| 958 | 4,711 | 4,733 | 4,754 | 4,776 | 4,797 | 4,818 | 4,840 | 4,861 | 4,883 | 4,904 |
| 959 | 4,926 | 4,947 | 4,969 | 4,990 | 5,012 | 5,033 | 5,054 | 5,076 | 5,097 | 5,119 |
| 960 | 5,140 | 5,161 | 5,183 | 5,204 | 5,226 | 5,247 | 5,269 | 5,290 | 5,311 | 5,333 |
| 961 | 5,354 | 5,376 | 5,397 | 5,418 | 5,440 | 5,461 | 5,482 | 5,504 | 5,525 | 5,547 |

Appendix B (continued)

## Lake Buchanan

### RESERVOIR AREA TABLE

TEXAS WATER DEVELOPMENT BOARD — March 2006 SURVEY

Conservation Pool Elevation 1020.5 ft

AREA IN ACRES — 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| 962 | 5,568 | 5,590 | 5,612 | 5,633 | 5,655 | 5,677 | 5,699 | 5,721 | 5,744 | 5,767 |
| 963 | 5,791 | 5,814 | 5,837 | 5,860 | 5,883 | 5,906 | 5,929 | 5,952 | 5,975 | 5,998 |
| 964 | 6,021 | 6,044 | 6,067 | 6,090 | 6,113 | 6,136 | 6,159 | 6,181 | 6,204 | 6,227 |
| 965 | 6,250 | 6,274 | 6,297 | 6,320 | 6,344 | 6,367 | 6,392 | 6,416 | 6,440 | 6,464 |
| 966 | 6,487 | 6,511 | 6,535 | 6,558 | 6,583 | 6,607 | 6,631 | 6,655 | 6,679 | 6,703 |
| 967 | 6,726 | 6,749 | 6,772 | 6,795 | 6,819 | 6,842 | 6,866 | 6,890 | 6,914 | 6,939 |
| 968 | 6,963 | 6,988 | 7,012 | 7,037 | 7,061 | 7,086 | 7,110 | 7,134 | 7,159 | 7,184 |
| 969 | 7,208 | 7,232 | 7,257 | 7,281 | 7,305 | 7,329 | 7,353 | 7,377 | 7,402 | 7,427 |
| 970 | 7,453 | 7,478 | 7,504 | 7,531 | 7,557 | 7,585 | 7,612 | 7,638 | 7,666 | 7,693 |
| 971 | 7,719 | 7,745 | 7,772 | 7,798 | 7,824 | 7,849 | 7,875 | 7,900 | 7,927 | 7,954 |
| 972 | 7,981 | 8,008 | 8,034 | 8,060 | 8,086 | 8,112 | 8,139 | 8,166 | 8,194 | 8,220 |
| 973 | 8,246 | 8,272 | 8,299 | 8,324 | 8,351 | 8,377 | 8,403 | 8,429 | 8,456 | 8,482 |
| 974 | 8,509 | 8,536 | 8,564 | 8,591 | 8,620 | 8,648 | 8,677 | 8,705 | 8,733 | 8,762 |
| 975 | 8,790 | 8,819 | 8,847 | 8,876 | 8,903 | 8,931 | 8,959 | 8,987 | 9,014 | 9,041 |
| 976 | 9,068 | 9,094 | 9,121 | 9,148 | 9,174 | 9,201 | 9,228 | 9,254 | 9,281 | 9,308 |
| 977 | 9,335 | 9,362 | 9,389 | 9,416 | 9,443 | 9,471 | 9,498 | 9,525 | 9,552 | 9,579 |
| 978 | 9,606 | 9,634 | 9,661 | 9,689 | 9,716 | 9,743 | 9,770 | 9,798 | 9,825 | 9,853 |
| 979 | 9,880 | 9,908 | 9,936 | 9,964 | 9,991 | 10,019 | 10,046 | 10,072 | 10,099 | 10,125 |
| 980 | 10,152 | 10,179 | 10,206 | 10,233 | 10,260 | 10,287 | 10,314 | 10,341 | 10,369 | 10,396 |
| 981 | 10,423 | 10,450 | 10,477 | 10,504 | 10,531 | 10,558 | 10,586 | 10,613 | 10,641 | 10,670 |
| 982 | 10,698 | 10,726 | 10,753 | 10,780 | 10,808 | 10,836 | 10,862 | 10,888 | 10,914 | 10,940 |
| 983 | 10,966 | 10,992 | 11,018 | 11,043 | 11,069 | 11,095 | 11,120 | 11,146 | 11,172 | 11,197 |
| 984 | 11,223 | 11,249 | 11,275 | 11,301 | 11,328 | 11,354 | 11,380 | 11,406 | 11,432 | 11,458 |
| 985 | 11,485 | 11,511 | 11,537 | 11,563 | 11,590 | 11,616 | 11,642 | 11,668 | 11,695 | 11,720 |
| 986 | 11,746 | 11,771 | 11,797 | 11,823 | 11,850 | 11,876 | 11,902 | 11,927 | 11,952 | 11,976 |
| 987 | 12,001 | 12,025 | 12,050 | 12,074 | 12,099 | 12,124 | 12,149 | 12,175 | 12,200 | 12,225 |
| 988 | 12,250 | 12,275 | 12,300 | 12,326 | 12,351 | 12,376 | 12,402 | 12,427 | 12,452 | 12,478 |
| 989 | 12,503 | 12,529 | 12,554 | 12,579 | 12,604 | 12,629 | 12,653 | 12,677 | 12,701 | 12,726 |
| 990 | 12,750 | 12,774 | 12,798 | 12,822 | 12,846 | 12,871 | 12,895 | 12,919 | 12,943 | 12,967 |
| 991 | 12,992 | 13,017 | 13,041 | 13,066 | 13,091 | 13,116 | 13,141 | 13,167 | 13,193 | 13,219 |
| 992 | 13,245 | 13,271 | 13,297 | 13,326 | 13,359 | 13,393 | 13,428 | 13,463 | 13,497 | 13,530 |
| 993 | 13,562 | 13,592 | 13,622 | 13,651 | 13,680 | 13,709 | 13,737 | 13,767 | 13,795 | 13,823 |
| 994 | 13,850 | 13,876 | 13,903 | 13,928 | 13,953 | 13,977 | 14,001 | 14,025 | 14,049 | 14,073 |
| 995 | 14,097 | 14,121 | 14,145 | 14,170 | 14,196 | 14,221 | 14,246 | 14,271 | 14,296 | 14,321 |
| 996 | 14,346 | 14,371 | 14,395 | 14,419 | 14,443 | 14,467 | 14,490 | 14,514 | 14,537 | 14,560 |
| 997 | 14,583 | 14,606 | 14,629 | 14,652 | 14,675 | 14,698 | 14,721 | 14,744 | 14,768 | 14,791 |
| 998 | 14,816 | 14,840 | 14,865 | 14,891 | 14,918 | 14,947 | 14,978 | 15,015 | 15,123 | 15,237 |
| 999 | 15,290 | 15,326 | 15,359 | 15,389 | 15,419 | 15,449 | 15,478 | 15,508 | 15,538 | 15,570 |
| 1,000 | 15,602 | 15,635 | 15,670 | 15,707 | 15,746 | 15,786 | 15,825 | 15,866 | 15,909 | 15,952 |
| 1,001 | 15,995 | 16,036 | 16,075 | 16,114 | 16,155 | 16,195 | 16,235 | 16,272 | 16,308 | 16,344 |
| 1,002 | 16,378 | 16,412 | 16,445 | 16,478 | 16,510 | 16,541 | 16,573 | 16,603 | 16,634 | 16,665 |
| 1,003 | 16,697 | 16,729 | 16,761 | 16,793 | 16,825 | 16,859 | 16,893 | 16,928 | 16,964 | 17,000 |
| 1,004 | 17,035 | 17,072 | 17,109 | 17,145 | 17,181 | 17,215 | 17,249 | 17,283 | 17,316 | 17,350 |
| 1,005 | 17,383 | 17,418 | 17,453 | 17,488 | 17,524 | 17,559 | 17,596 | 17,633 | 17,671 | 17,708 |
| 1,006 | 17,745 | 17,783 | 17,821 | 17,862 | 17,904 | 17,950 | 17,999 | 18,046 | 18,092 | 18,135 |
| 1,007 | 18,176 | 18,215 | 18,253 | 18,289 | 18,325 | 18,361 | 18,397 | 18,433 | 18,470 | 18,508 |
| 1,008 | 18,548 | 18,590 | 18,634 | 18,678 | 18,721 | 18,765 | 18,810 | 18,856 | 18,899 | 18,942 |
| 1,009 | 18,984 | 19,024 | 19,063 | 19,099 | 19,134 | 19,168 | 19,201 | 19,236 | 19,270 | 19,305 |
| 1,010 | 19,340 | 19,375 | 19,411 | 19,447 | 19,484 | 19,523 | 19,561 | 19,599 | 19,637 | 19,676 |
| 1,011 | 19,717 | 19,762 | 19,805 | 19,847 | 19,889 | 19,931 | 19,973 | 20,013 | 20,052 | 20,090 |
| 1,012 | 20,128 | 20,166 | 20,203 | 20,240 | 20,277 | 20,314 | 20,349 | 20,383 | 20,416 | 20,448 |
| 1,013 | 20,479 | 20,508 | 20,537 | 20,565 | 20,594 | 20,623 | 20,651 | 20,681 | 20,710 | 20,739 |
| 1,014 | 20,769 | 20,800 | 20,832 | 20,863 | 20,893 | 20,923 | 20,953 | 20,982 | 21,011 | 21,039 |
| 1,015 | 21,066 | 21,093 | 21,118 | 21,143 | 21,168 | 21,192 | 21,215 | 21,239 | 21,262 | 21,284 |
| 1,016 | 21,306 | 21,329 | 21,351 | 21,374 | 21,397 | 21,420 | 21,443 | 21,467 | 21,490 | 21,512 |

Appendix B (continued)

## Lake Buchanan

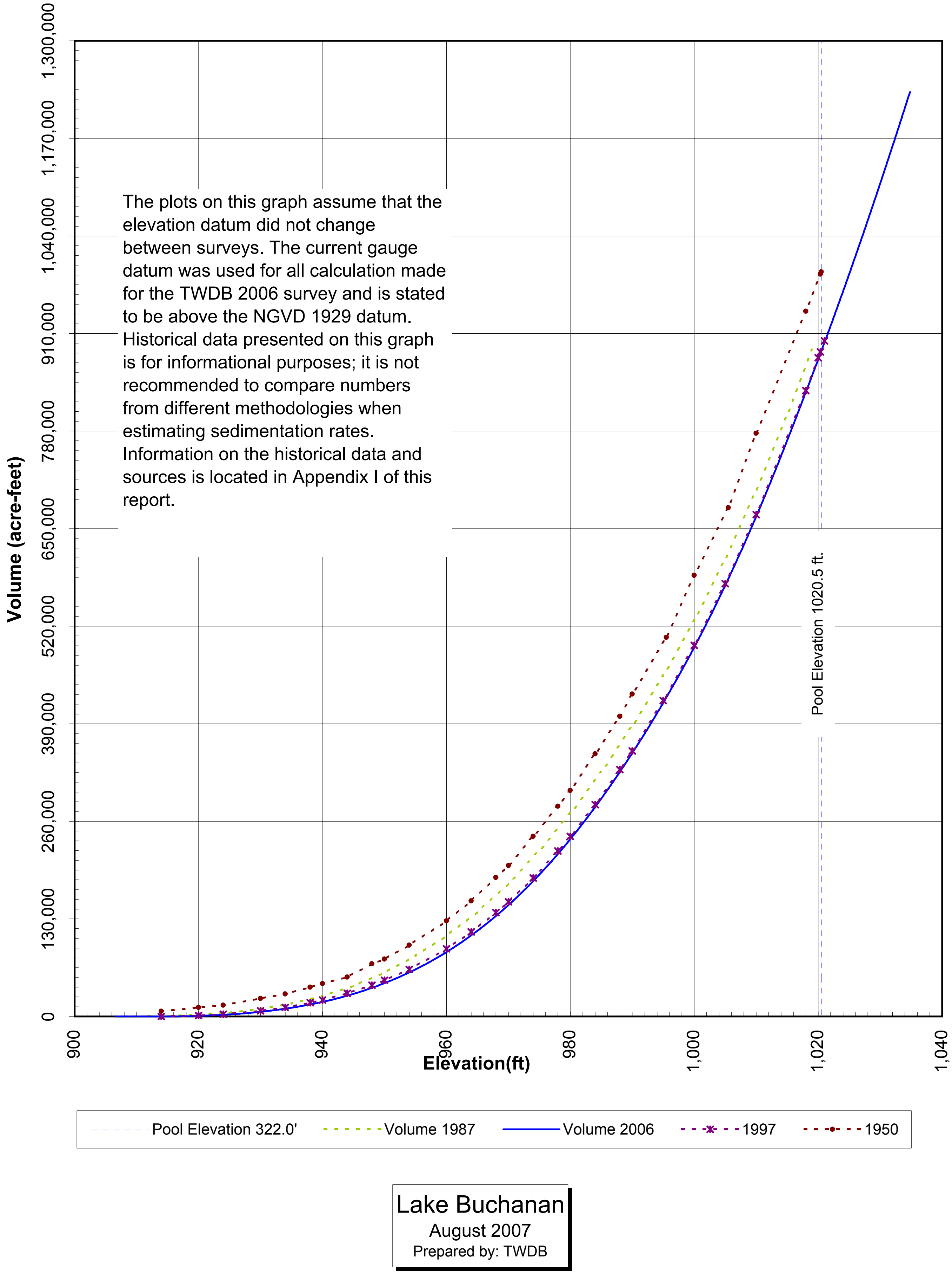
### RESERVOIR AREA TABLE

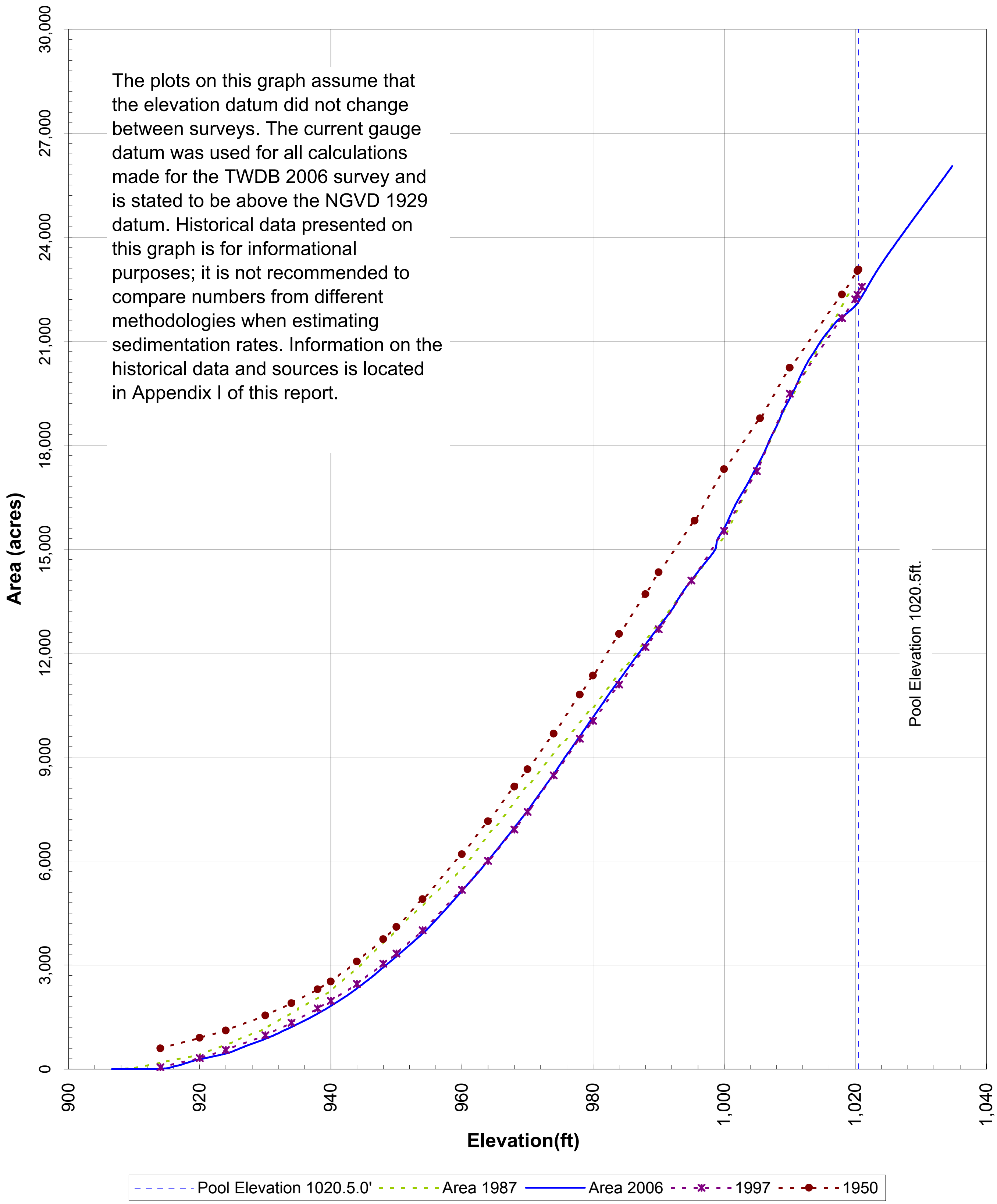
TEXAS WATER DEVELOPMENT BOARD | March 2006 SURVEY

Conservation Pool Elevation 1020.5 ft

AREA IN ACRES | 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 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1,017 | 21,534 | 21,555 | 21,576 | 21,595 | 21,613 | 21,630 | 21,645 | 21,660 | 21,674 | 21,688 |
| 1,018 | 21,701 | 21,715 | 21,729 | 21,742 | 21,757 | 21,771 | 21,786 | 21,801 | 21,816 | 21,831 |
| 1,019 | 21,846 | 21,862 | 21,877 | 21,893 | 21,909 | 21,925 | 21,942 | 21,959 | 21,978 | 21,997 |
| 1,020 | 22,017 | 22,038 | 22,061 | 22,085 | 22,111 | 22,137 | 22,165 | 22,194 | 22,223 | 22,254 |
| 1,021 | 22,285 | 22,316 | 22,348 | 22,380 | 22,413 | 22,446 | 22,479 | 22,512 | 22,545 | 22,578 |
| 1,022 | 22,611 | 22,644 | 22,677 | 22,710 | 22,742 | 22,775 | 22,807 | 22,838 | 22,870 | 22,901 |
| 1,023 | 22,932 | 22,962 | 22,992 | 23,022 | 23,052 | 23,081 | 23,111 | 23,140 | 23,168 | 23,197 |
| 1,024 | 23,225 | 23,253 | 23,282 | 23,310 | 23,338 | 23,366 | 23,393 | 23,421 | 23,448 | 23,475 |
| 1,025 | 23,502 | 23,529 | 23,556 | 23,583 | 23,609 | 23,636 | 23,663 | 23,690 | 23,716 | 23,743 |
| 1,026 | 23,770 | 23,796 | 23,822 | 23,849 | 23,875 | 23,901 | 23,927 | 23,953 | 23,980 | 24,006 |
| 1,027 | 24,032 | 24,058 | 24,084 | 24,110 | 24,137 | 24,163 | 24,189 | 24,215 | 24,241 | 24,268 |
| 1,028 | 24,294 | 24,320 | 24,346 | 24,373 | 24,398 | 24,425 | 24,451 | 24,477 | 24,503 | 24,529 |
| 1,029 | 24,554 | 24,580 | 24,606 | 24,631 | 24,657 | 24,682 | 24,708 | 24,733 | 24,759 | 24,784 |
| 1,030 | 24,810 | 24,836 | 24,861 | 24,887 | 24,913 | 24,938 | 24,963 | 24,989 | 25,014 | 25,040 |
| 1,031 | 25,065 | 25,090 | 25,115 | 25,141 | 25,166 | 25,192 | 25,217 | 25,242 | 25,268 | 25,293 |
| 1,032 | 25,319 | 25,344 | 25,370 | 25,396 | 25,422 | 25,448 | 25,474 | 25,500 | 25,526 | 25,552 |
| 1,033 | 25,577 | 25,603 | 25,629 | 25,655 | 25,681 | 25,707 | 25,733 | 25,759 | 25,785 | 25,811 |
| 1,034 | 25,838 | 25,864 | 25,890 | 25,916 | 25,942 | 25,968 | 25,994 | 26,020 | 26,046 | 26,072 |
| 1,035 | 26,097 | | | | | | | | | |


Volume (acre-feet)
0
130,000
260,000
390,000
520,000
650,000
780,000
910,000
1,040,000
1,170,000
1,300,000
900
920
940
960
980
1,000
1,020
1,040
Elevation(ft)
The plots on this graph assume that the elevation datum did not change between surveys. The current gauge datum was used for all calculation made for the TWDB 2006 survey and is stated to be above the NGVD 1929 datum. Historical data presented on this graph is for informational purposes; it is not recommended to compare numbers from different methodologies when estimating sedimentation rates. Information on the historical data and sources is located in Appendix I of this report.
Pool Elevation 1020.5 ft.
Pool Elevation 322.0'
Volume 1987
Volume 2006
1997
1950
Lake Buchanan
August 2007
Prepared by: TWDB



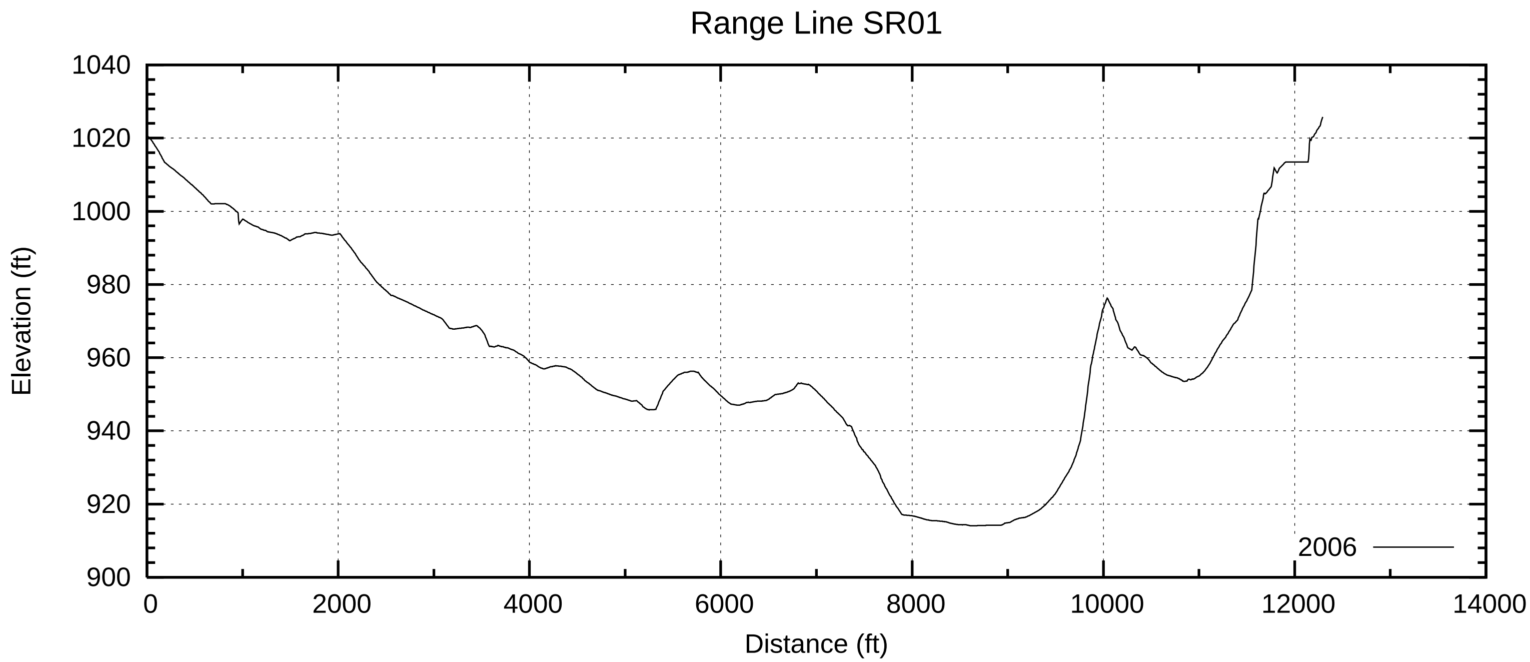

Lake Buchanan
August 2007
Prepared by: TWDB

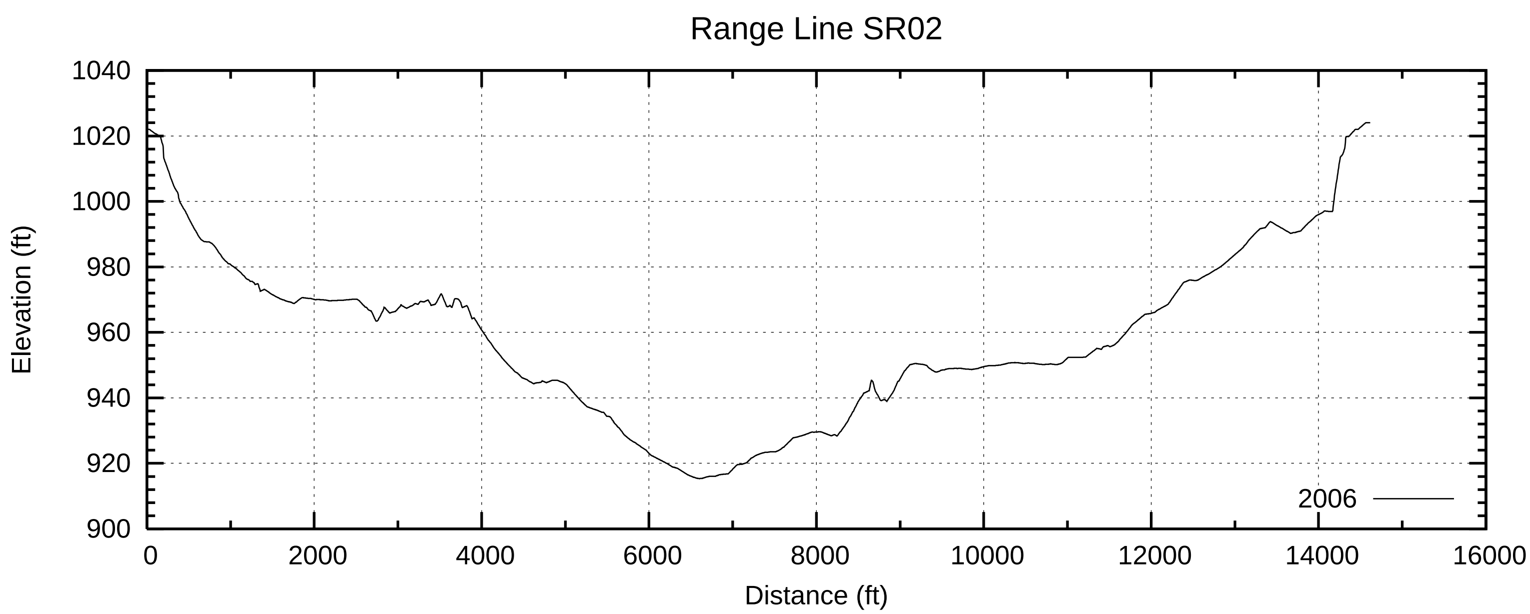
Appendix D Elevation vs. Area

# Appendix E

Lake Buchanan Range Line Cross Sectional Plots

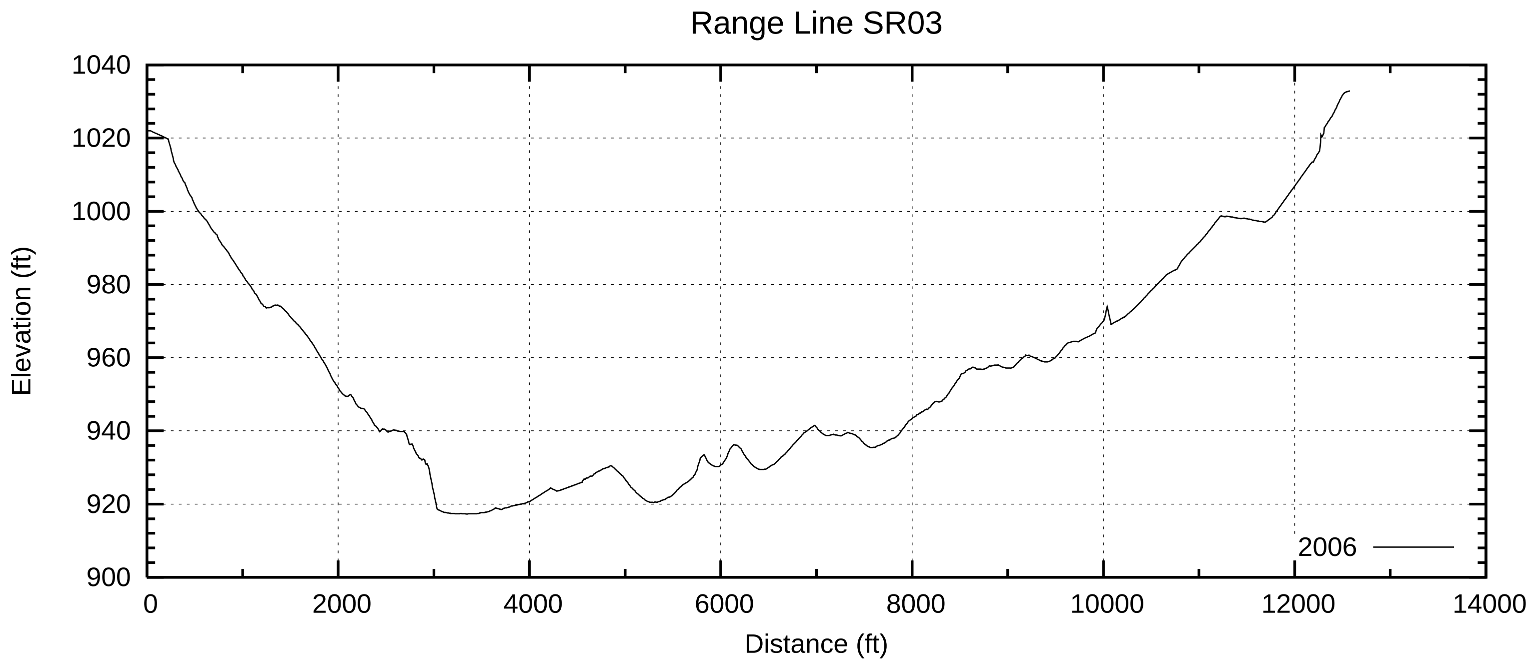
# Lake Buchanan

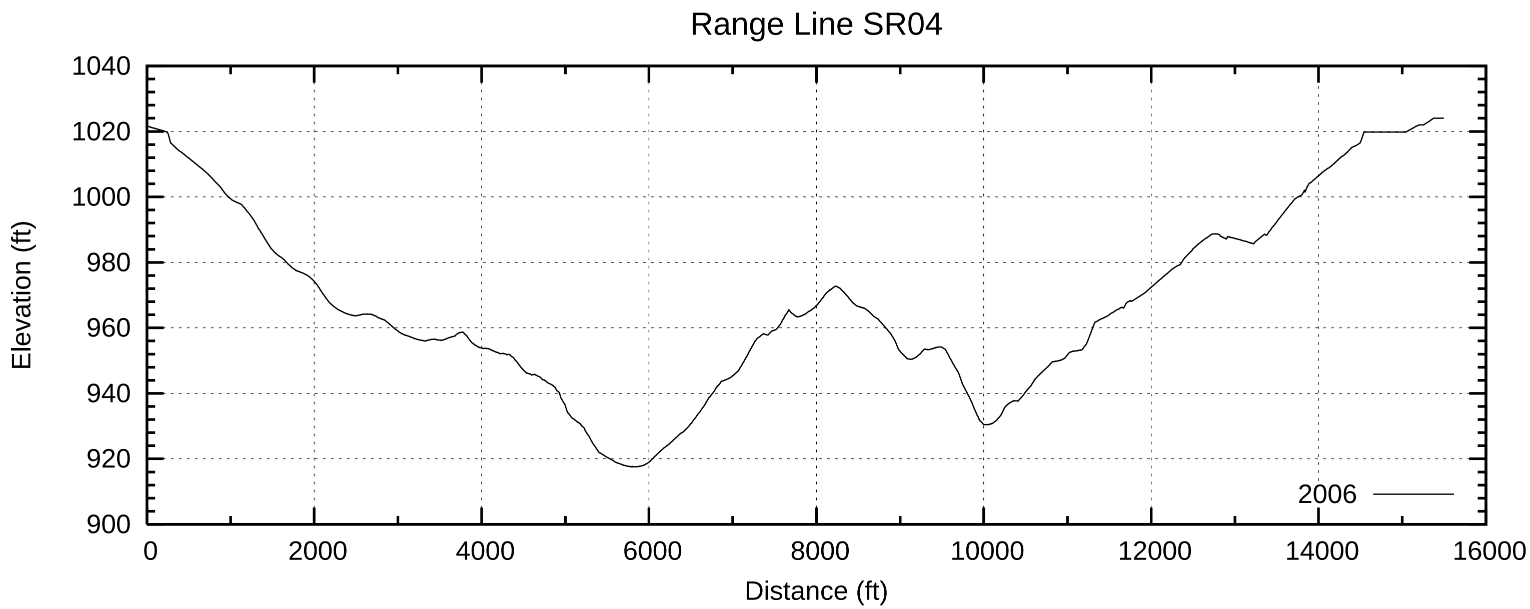



Appendix E

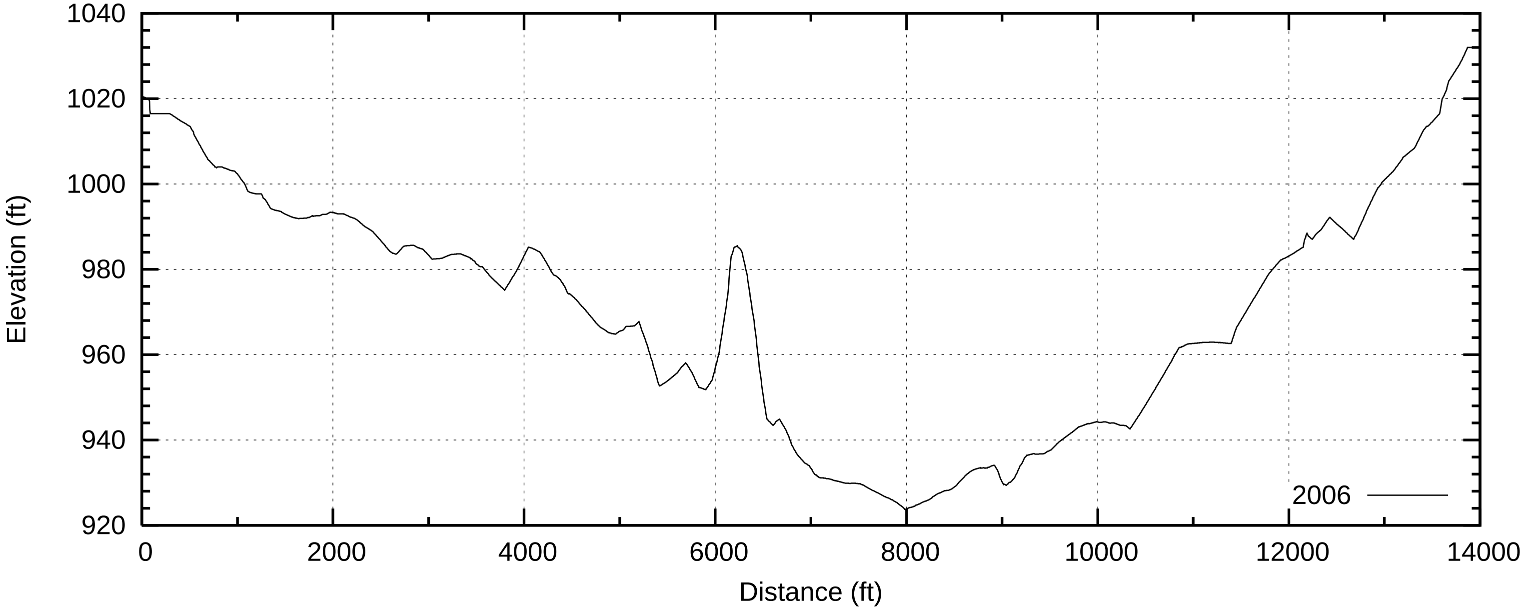
# Lake Buchanan



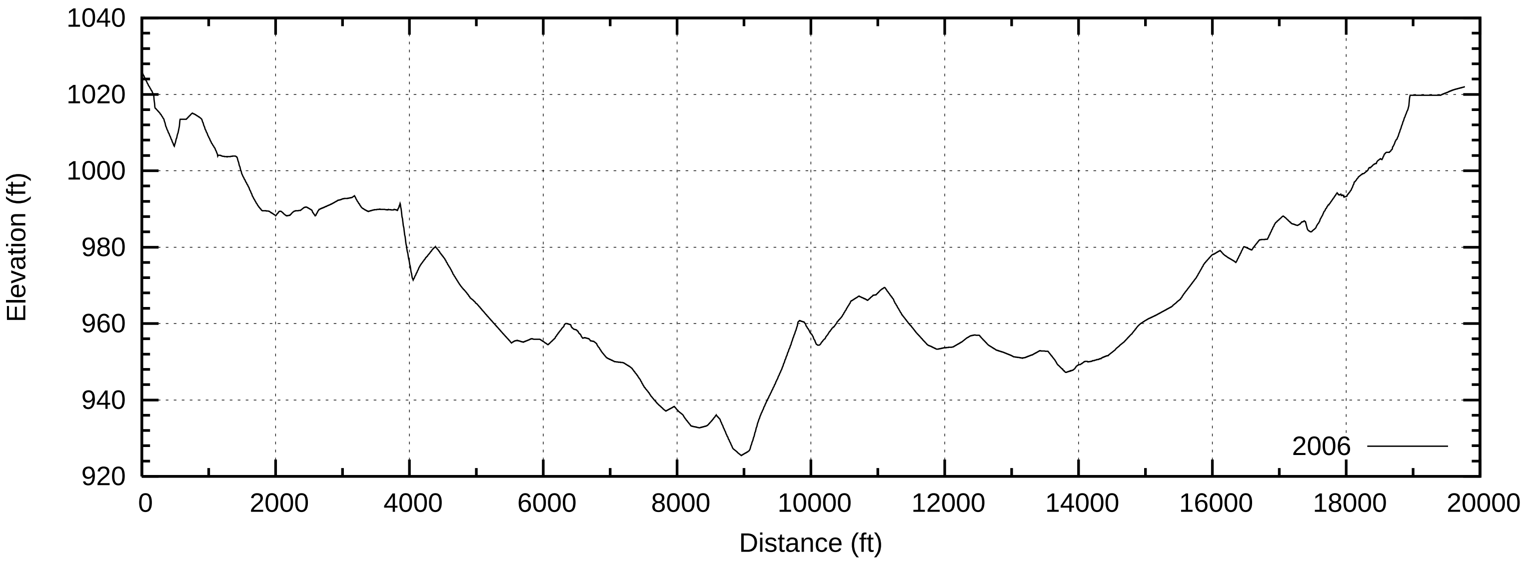



# Lake Buchanan

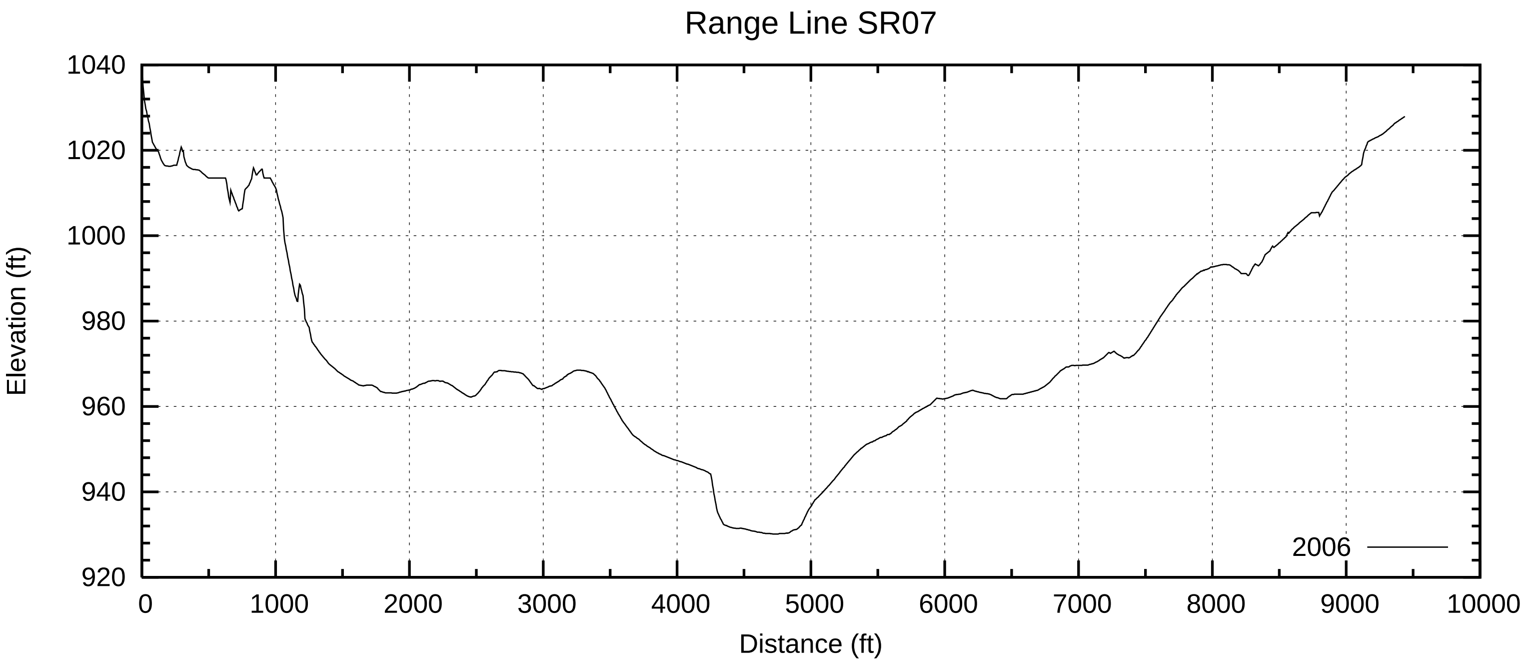
Range Line SR05

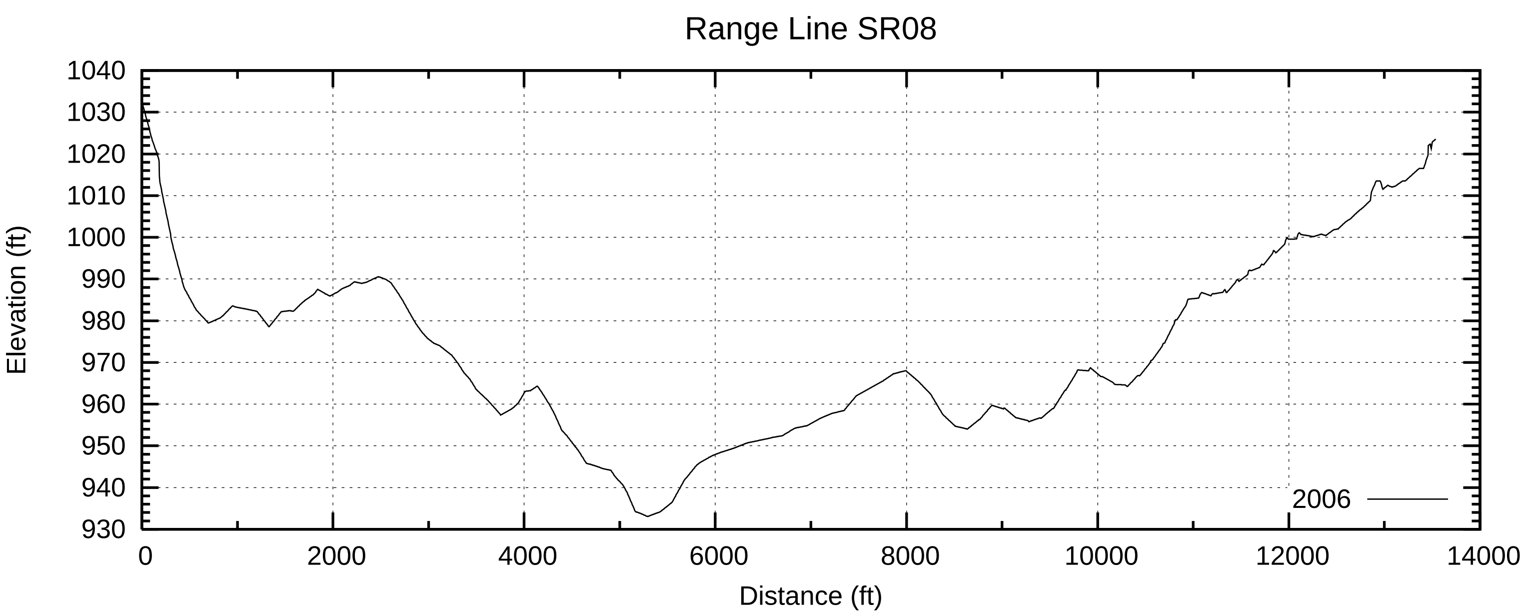



Range Line SR06

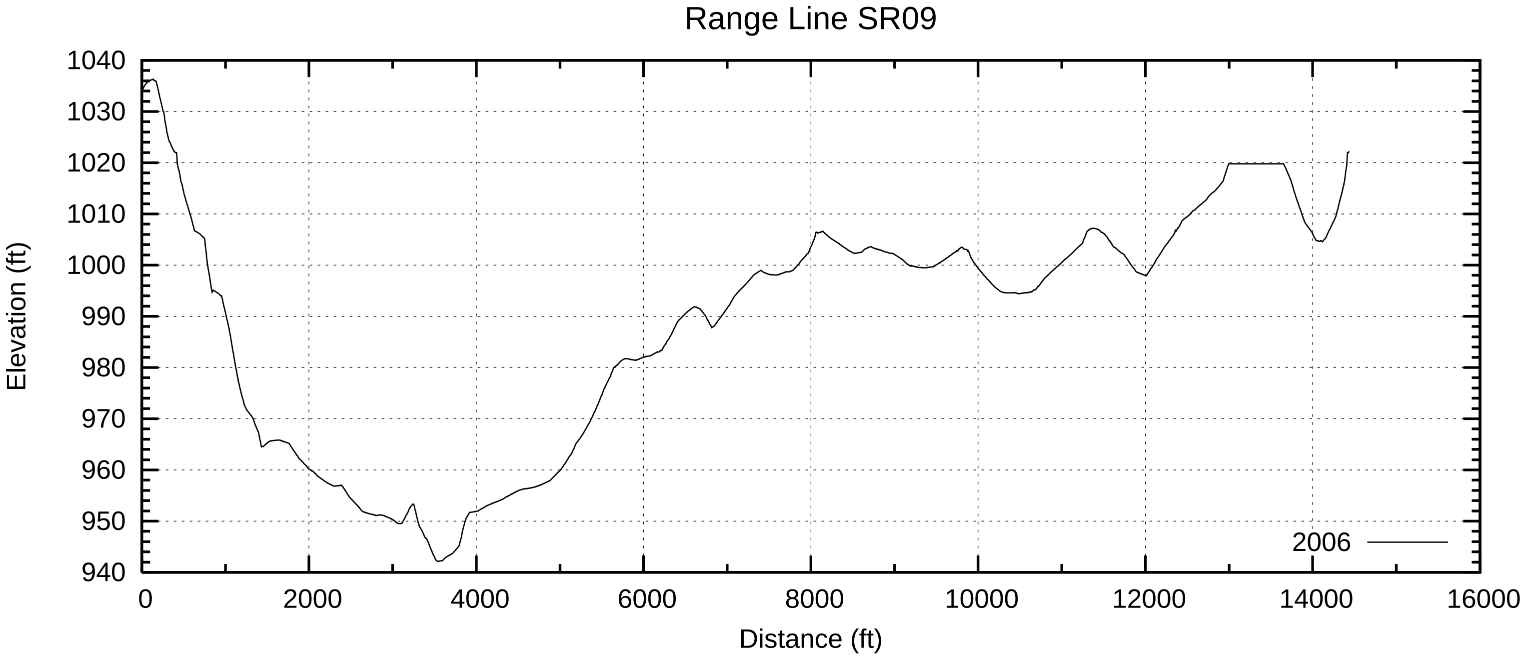


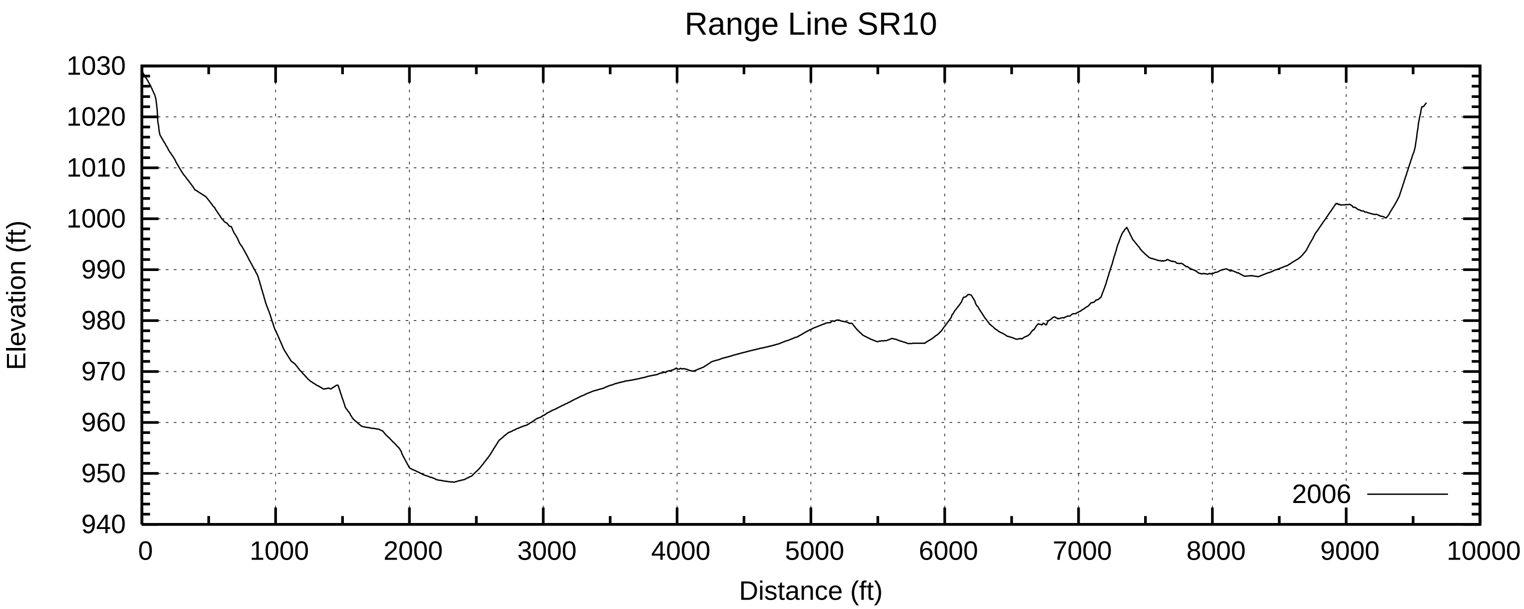
# Lake Buchanan



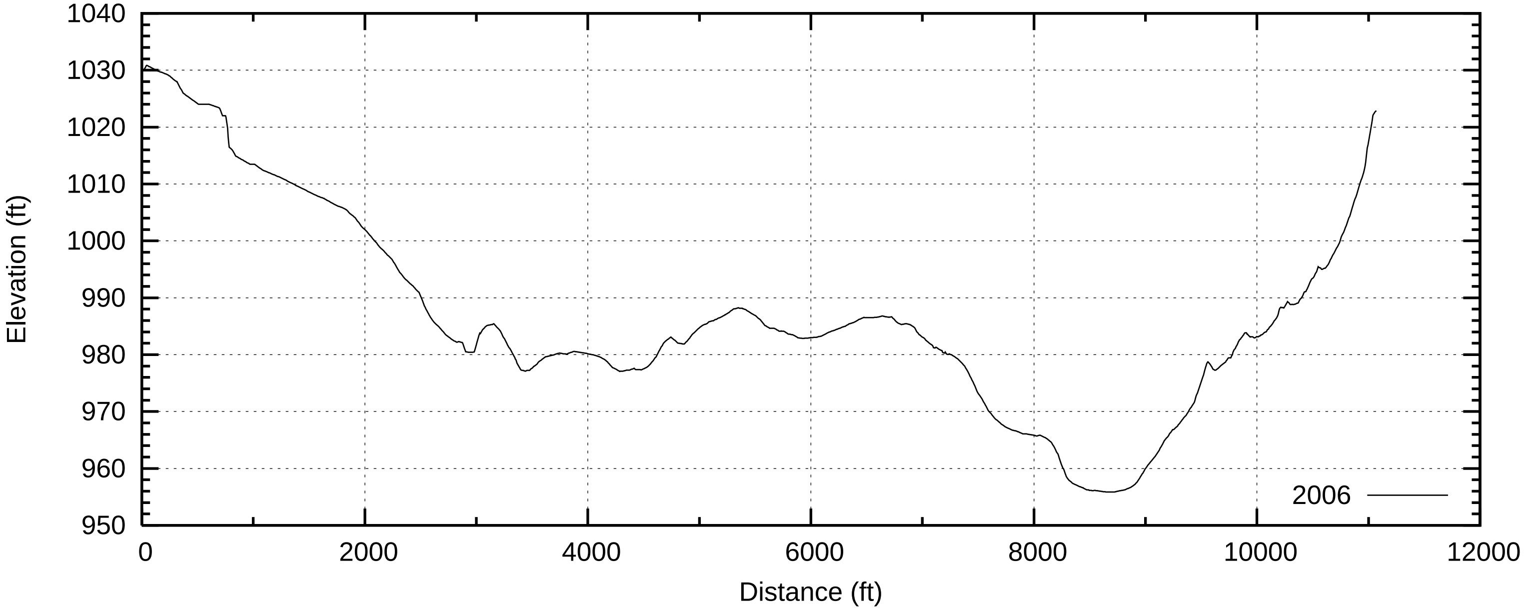
# Lake Buchanan



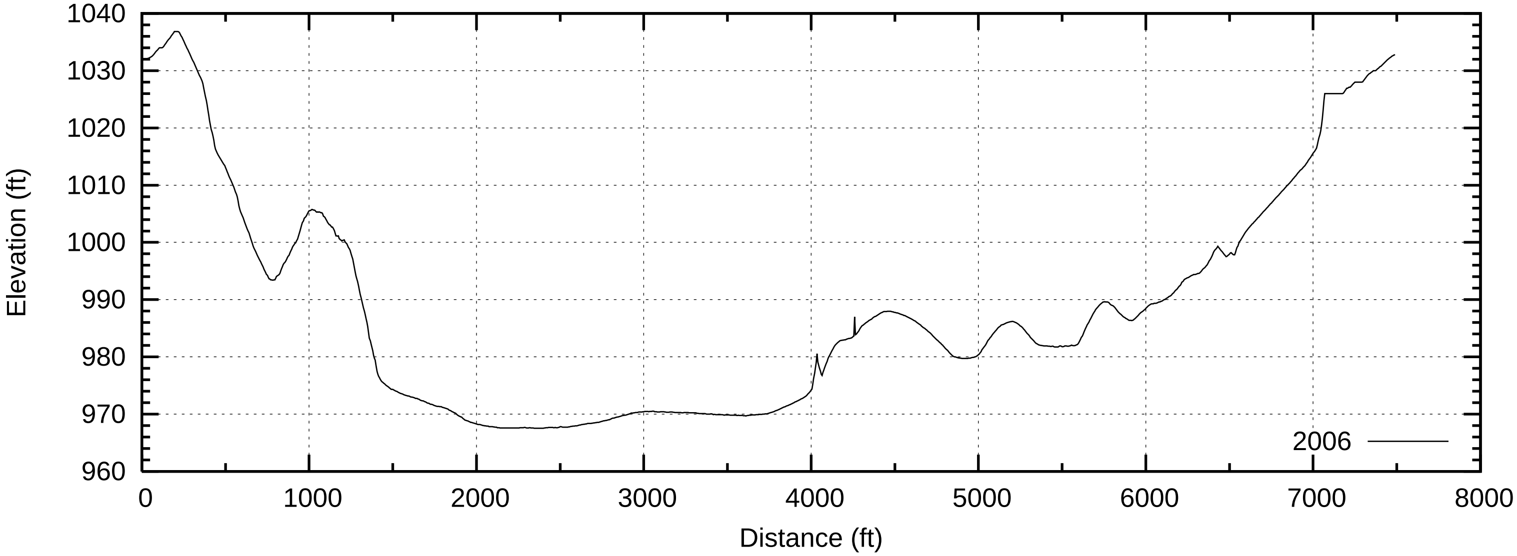



# Lake Buchanan

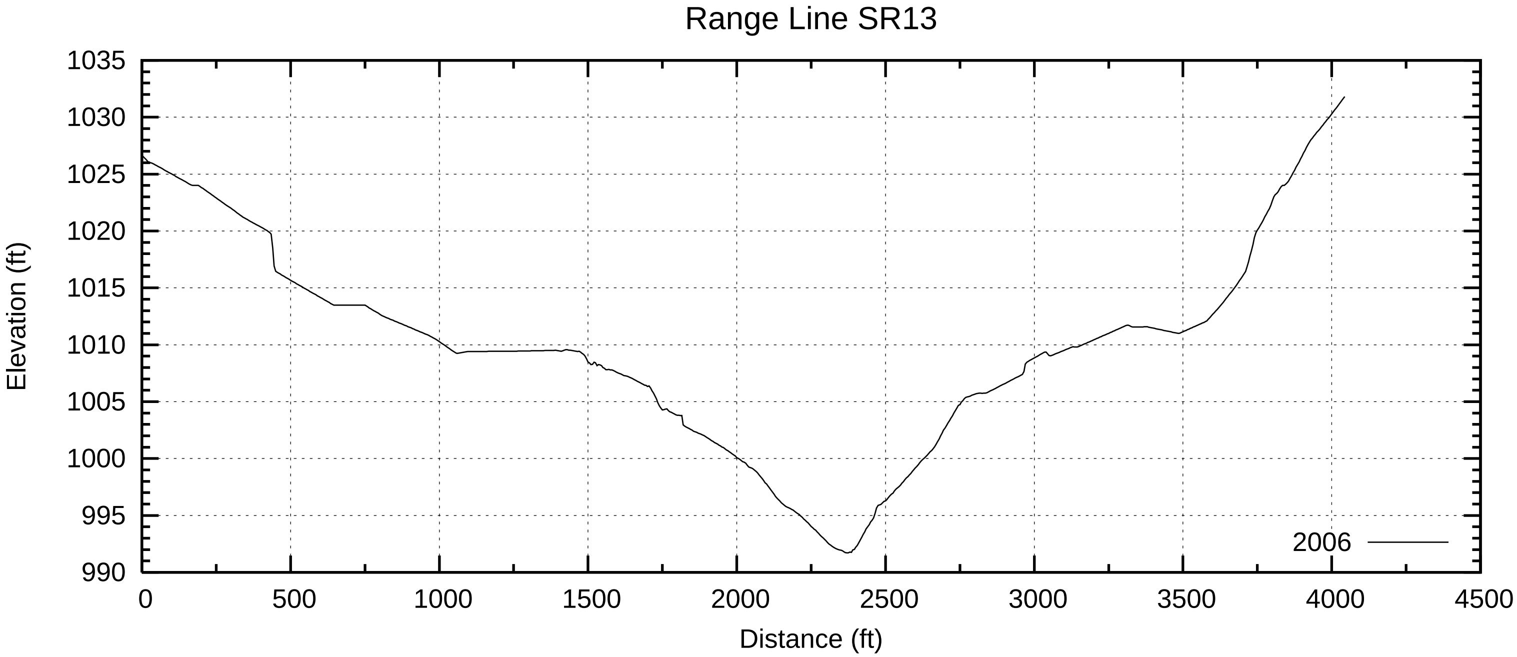
Range Line SR11

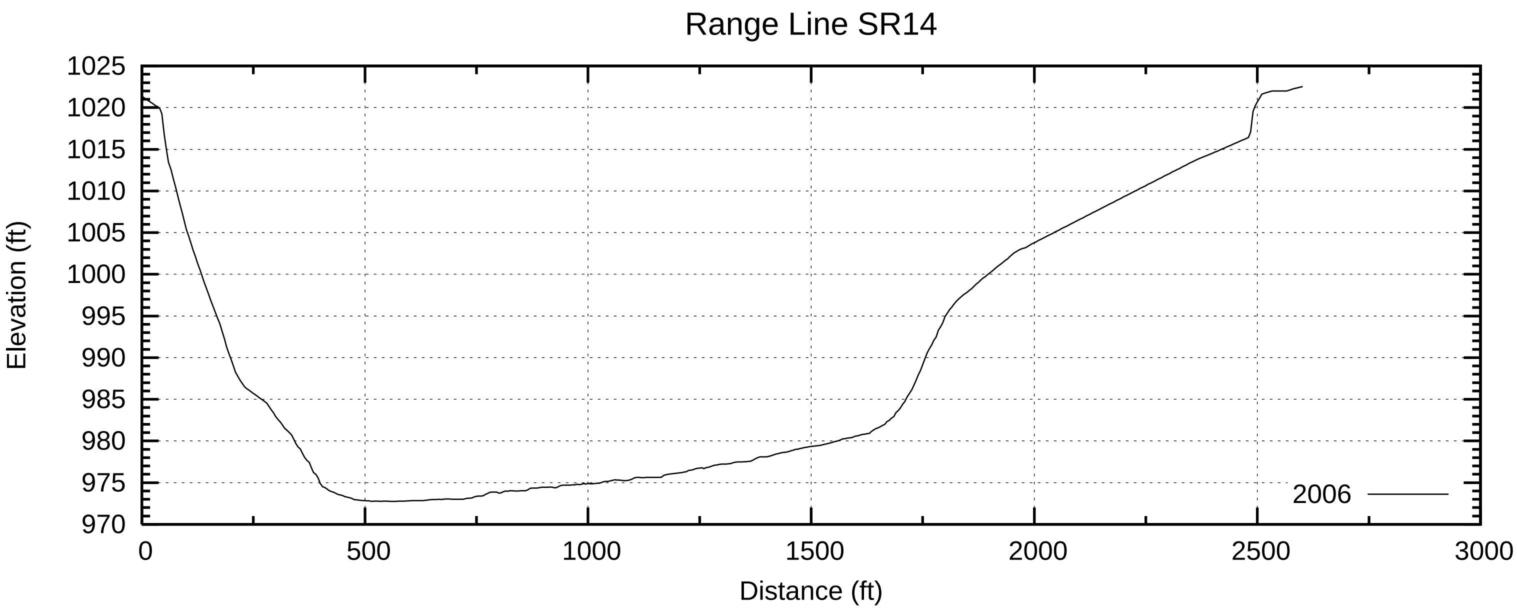



Range Line SR12

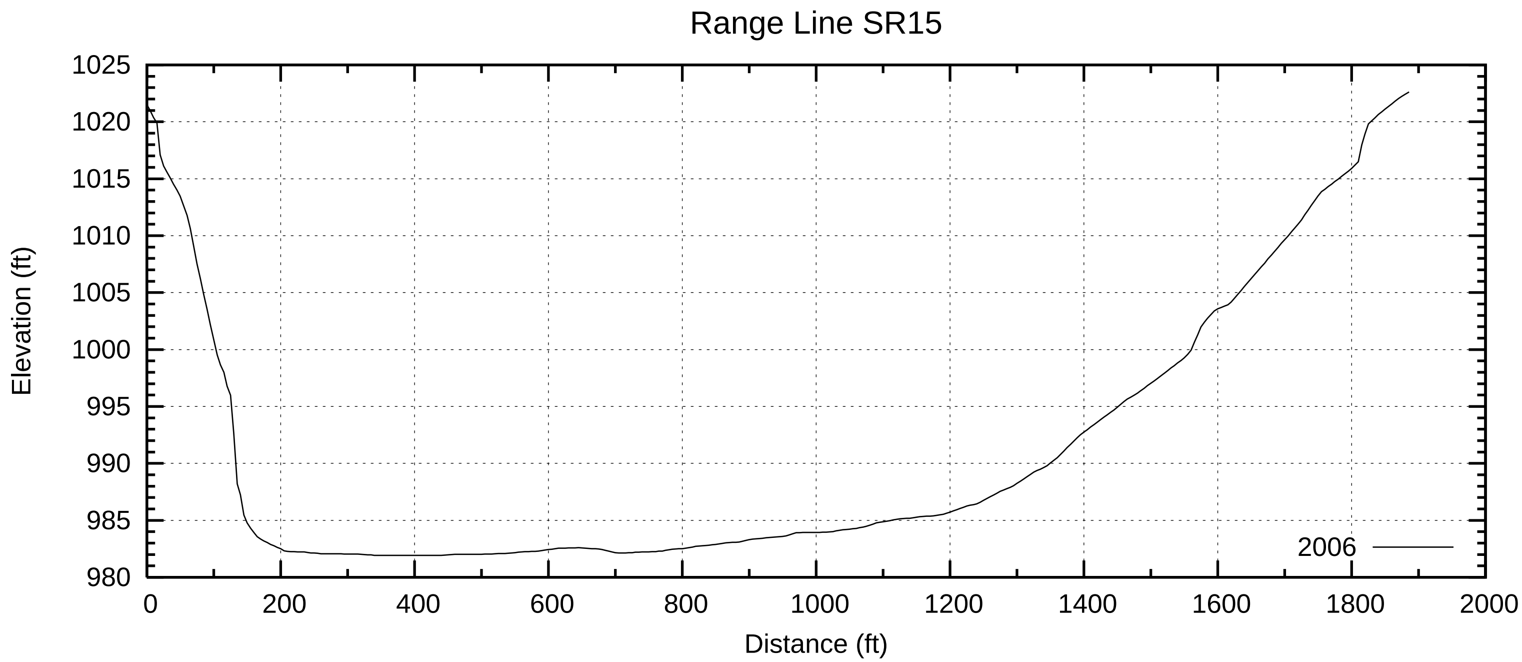


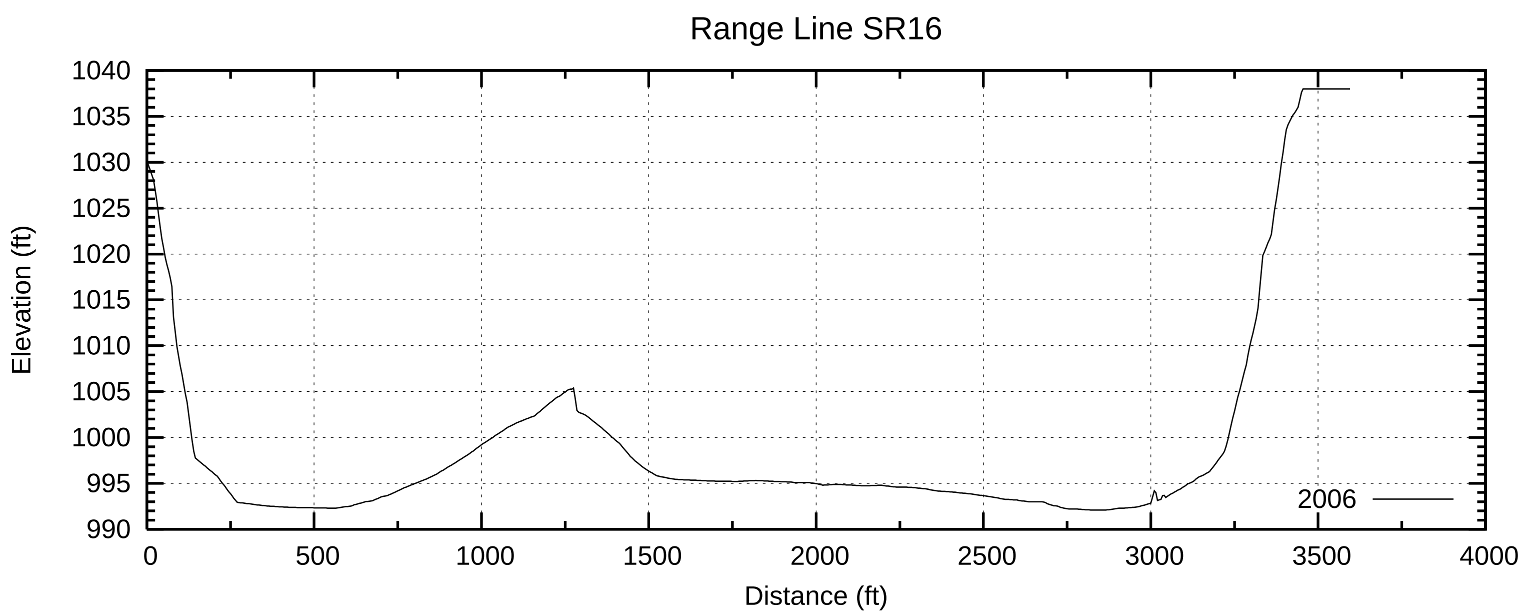
# Lake Buchanan



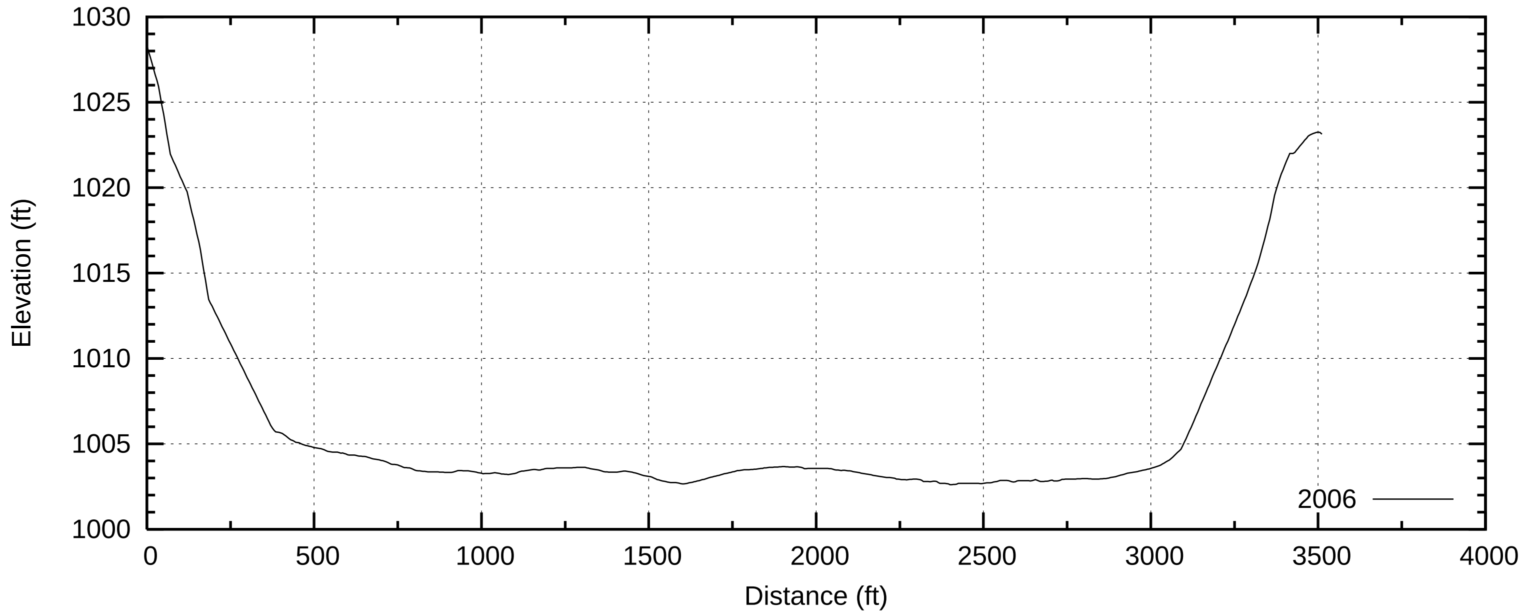
# Lake Buchanan



# Lake Buchanan

## Range Line SR17

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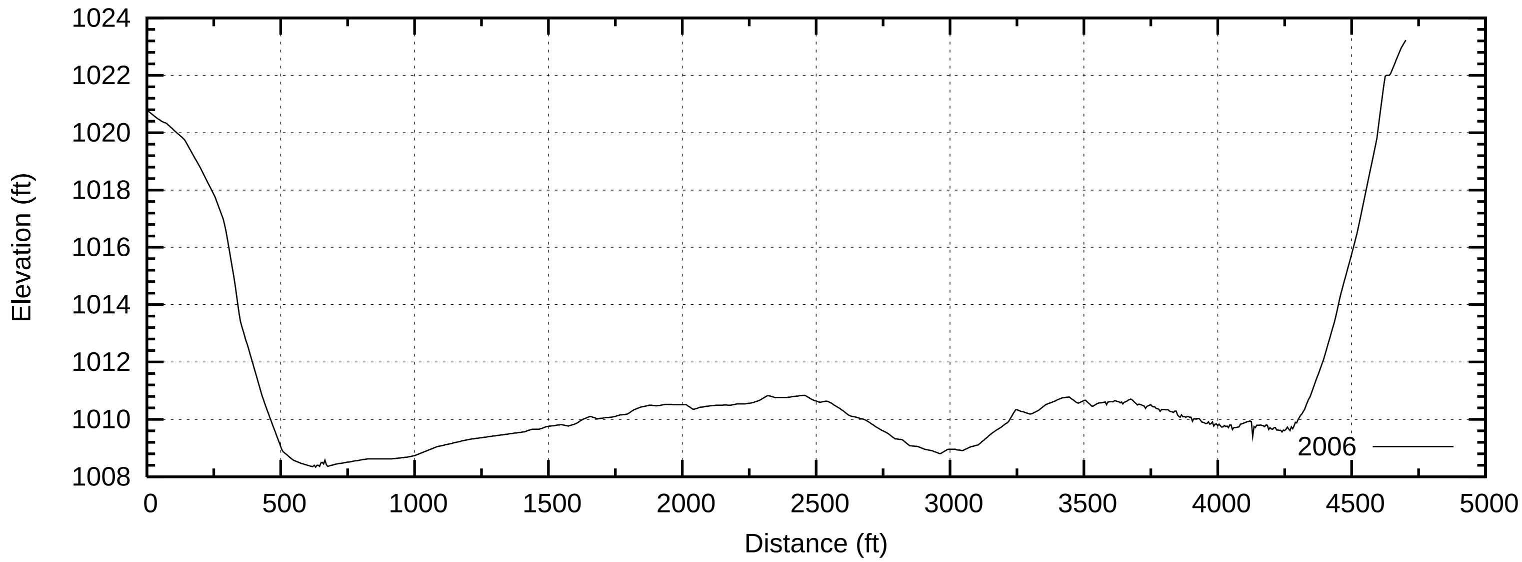
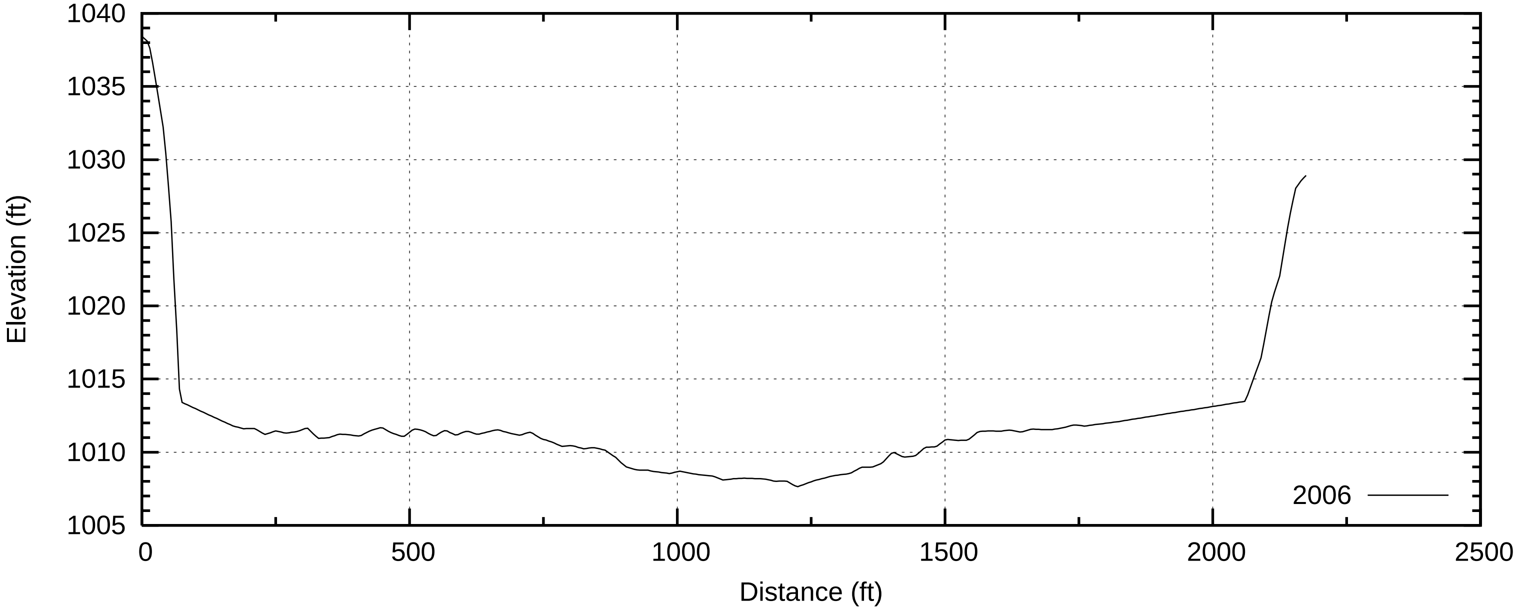
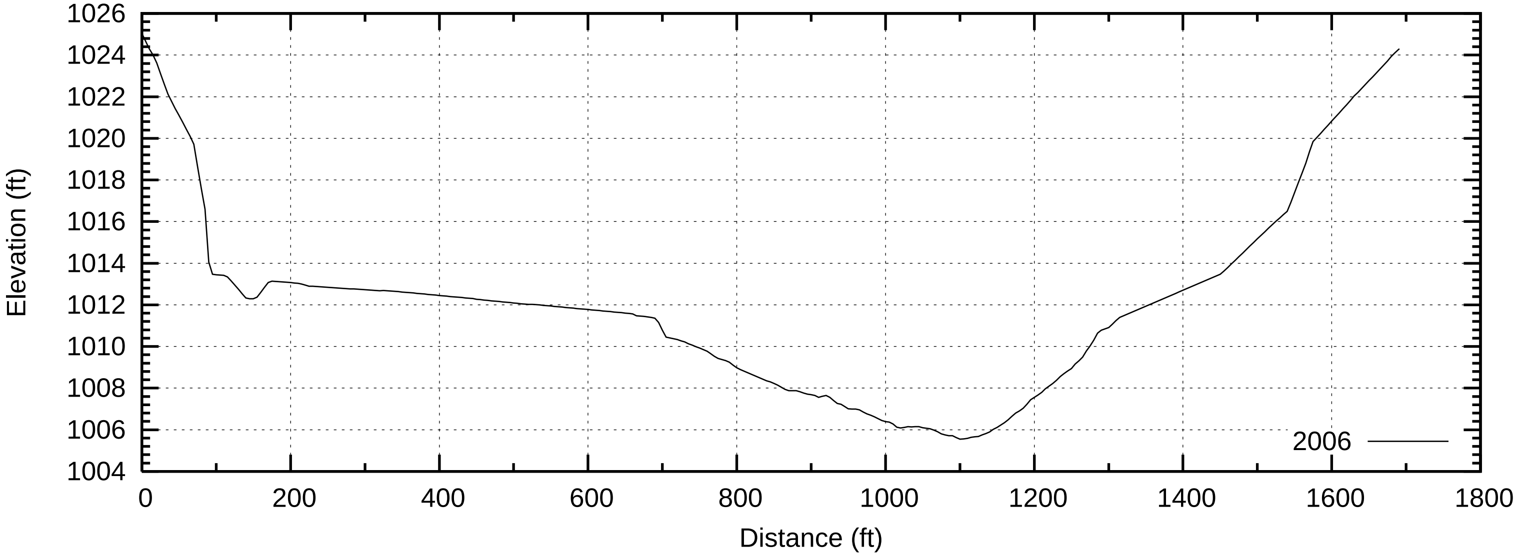


# Lake Buchanan

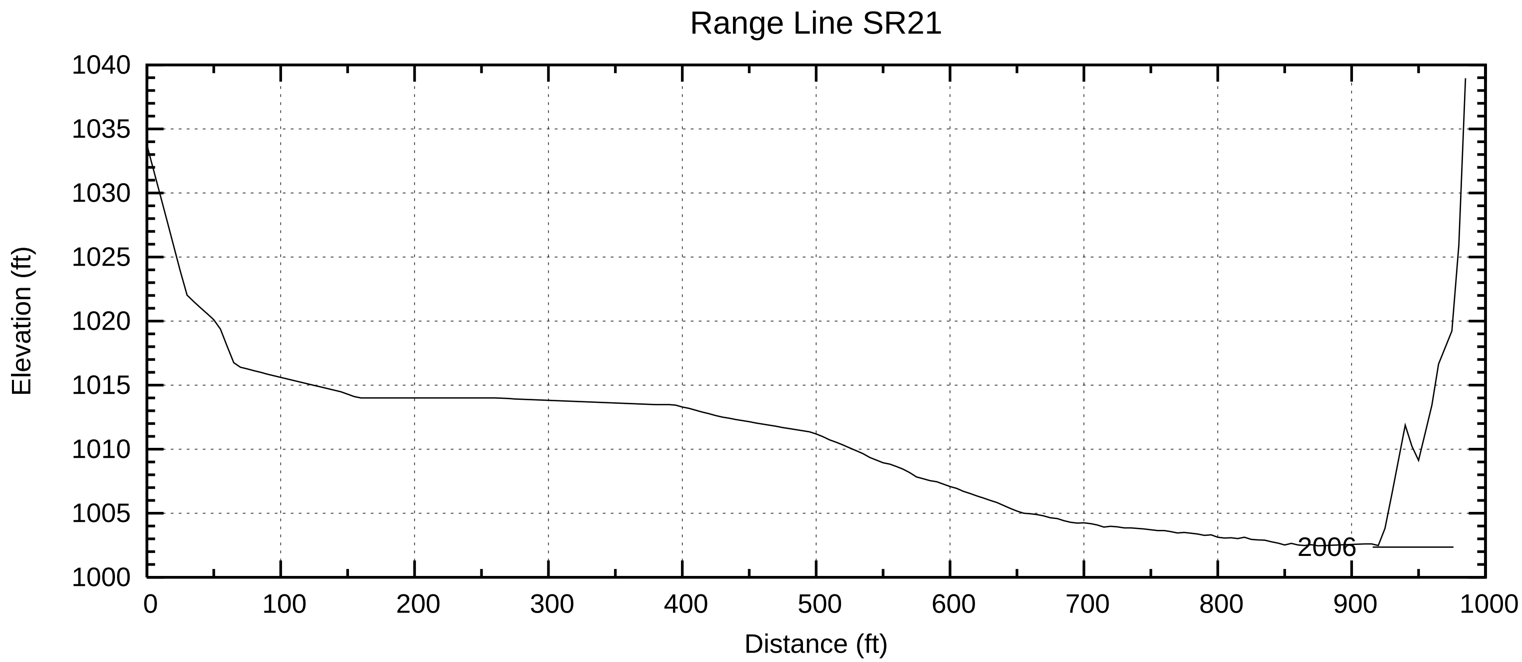
Range Line SR19

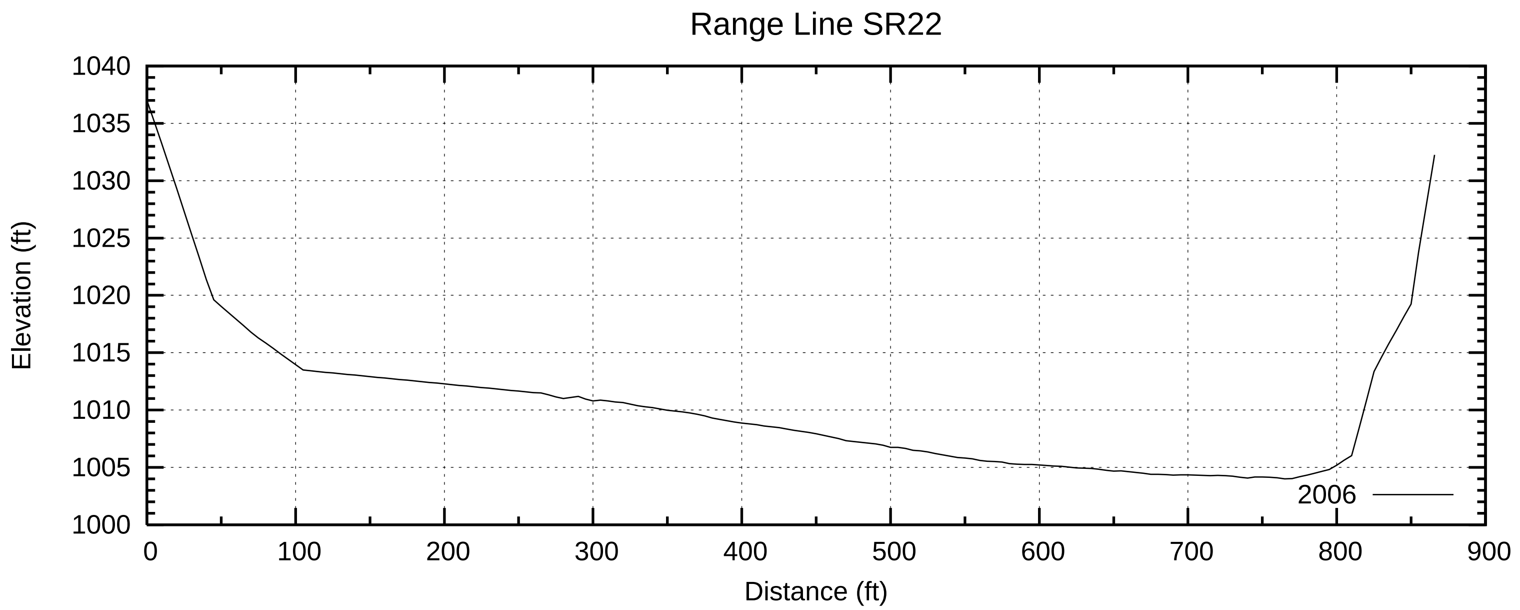



Range Line SR20



# Lake Buchanan

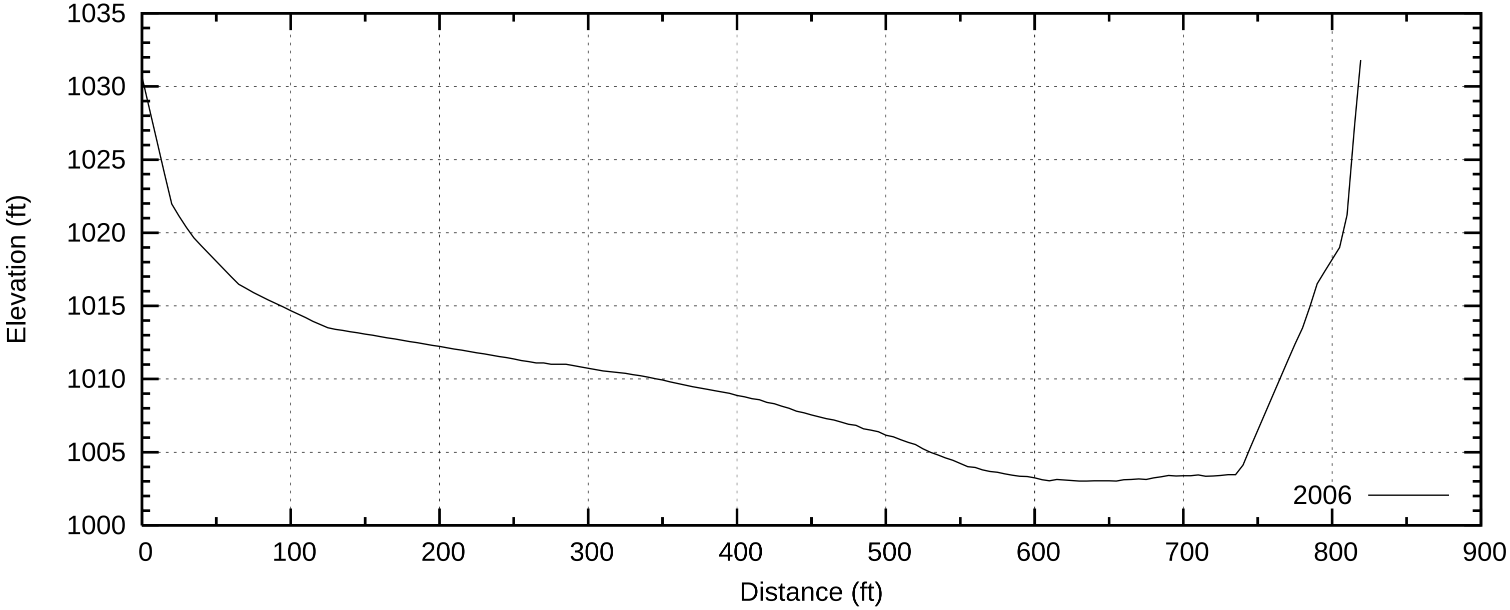


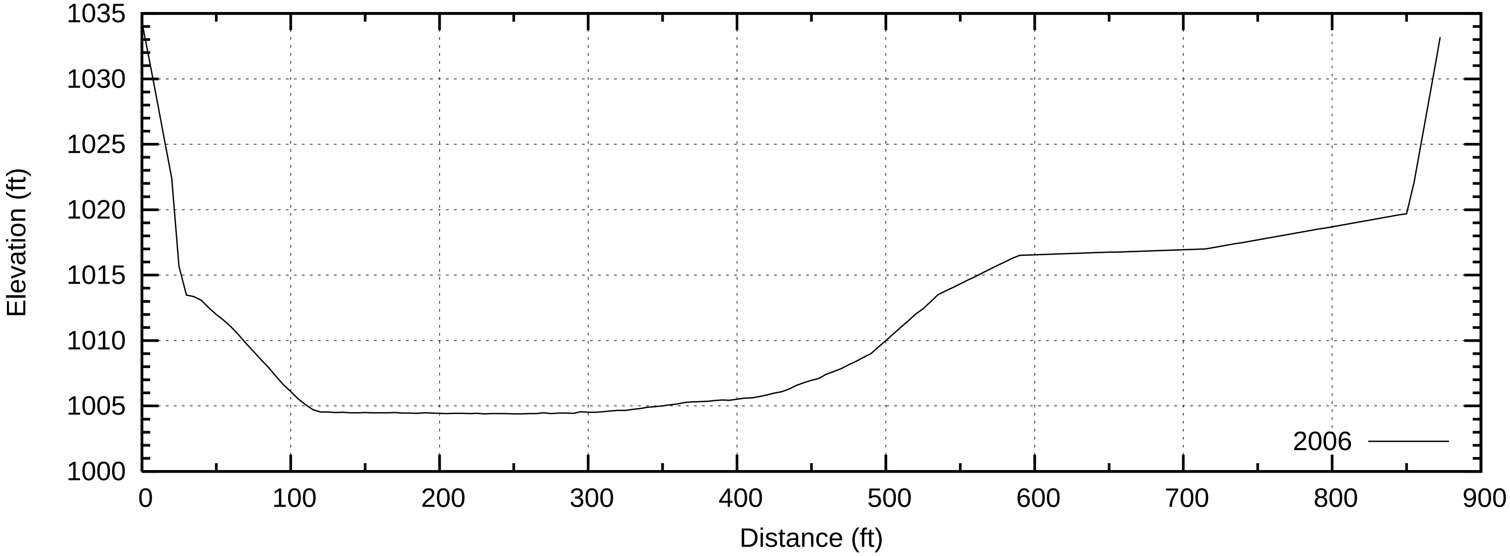

Appendix E

# Lake Buchanan

Range Line SR23

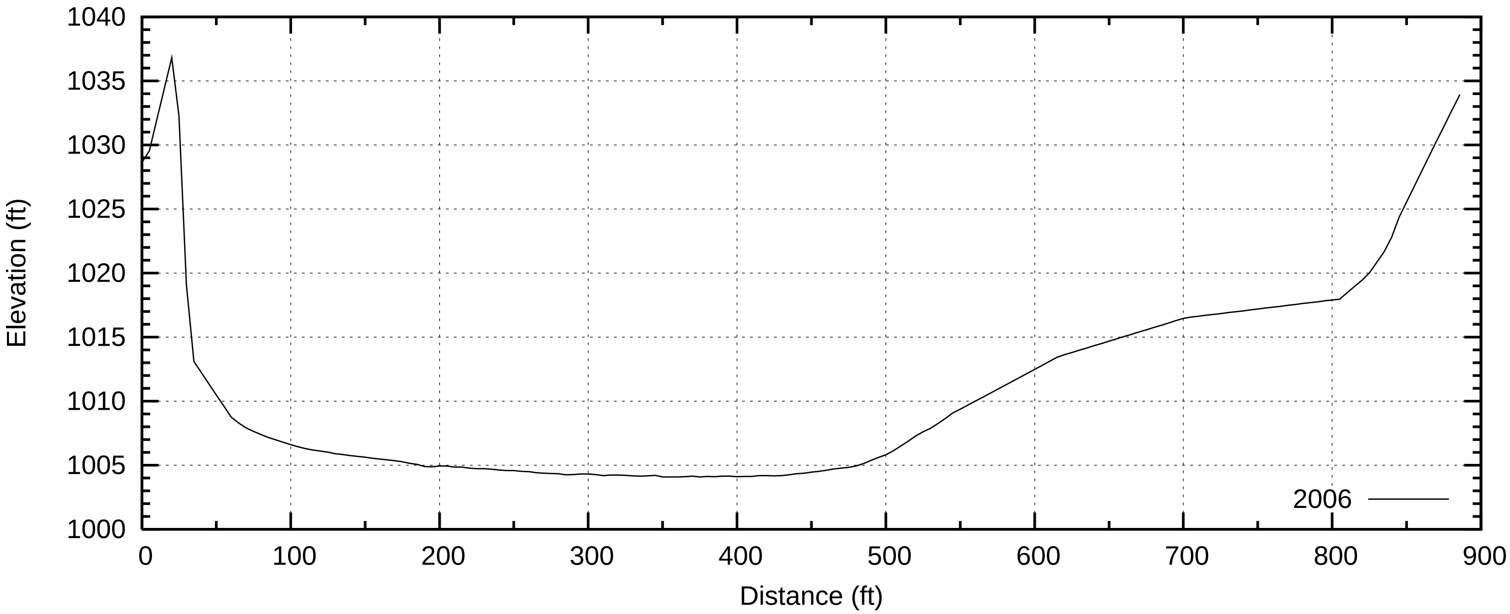



Range Line SR24

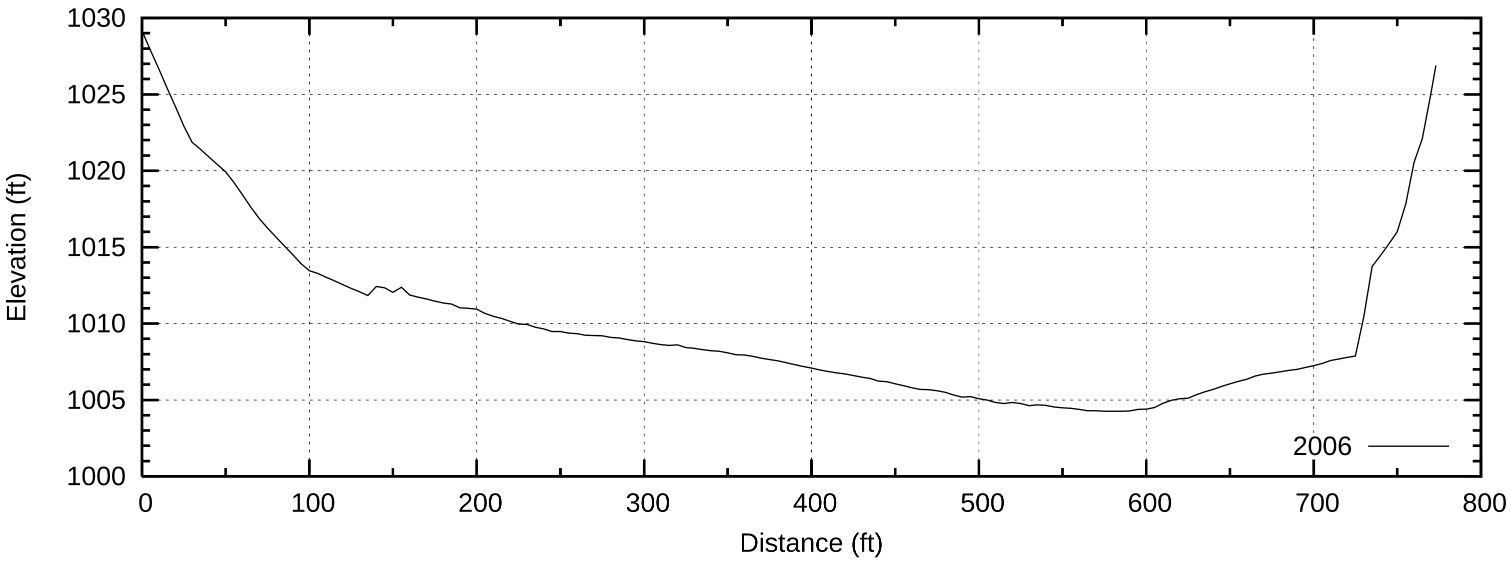


# Lake Buchanan

## Range Line SR25



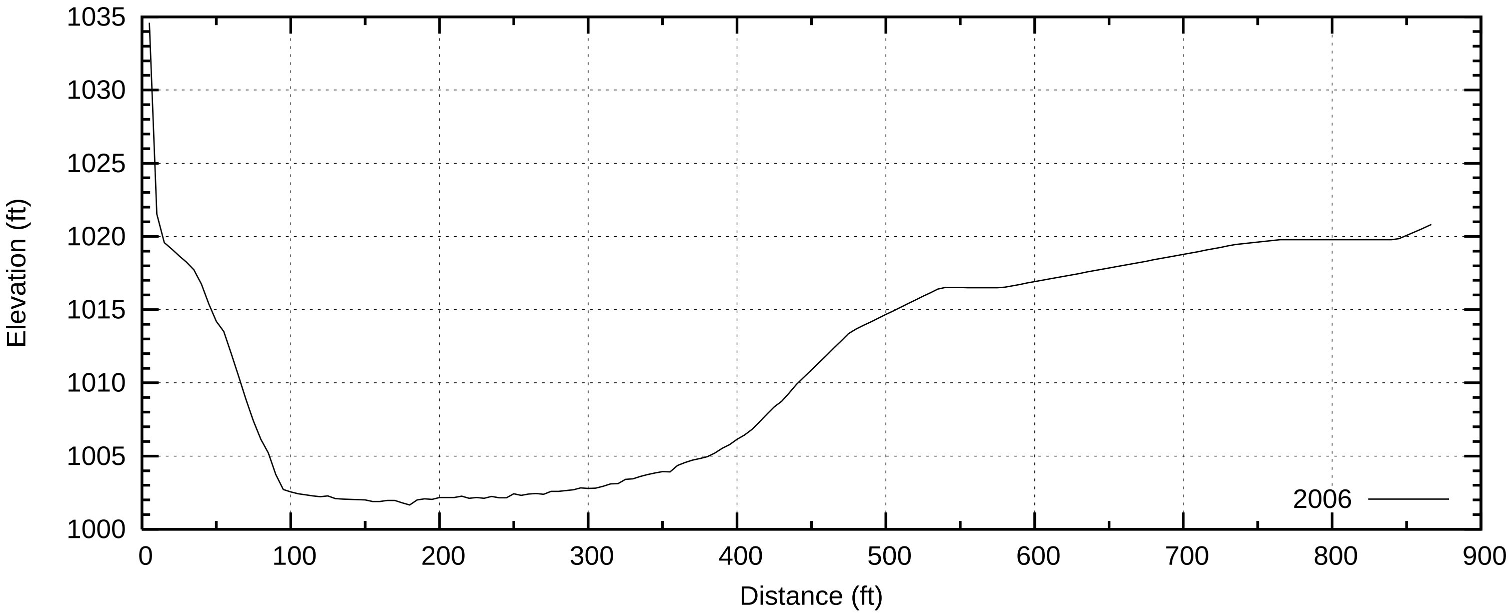

## Range Line SR26



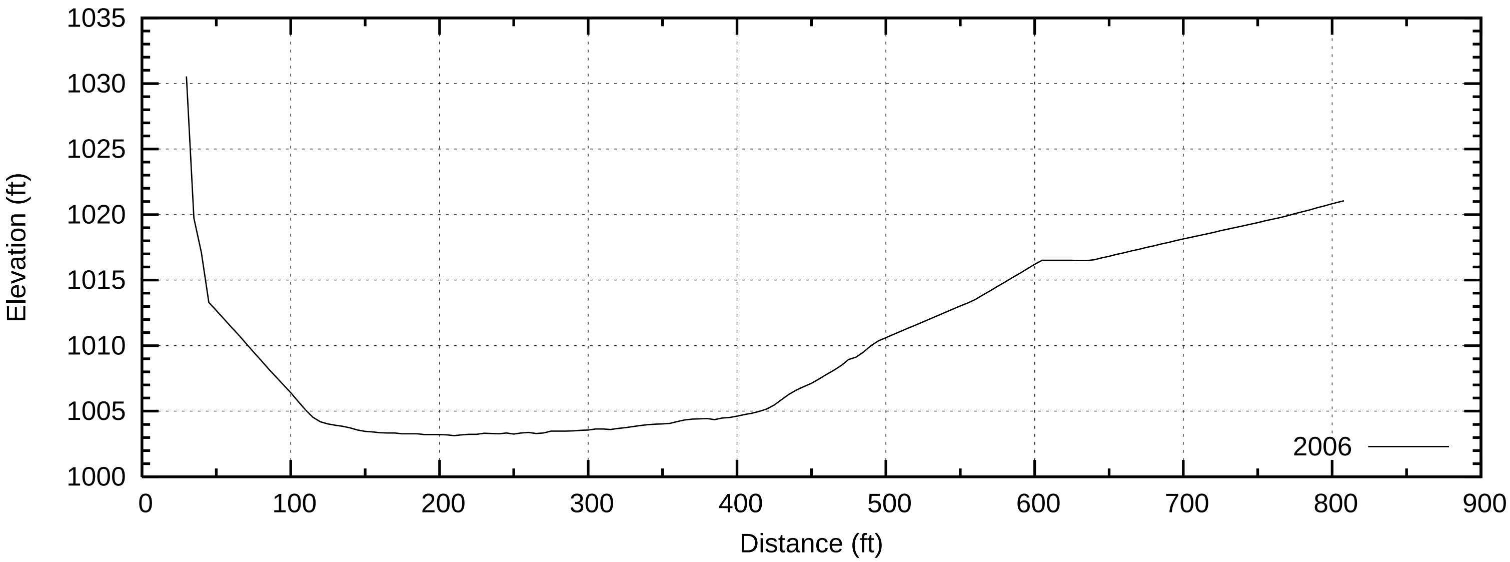

Appendix E

# Lake Buchanan

Range Line SR27



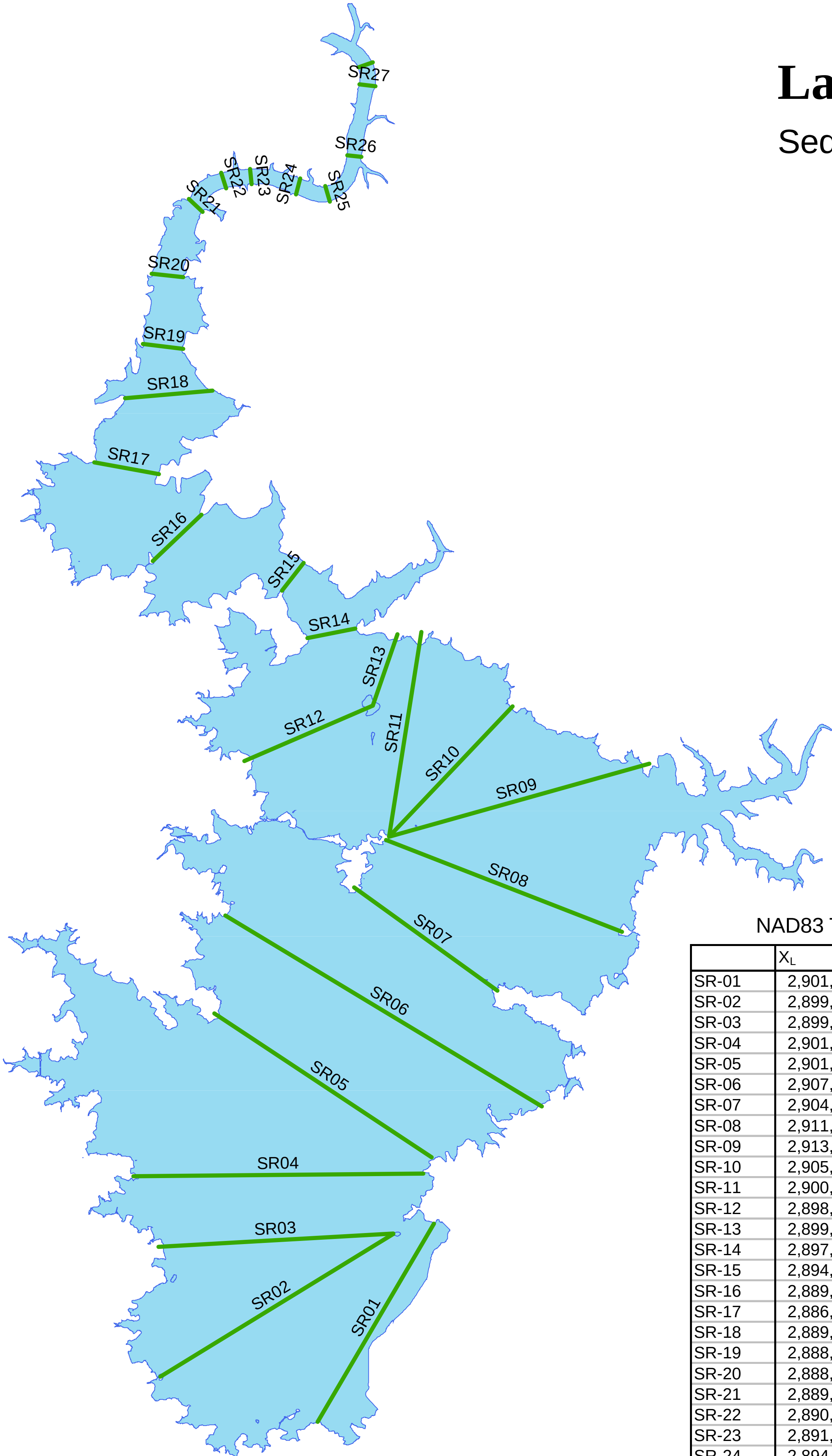

Range Line SR28



# Appendix F

# Lake Buchanan

## Sediment Range Lines




Endpoint Coordinates
NAD83 Texas State Plane Central Zone

| | $X_L$ | $Y_L$ | $X_R$ | $Y_R$ |
|---|---|---|---|---|
| SR-01 | 2,901,565 | 10,249,912 | 2,895,356 | 10,239,303 |
| SR-02 | 2,899,405 | 10,249,377 | 2,886,946 | 10,241,731 |
| SR-03 | 2,899,405 | 10,249,386 | 2,886,846 | 10,248,675 |
| SR-04 | 2,901,000 | 10,252,608 | 2,885,503 | 10,252,455 |
| SR-05 | 2,901,456 | 10,253,472 | 2,889,832 | 10,261,166 |
| SR-06 | 2,907,353 | 10,256,200 | 2,890,427 | 10,266,421 |
| SR-07 | 2,904,965 | 10,262,386 | 2,897,313 | 10,267,911 |
| SR-08 | 2,911,629 | 10,265,548 | 2,899,011 | 10,270,454 |
| SR-09 | 2,913,096 | 10,274,547 | 2,899,199 | 10,270,640 |
| SR-10 | 2,905,790 | 10,277,609 | 2,899,182 | 10,270,645 |
| SR-11 | 2,900,907 | 10,281,586 | 2,899,176 | 10,270,652 |
| SR-12 | 2,898,311 | 10,277,647 | 2,891,431 | 10,274,687 |
| SR-13 | 2,899,625 | 10,281,470 | 2,898,311 | 10,277,646 |
| SR-14 | 2,897,369 | 10,281,771 | 2,894,817 | 10,281,265 |
| SR-15 | 2,894,613 | 10,285,289 | 2,893,449 | 10,283,805 |
| SR-16 | 2,889,145 | 10,287,866 | 2,886,537 | 10,285,392 |
| SR-17 | 2,886,868 | 10,290,044 | 2,883,414 | 10,290,681 |
| SR-18 | 2,889,736 | 10,294,514 | 2,885,051 | 10,294,109 |
| SR-19 | 2,888,170 | 10,296,759 | 2,886,010 | 10,297,012 |
| SR-20 | 2,888,161 | 10,300,601 | 2,886,480 | 10,300,780 |
| SR-21 | 2,889,200 | 10,304,078 | 2,888,464 | 10,304,773 |
| SR-22 | 2,890,458 | 10,305,344 | 2,890,195 | 10,306,169 |
| SR-23 | 2,891,832 | 10,305,572 | 2,891,751 | 10,306,387 |
| SR-24 | 2,894,200 | 10,305,022 | 2,894,420 | 10,305,866 |
| SR-25 | 2,896,014 | 10,304,626 | 2,895,755 | 10,305,473 |
| SR-26 | 2,897,701 | 10,307,030 | 2,896,934 | 10,307,121 |
| SR-27 | 2,898,455 | 10,310,806 | 2,897,595 | 10,310,917 |
| SR-28 | 2,898,313 | 10,312,089 | 2,897,550 | 10,311,824 |

**Appendix G**

Findings of Multi-frequency data collection at Lake Buchanan

March 10, 2006 to April 10, 2006

## Executive Summary

The measured sediment volume in Lake Buchanan is 34,275 acre-ft, although this is likely an under-estimate of the actual sediment volume. Rudimentary error estimates suggest that the actual sediment volume in Lake Buchanan may be up to 5% above or below the measured sediment volume. Due to shallow water conditions, TWDB was unable to fully survey the entire lake using the multi-frequency depth-sounder needed for sediment analyses. Also, interpretation of multi-frequency sounding data is difficult in areas where frequent wetting/drying occur, such as in Lake Buchanan upstream of the Silver Creek confluence. Based on analyses with available cross-section data from 1991, little sedimentation seems to have occurred in the upper reaches of Lake Buchanan since that time. Sedimentation rates in Lake Buchanan are likely to have declined since the time of impoundment due to land use changes and the construction of upstream reservoirs. To better assess sedimentation in Lake Buchanan, a complete re-survey of the lake is suggested in 5-10 years or after 3 to 4 major flood events (similar to the flood events in the summer of 2007). Any re-survey should occur at a time when the water level is at or above the conservation pool elevation.

## Introduction

This appendix includes the results of the sediment investigation using multi-frequency depth sounder data collected during the period March 10, 2006 to April 10, 2006 by the Texas Water Development Board (Board). On August 26, 2006 John Dunbar Geophysical Consulting (JDGC), a subcontractor of the Board, collected six core samples of the impoundment bottom throughout the reservoir. The samples were used to correlate the multi-frequency signal return to sediment thickness. The JDGC report in Appendix H describes the coring process and interpretation of each sample. The following discussion presents the sedimentation results from analysis of the core samples and multi-frequency sounding data.

## Results

The total estimated volume of sediment measured during the survey ranges from 34,128 ac-ft to 34,421 ac-ft. The range of values is a result of the two different methods used to calculate sediment volume:

1) Subtracting the Present Surface Volume from the Pre-Impoundment Surface Volume, and
2) Computing a sediment thickness surface and volume

In theory, the results from each method should be identical. In practice, however, each method involves sediment volume determinations over different spatial scales, and the summations over all scales affect the computed sediment volumes. A small difference in volumes between the two methods, therefore, indicates that either method of sediment volume computation is valid and provides confidence in the TIN model representation of the sediment data.

For method #1, two separate TIN models were constructed from the multi-frequency data and data interpolated using the self-similar interpolation technique[1]. The first surface was a representation of the present bathymetric bottom of the reservoir, and the second surface was an estimated pre-impoundment bottom derived from analyses of the multi-frequency data and core samples (See Appendix H). Each TIN model was created using the elevation 1,013.5 ft as the TIN model boundary (This boundary was derived from 1995 aerial photographs and is the boundary to which the self-similar interpolation routine was applied). Reservoir volumes were computed for each TIN (at elevation 1,013.5 ft), and subtracting the volumes yielded a sediment volume estimate of 34,128 ac-ft.

For method #2, a TIN model was created based on sediment thickness data, assuming a 0-ft sediment thickness at the TIN model boundary (defined as the 1,013.5 ft elevation contour). Sediment thickness at each sounding location was computed as the difference between the current bathymetric surface and the pre-impoundment bathymetric surface (See Appendix H). Using the self-similar interpolation technique,[1] sediment thicknesses between measured survey lines were also computed. The sediment thickness TIN model, therefore, was created using the 1,013.5 ft boundary (assigned a 0-ft thickness), and both the surveyed and interpolated thickness values. The effect of this would be to invert the reservoir and pile the sediment as if on a flat plane. From this TIN model, the volume of sediment was estimated to be 34,421 ac-ft. Figure G1 depicts the sediment thickness in Lake Buchanan up to the 1,013.5 ft contour elevation. The thickest sediment deposits occur in the upper portion of the reservoir and at confluences between tributaries and the main submerged Colorado River channel.

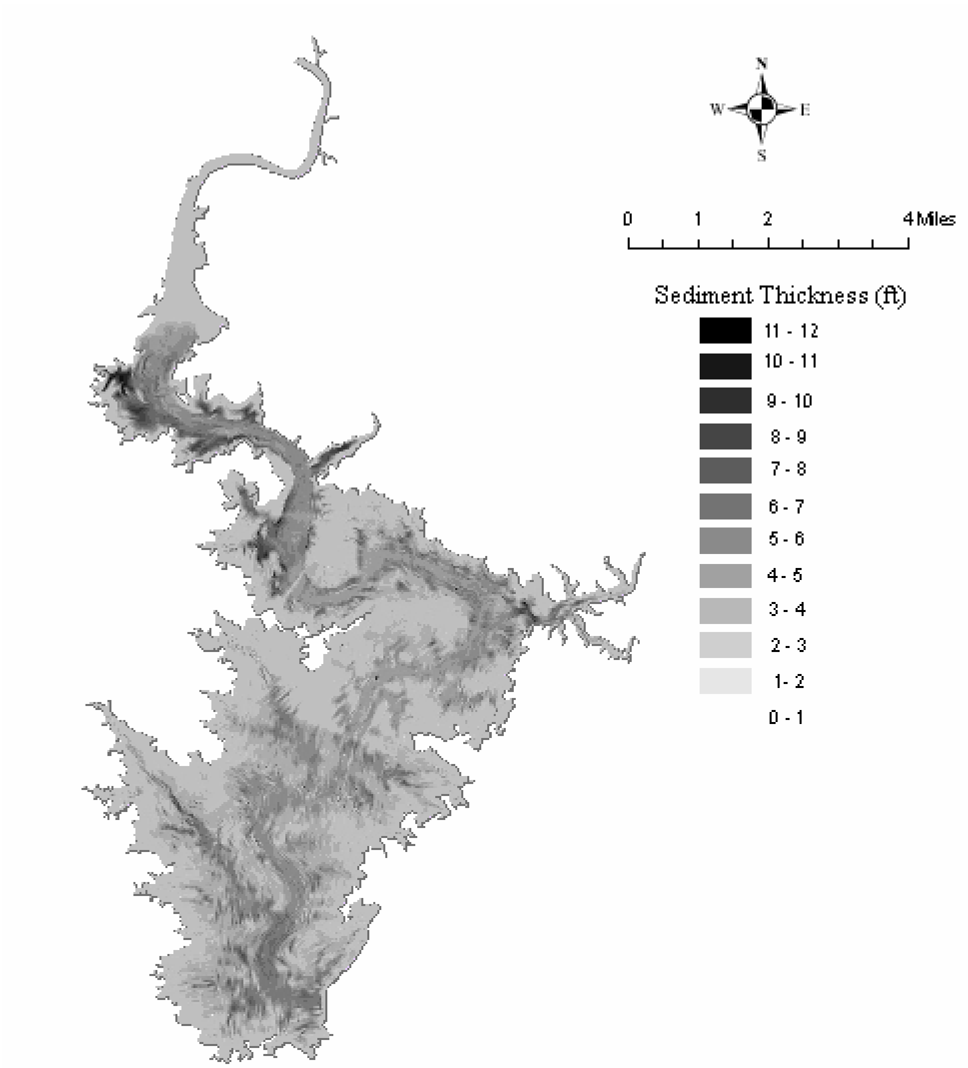



*Figure G1 - Sediment Thicknesses in Lake Buchanan derived from multi-frequency sounding data up to the 1,013.5 ft elevation.*

In comparing the sediment volume results from each method, there is a 293 acre-ft volume difference, which is 0.8% of the averaged volume computed from both methods. As a final reported sediment volume, the average of the results from methods #1 and #2 is used:

Measured Sediment Volume for Lake Buchanan: **34,275 acre-ft**

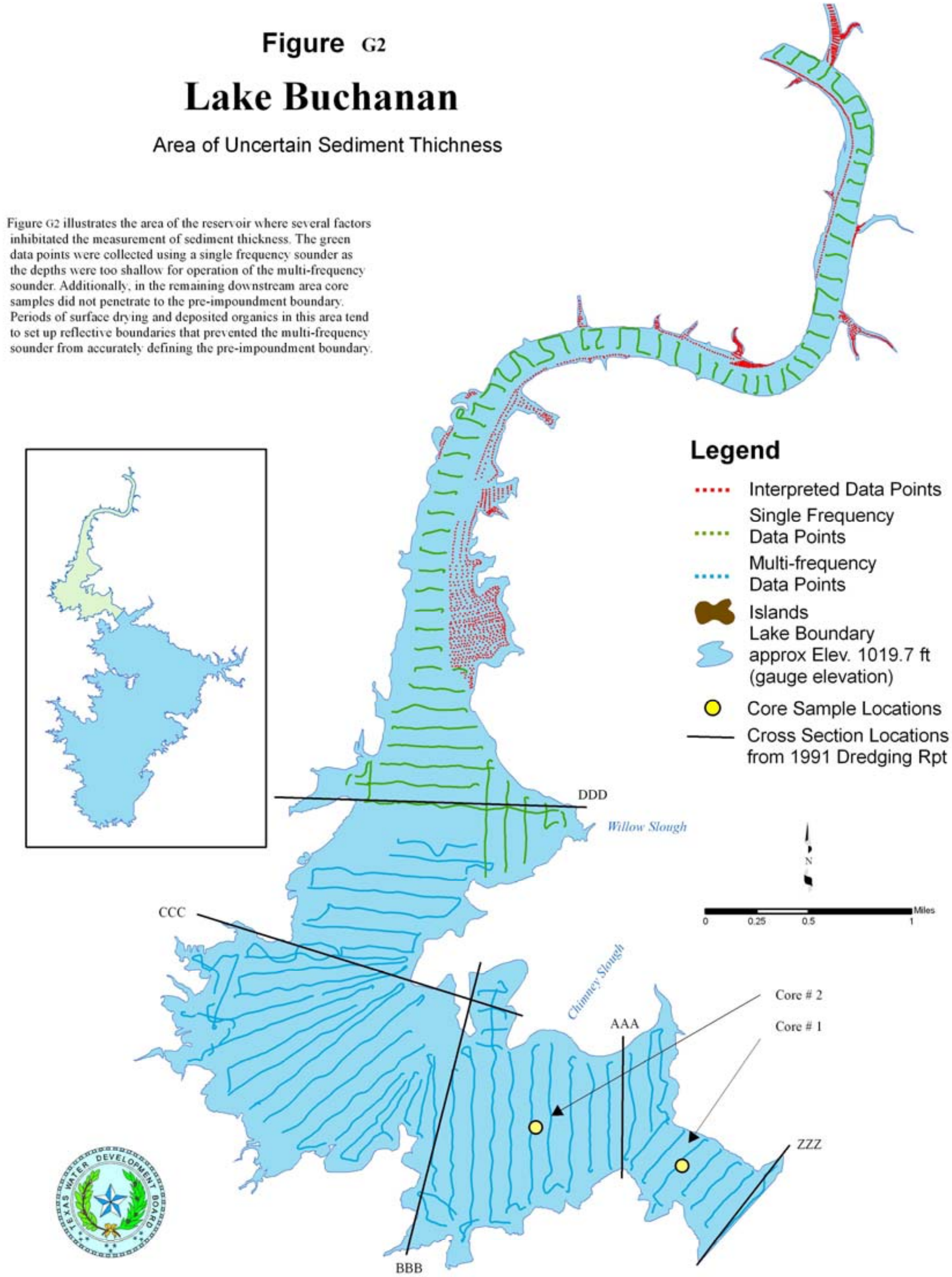
## Discussion

The results presented above are likely to be underestimates of the total sediment volume in Lake Buchanan, due to the limitations experienced during the data collection process. In this section, these limitations are described and their impact on the sediment volume computations is assessed.

Upon comparing historical[2] elevation measurements, core samples (See Appendix H), and measured data from this survey, it is evident that the pre-impoundment surface in the upper reaches of the reservoir was not well identified. For all areas just upstream of Silver Creek (where the reservoir widens near Chimney Slough – See Figure G2), the shallow water conditions during data collection impeded the multi-frequency depth sounder's ability to fully penetrate the sediment layers. The data collected in this area, however, also suggests that the existing sediment (which may be thick) is interlaced with reflective layers that interfere with the depth sounder pulses and make interpretation of the data extremely difficult.

The shallow nature of the area upstream of Silver Creek causes the exposure of the reservoir bottom to the atmosphere during times when the reservoir water elevation is low. During times of such exposure, the bottom dries and hardens. With subsequent storm events organics are heavily deposited on these hard layers, and when these organics are covered by more sediment (during times of higher water surface elevations), the gasses in the decomposing organic material becomes trapped within the sediment layers. The result of this continual wetting/drying process is that the density of the sediment becomes highly variable in the vertical direction. This density stratification in the sediment layers causes numerous reflections of the multi-frequency depth sounder signals, and ultimately scatters and attenuates the acoustic return signal[3]. Additionally, the intermittent drying of the surface may also yield the presence of intermittent layers of organic material within the core samples. Such intermittent organic layers in the core samples often makes it difficult to identify the pre-impoundment surface. Therefore, due to the intermittent wetting/drying of the area upstream of Silver Creek, sediment interpretations based on core samples and multi-frequency data are unlikely to be made with high-confidence.

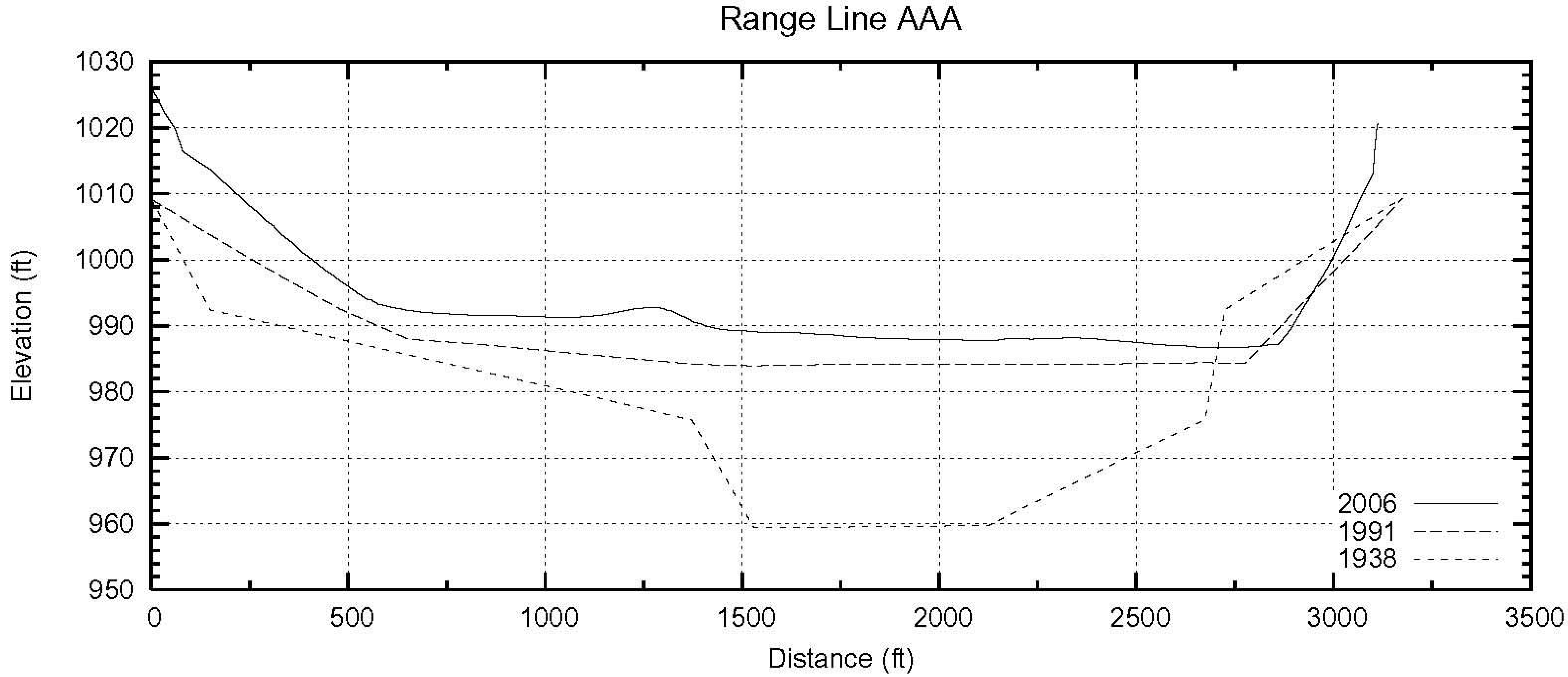
Sediment estimates are also likely to be low because the most upstream portion of Lake Buchanan was unsurveyable with the multi-frequency depth sounder during the time of the data collection. The multi-frequency depth sounder data is unreliable when used in areas where the water depth is generally less than 4 ft. As such, only the single-beam depth sounder was used in data collection efforts upstream of Willow Slough (Figure G2). Therefore any sediment that might exist in this area was not included in the sediment volume estimates provided above.




While estimating sediment accumulation within the upper reaches proved difficult, further analyses were conducted to qualitatively estimate the rate at which sediment might be expected to be entering of Lake Buchanan. To investigate recent sedimentation rates, cross sections (See Figure G2 for locations) derived from the present surface TIN model were compared with cross-sections from the 1991 Lake Buchanan Dredging Feasibility Analysis[2]. The Feasibility Analysis report[4] describes these cross-sections as being extracted or developed from a LCRA 1991 5-ft contour map and a 1938 20-ft contour map of the lake bottom.[2] The report also assumes that each map meets the National Mapping Accuracy Standard[4] for vertical accuracy of one-half the contour interval, therefore elevations in the 1991 cross-sections are +/- 2.5 ft while elevations in the 1938 cross-sections are +/- 10 ft. Theses plots are presented in Figures G3, G4, and G5 and appear to indicate no significant sedimentation occurring in this area of the reservoir since 1991. The 1938 data is ignored given the uncertainty in the vertical datum uses and the potentially large error in elevations relative to the shallow depths.

Factors affecting the sedimentation rates in Lake Buchanan are the introduction of dams into the drainage basin and over time changes in land use and land cover. The total drainage area upstream of Lake Buchanan is over 20,000 $mi^2$. However, by digitizing the remaining unrestricted watershed using stream segments from the National Hydrography Dataset,[5] we can estimate that about 5,800 $mi^2$ remains unrestricted by major impoundment. Figure G6 illustrates the relatively small portion of the Lake Buchanan drainage basin remaining without any major impeding dam structures. Five major impoundments trap sediment before it enters Lake Buchanan. These impoundments are: O.H. Ivie Reservoir (built in 1989), O.C. Fisher Lake (built in 1951), Lake Nasworthy (built in 1930), Lake Brownwood (built in 1933), and Brady Creek Reservoir (built in 1963). There are an additional eleven reservoirs upstream of these five impoundments, with six of those eleven having been constructed after 1963. Additionally, the historic change in land use from tilled agricultural and row crops back to grassland or pasture peaked around the mid-20$^{th}$ century. The combination of all these factors has likely slowed the amount of sediment delivered to Lake Buchanan.

# Lake Buchanan



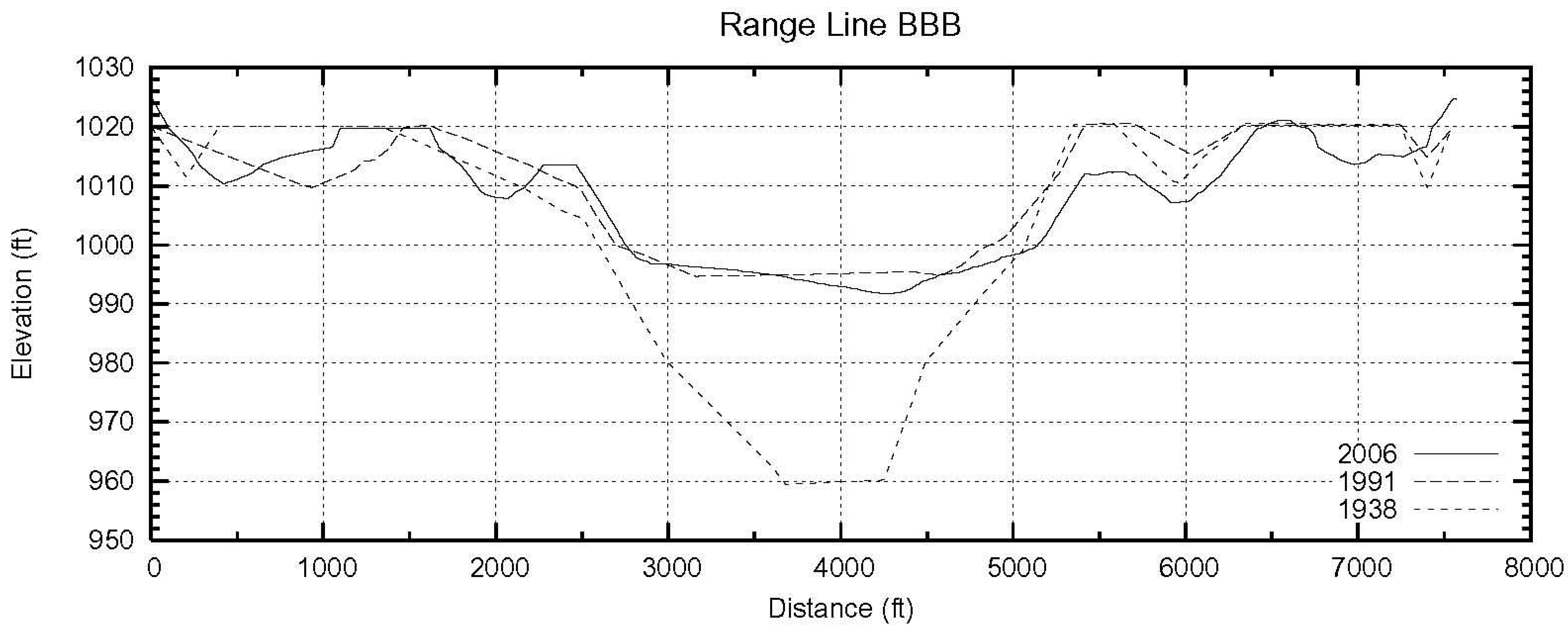
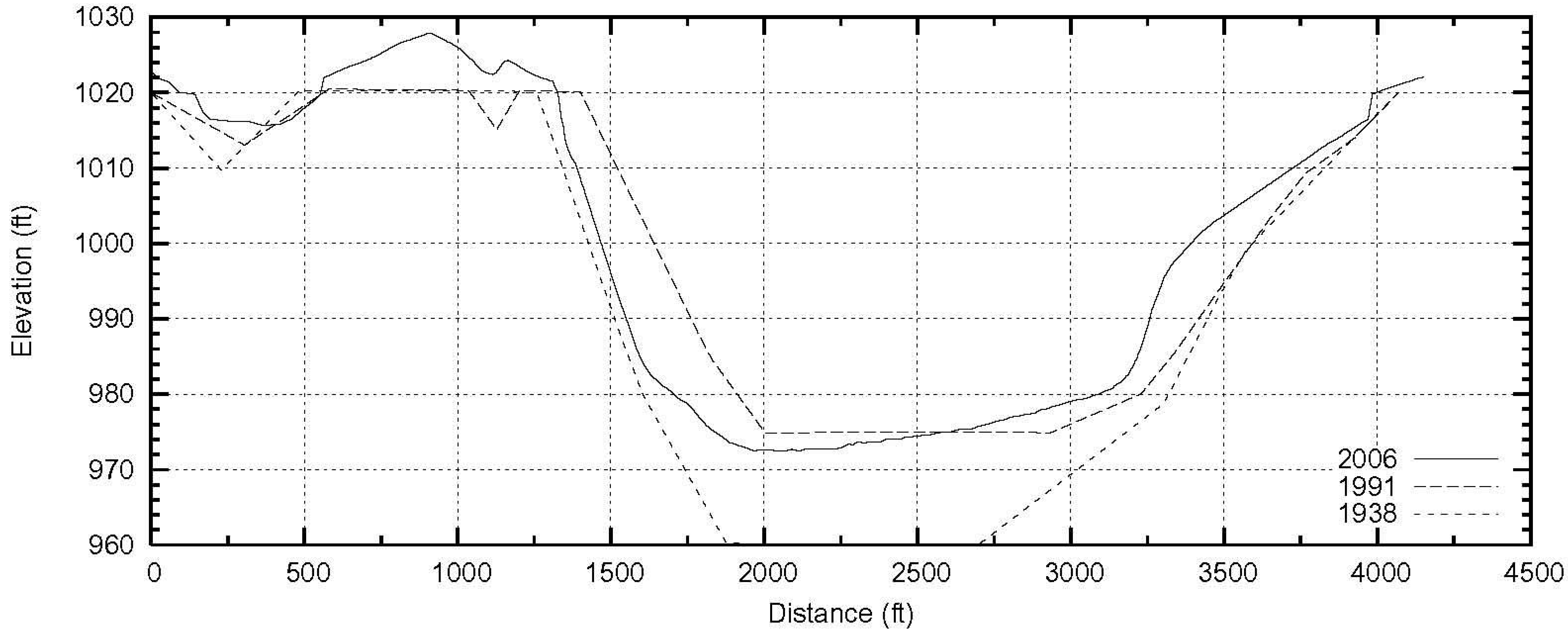




Figure G3

# Lake Buchanan

Range Line YYY




Range Line ZZZ

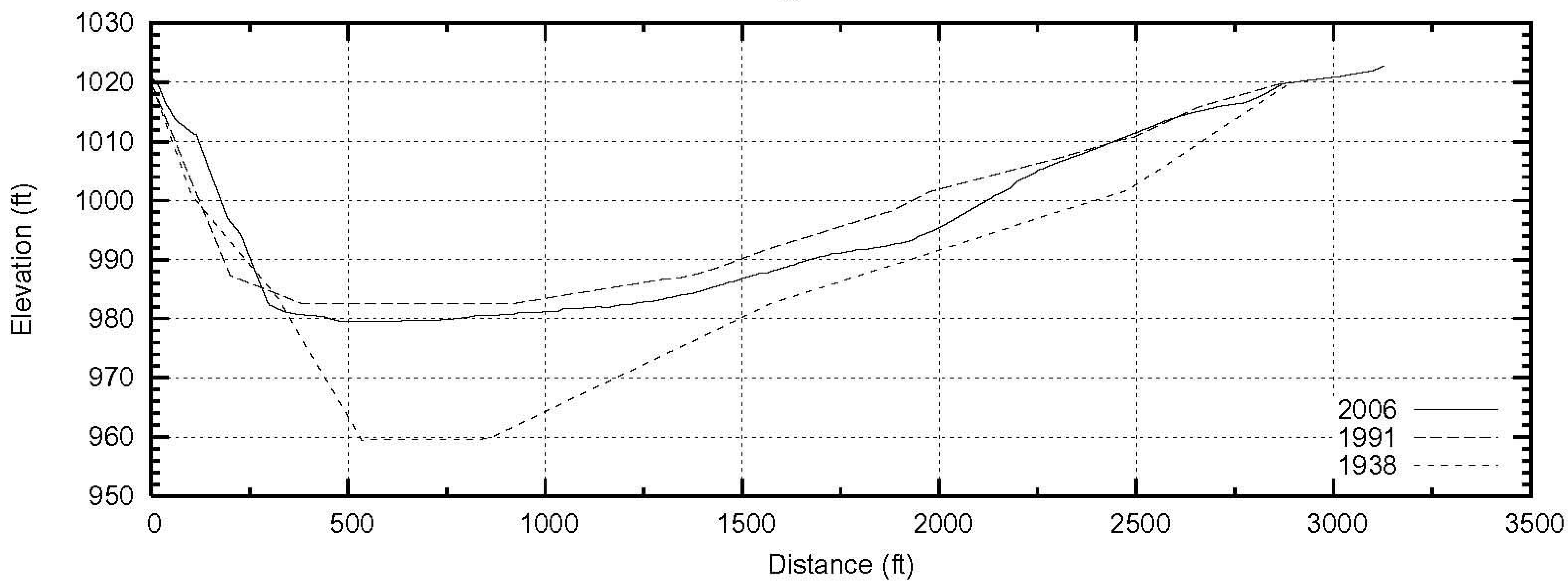
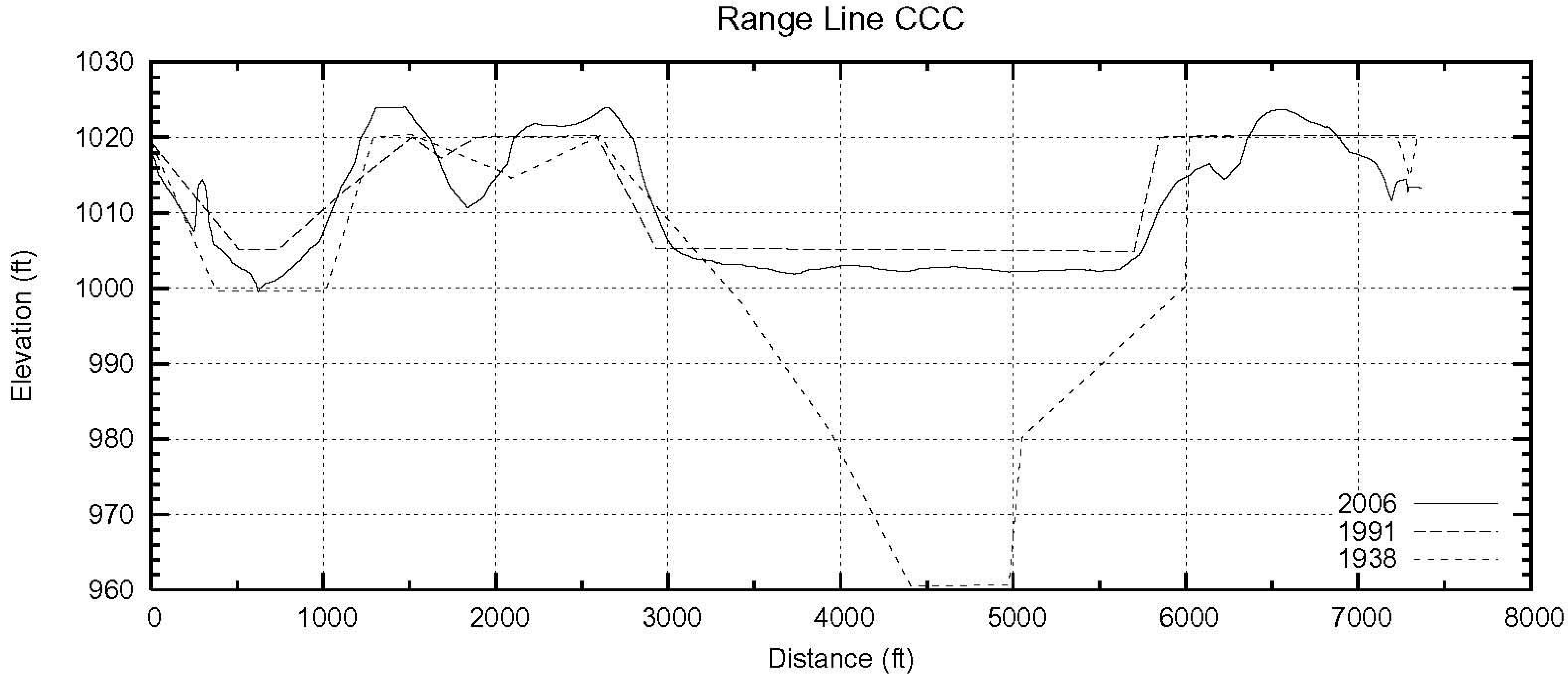



Figure G5

# Lake Buchanan



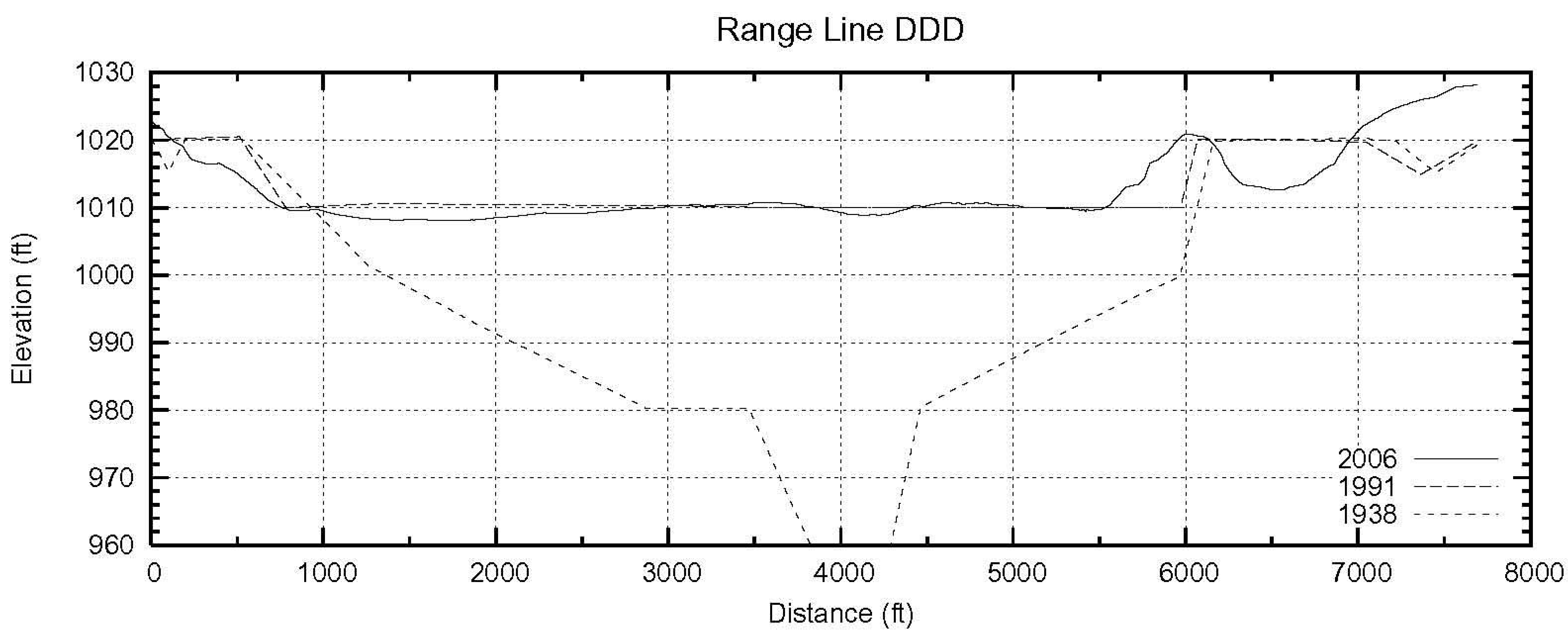




Figure G4

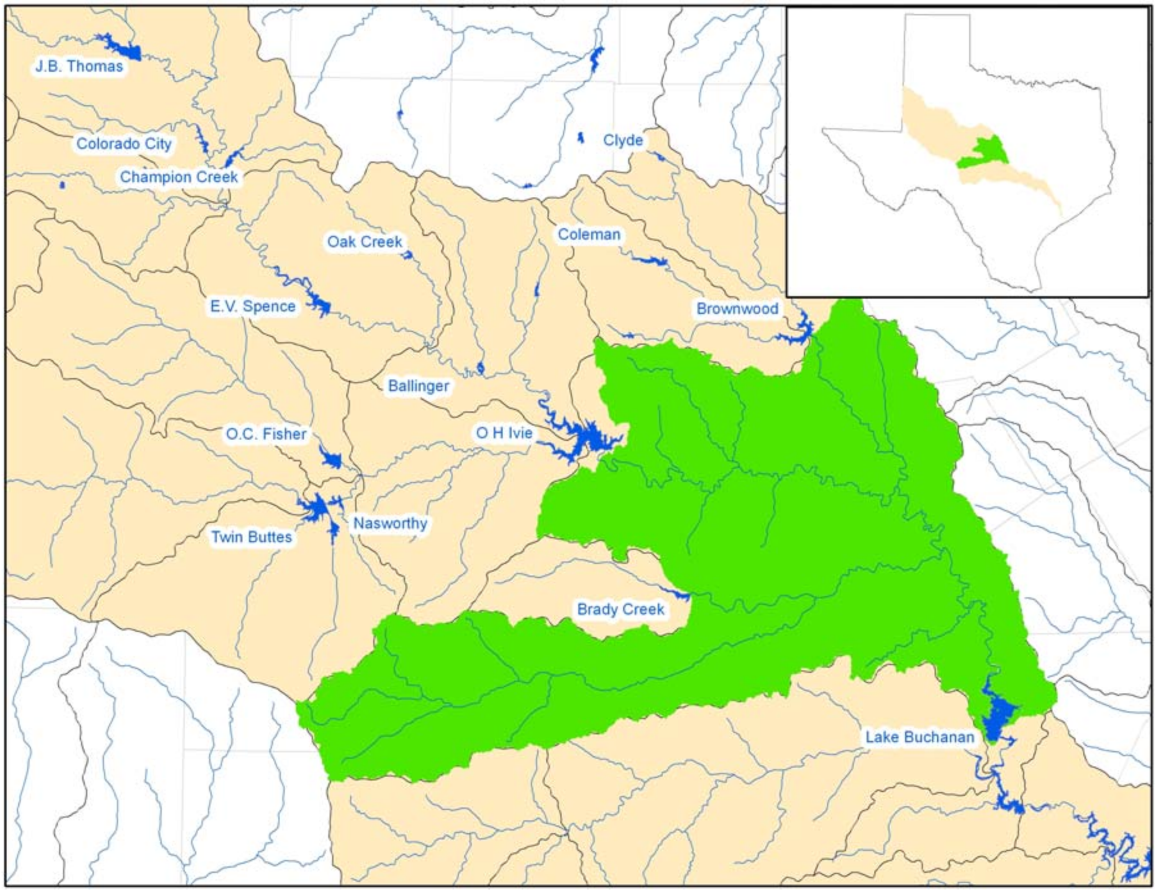



***Figure G6.*** *Portion of Colorado River Basin (in green) downstream of major reservoirs and upstream of Lake Buchanan. The addition of reservoirs upstream likely contributed to a reduction of sediment delivered to Lake Buchanan since initial impoundment.*

## Sediment Error Estimation

To determine the possible extent by which the accumulated sediment value reported herein (34,275 acre-ft) may be an underestimate of the total accumulated sediment within Lake Buchanan, two methods of analysis were performed:

- Data Extrapolation into the area upstream of Willow Slough, and
- Sensitivity Analysis assuming variable accuracies of the sediment thickness values.

Results from these further analyses may be useful when planning future sedimentation surveys of Lake Buchanan, however should not be considered as to provide a definitive estimate of the accuracy of the accumulated sediment value reported herein.

To assess the approximate amount of sediment within the 924-acre portion of Lake Buchanan that was too shallow for surveying with the multi-frequency depth sounder (Figure G2), sediment thickness data from a cross-section close to Willow Slough was extrapolated to all other cross-sections in this region. Specifically, sediment thickness values measured along a "target" cross-section just downstream from Willow Slough (Figure G7) were applied to all upstream cross-sections on a normalized-channel width basis, similar in principle to the basis of the Self-Similar data interpolation technique.[1] As shown in Figure G7, sediment thickness for this target cross-section ranged from 2.1-3.5 ft, with a mean value of approximately 3 ft.

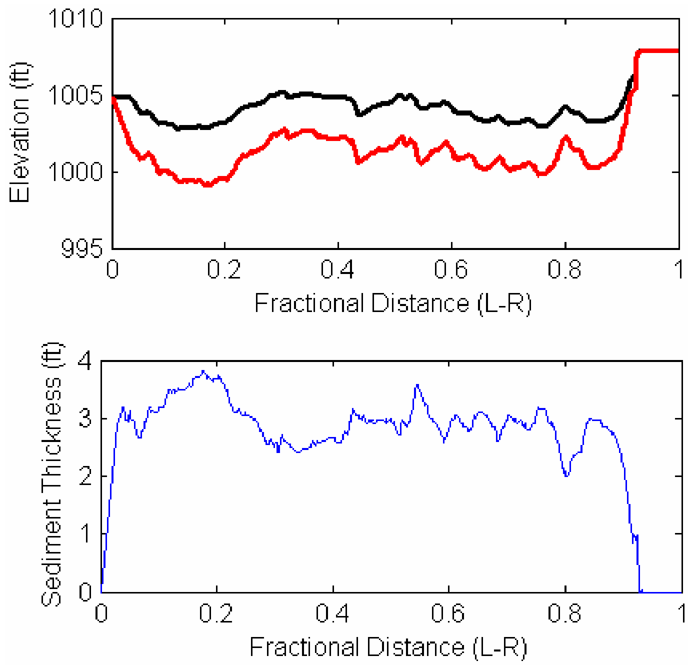



***Figure G7** – Surface & Sediment thickness data from a surveyed cross-section downstream of Willow Slough: Current Surface (Black), Pre-Impoundment Surface (Red), Sediment Thickness (Blue). Data shown with a normalized channel width as applied to upstream measured cross-sections. Cross section location (Green) shown in Figure G8.*

To produce a smooth, simulated sediment thickness TIN model, the self-similar interpolation technique was applied to the simulated data within ArcGIS. Figure G8 demonstrates the data extrapolation process, showing the original TIN model (Figure G8A), the surveyed cross-sections to which the sediment data is extrapolated (Figure G8B), and the resulting sediment thickness TIN model (Figure G8C). It should be noted that data extrapolation was not performed for all of the lake area upstream of Willow Slough.

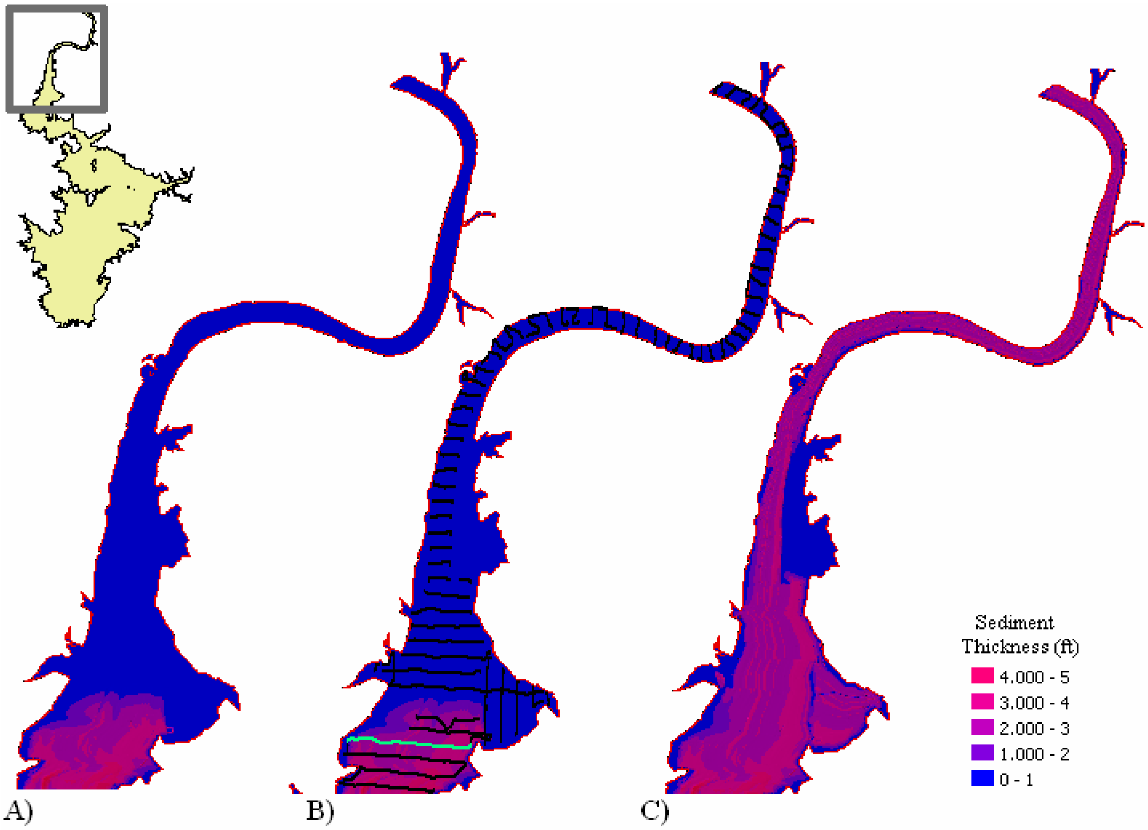



***Figure G8*** *- Sediment Thickness Data Extrapolation Results: A) Original TIN model without extrapolation, B) Original TIN with overlayed survey lines to which data is extrapolated, C) Extrapolated TIN showing sediment thicknesses upstream of Willow Slough. Target cross section is shown in green.*

The sediment volume derived from the Extrapolated TIN model (Figure G8C) was 36,251 acre-ft, which is 1,976 acre-ft more than the surveyed sediment volume reported herein. This extrapolated volume represents a 5.8% increase in volume over the surveyed volume. This percentage increase is slightly larger than the percentage of lake area in which the data extrapolation occurred (4.5% of lake area at water surface elevation 1,013.5 ft). This non-linear increase in sediment volume with increase in surveyed (or extrapolated) lake area may indicate that the extrapolated values used in creating Figure G8 are not necessarily accurate estimates of the sediment thickness upstream of Willow Slough. As such, and because no validation data is available to assess the accuracy of this extrapolation, the results of this analysis should be used with caution.

To determine the sensitivity of the calculated sediment volumes to potential inaccuracies of the sediment thickness measurements, a model sensitivity analysis was performed. In this sensitivity analysis, 6 alternative sediment thickness TIN models were created, with each model differing from the "base" model due to the uniform and random adjustments of the individual measured sediment thickness values. The thickness adjustments were selected to approximate potential data interpretation errors possibly derived when processing the multi-frequency depth sounder data within the DepthPic software package (See Appendix H). In this analysis, sediment thickness values were adjusted by up to either 0.1 ft or 0.5 ft, with the former value representing the likely error in interpretation in DepthPic and the later value (0.5 ft) representing an extreme error which is unlikely to occur. In each alternative sediment thickness dataset, the original sediment thickness value was adjusted either by one of these values or a random fraction of these values, and the adjustments could be up or down. The random adjustments are most likely to approximate the actual error in the DepthPic processing, and the signal digitizing is performed manually and errors in interpretation are not likely to be consistent. Table G1 presents the sensitivity analysis results.

Table G1: Sediment Thickness Sensitivity Analysis Results

| Sediment Thickness Surface | Sediment Volume | % Difference |
|---|---|---|
| BASE | 34,275 acre-ft | N/A |
| BASE ± 0.1 ft (Random) | 34,456 acre-ft | 0.5% |
| BASE ± 0.5 ft (Random) | 34,478 acre-ft | 0.6% |
| BASE - 0.1 ft | 32,992 acre-ft | -3.7% |
| BASE + 0.1 ft | 35,910 acre-ft | 4.8% |
| BASE - 0.5 ft | 27,464 acre-ft | -19.8% |
| BASE + 0.5 ft | 41,758 acre-ft | 21.8% |

As indicated in Table G1, the percentage differences in sediment volume between the BASE surface and the randomly adjusted surfaces is less than 1% of the measured sediment volume. This provides confidence in the accuracy of the sediment volume reported herein as such random errors are expected to have occurred when processing the multi-frequency data in DepthPic. Larger percentage errors were obtained when the measured sediment thicknesses were uniformly adjusted. This result was also expected and these results should only be interpreted as unlikely error bounds to the sediment volume reported herein.

For volumetric surveys, the Texas Water Development Board strives to measure water depths to a 0.1 ft accuracy. It is therefore interesting to note that this same level of accuracy in the sediment thickness data (Table G1) results in a possible sediment volume percentage error of the same order as obtained when extrapolating survey data to the unsurveyable (with the multi-frequency depth sounder) lake area upstream of Willow Slough. This coincidence is not scientifically defensible, however it supports the notion that greatest accuracy can be achieved only by conducting surveys of the entire reservoir while the water level is at the conservation pool elevation (i.e. nearly all lake areas are surveyable).

## Conclusions & Recommendations

While there remains some uncertainty in the total amount of sediment, the multi-frequency data collected during this survey indicates that a minimum of 34,275 acre-ft of sediment has been delivered to Lake Buchanan since impoundment. Figure G1 shows that the majority of sediment remains confined to the original river channel, with the thickest sediment deposits near tributary confluences and in the upper-reaches of the reservoir. Qualitative comparisons with available cross-section data from 1991 suggest that little additional sediment has been input to Lake Buchanan since that time.

In order to improve sedimentation rate estimates for Lake Buchanan, TWDB recommends the following:

1. Repeat the multi-frequency survey in 5-10 years or after 3-4 large flooding events
2. Conduct the next survey at a time when the reservoir water surface elevation is at or above the 1020.5 ft conservation pool elevation
3. Concentrate core sampling and spud bar measurements in the area upstream of Silver Creek
4. Use higher-power settings on the multi-frequency depth sounder as well as longer core-sampling tubes

Following each of these recommendations should produce a survey from which a full assessment of Lake Buchanan sediment accumulation rates may be obtained. Also, comparing such a survey with the results from this survey (in a fashion similar to the method #1 analysis described above) would provide further confidence in the sediment assessment technique. Recommendations #2 to #4 above are particularly important, as they permit for multi-frequency surveying over a greater portion of the lake (i.e. upstream from Willow Slough) and provide better calibration/validation data for use when interpreting the multi-frequency depth sounder signals.

## References


1. Furnans, Jordan. Texas Water Development Board. 2006. "HydroEdit User's Manual."
2. Engitech Inc., Lake Buchanan Dredging Feasibility Analysis for the Lower Colorado Rive Authority. December 1991.
3. Dunbar, John A. and Peter Allen. Baylor University, Department of Geology. Sediment Thickness from Coring and Acoustics within Lakes Aquilla, Granger, Limestone, and Proctor: Brazos River Watershed, TX. June 2003.
4. Department of the Army, U.S. Army Corps of Engineers, Engineering Manual Number 1110-2-1003, Engineering and Design Hydrographic Surveying, Chapter 21, Depth Measurements Over Irregular or Unconsolidated Bottoms, pg. 21-25, http://erg.usgs.gov/isb/pubs/factsheets/fs17199.html, Accessed February 2007.
5. http://nhd.usgs.gov/, Accessed February 2007.

## Appendix H

Core Sampling Report

***Note: This appendix was derived entirely from the report submitted by John Dunbar, Geophysical Consulting, a subcontractor to the Texas Water Development Board. The presented report was not altered by TWDB, and was accepted "as-is" by TWDB.

John Dunbar, Geophysical Consulting

# Sediment Thickness from Coring and Acoustic Profiling, Lake Buchanan, Llano and Burnet Counties, TX

## Final Report

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By John A. Dunbar and Peter M. Allen

TWDB Contract No. 0604800622 April 12, 2007

## SUMMARY

On August 26, 2006 we collected six vibracore samples in Lake Buchanan, Llano and Burnet Counties, Texas. We also collected short profiles through each core location using a multi-frequency sub-bottom acoustic profiling system from Specialty Devices Inc., of Wylie, Texas (SDI). The SDI profiler imaged the water bottom and sub-bottom at signal frequencies of 208, 50, and 25 kHz. These data were used to verify acoustically determined sediment thicknesses in a sediment survey conducted by the Texas Water Development Board (TWDB). Of the six cores, three contained only post-impoundment sediment and no pre-impoundment material, and three successfully penetrated the entire post-impoundment sediment layer and sampled underlying pre-impoundment material. Overall, the coring results indicate that the post-impoundment layer is thickest in the northern part of the reservoir, near the main tributary inlet. The layer varies from a thickness of about 2 m in the northern part of the reservoir to a few tens of centimeters, south of the middle of the reservoir. In the north, the base of the post-impoundment layer appears to coincide with base of returns of the 50 kHz signal, although this was not directly proven by coring. In the mid-lake region, the base of returns at all three frequencies track the base of the post-impoundment layer. South of the mid-lake region, where the sediment is only a few tens of centimeters thick, the base of sediment coincides with the base of returns of the 208 kHz signal.

## ACKNOWLEDGEMENTS

We gratefully acknowledge the financial support provided by the Texas Water Development Board and technical and logistical help provided by Randall Burns of the Texas Water Development Board.

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# 1. INTRODUCTION

On August 26, 2006 we collected six vibracore samples in Lake Buchanan, Llano and Burnet Counties, Texas. The goal of this study was to determine the thickness of sediments that have accumulated in the reservoir since its impoundment in 1937 to verify acoustically determined sediment thicknesses in a sediment survey conducted by the Texas Water Development Board (TWDB). This report describes the results of the coring operation.

# 2. PROCEDURES

## 2.1 Sediment Coring

A commercially available vibracoring system from Specialty Devices, Inc. of Wylie, Texas (SDI) was used to collect 3-in diameter sediment cores of varying length. The SDI vibracore uses a 1-HP, DC motor that drives a pair of eccentrically mounted weights, which vibrates an attached aluminum core tube into the bottom. The vibration liquefies the sediment adjacent to the tube wall, allowing the sediment core to slide into the tube with relatively little disturbance to the sample. Cores were collected by lowering the vibrator with core tube attached to the bottom by hand winch, switching on the vibrator, and allowing the tube to slowing vibrate into the bottom. When the core had reached the point of refusal, the vibrator was turned off and the core was winched out of the bottom. On deck, the retrieved cores were capped top and bottom with rubber end-caps and stored upright during transport. While still at anchor the geographic position of the core the locations were determined with the differential Global Positioning System (DGPS) built into the SDI profiler.

## 2.2 Core analysis:

The main objective of our core analysis was to determine the thickness of the post-impoundment sediment so that the base of sediment could be identified on co-located acoustic records. In this analysis, we relied on visual examination of the sampled material and measurements of the water content and sediment penetration resistance. The cores were brought back from the field, cut in half lengthwise and split open for examination for evidence of the pre-impoundment surface. Once the visual examination was complete, the sediment within each 5-cm interval was weighed, dried for 48 hours at 106º C, reweighed and stored for further analysis. The wet and dry weights of the samples were used to compute water content profiles along the cores. During the sub-sampling operation the penetration resistance of the sediment was determined using a penetrometer to measure the force required to drive a 2.5 cm diameter disk into the sediment. These tests were performed on each 5 cm sub-sample, while the sample was confined in the core tube.

## 2.3 Discriminating Between Pre- and Post-impoundment materials

We determined the depth to the pre-impoundment surface in cores where it was present based on the following evidence: (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. Sediments deposited in reservoirs typically have water contents that range from 60 to 80% at the water bottom and decrease with burial to 30 to 40% at depths of several meters. Soils, in contrast, typically have water contents of 20 to 30% when saturated. The penetration resistance of reservoir sediments (as measured with penetration devices) typically ranges from near 0 to 2 $kg/cm^2$. The penetration resistance of saturated clay-rich soils typically ranges from 3 to over 10 $kg/cm^2$.

### 2.4 Acoustic Profiling

We used an acoustic sub-bottom profiling system to select coring locations and to record co-located acoustic records at the core sites. The acoustic profiling system we used is a high-resolution version of the SDI profiler used by the TWDB in its sediment surveys. Normally, the system images the bottom and sub-bottom sediments with acoustic transducers with frequencies of 208, 125, 50, 25, and 12 kHz. The high-resolution system samples the acoustic signals up to 1,000,000 times per second, compared to 100,000 samples per second in the conventional SDI profiler. For this study we used only the 208, 50, and 25 kHz, signals sampled 500,000 samples per second, so that the resulting data would approximate that collected with the TWDB system. We used this system to collect short profiles through each core location to compare with the coring results. During post-survey processing core diagrams that show the interpreted post-impoundment sediment thicknesses were posted on the acoustic data at the point of closest approach of the profiles to the core locations.

## 3. Results

Six cores were collected in Lake Buchanan at locations selected by the TWDB to span the range of apparent sediment thicknesses observed in their survey (Figure 3-1). A summary of core locations, core lengths, and the interpreted depth to the pre-impoundment surface is given in Table 3-1. Water content and penetration resistance versus depth in the cores are shown in Figure 3-2. Interpreted pre- and post-impoundment intervals are posted on co-located acoustic profiles in Figures 3-3 to 3-8. Tables recording the results of the physical analysis of the cores are given in Appendix A.

Of the six cores, three contained only lake sediments and pre-impoundment material, and three penetrated the complete post-impoundment layer and sampled the underlying pre-impoundment material. Cores 1 and 2, were the northern-most cores collected. The normal water depth at these core locations was the shallowest of the six core sites and the locations were the closest to the main tributary inlet. Cores 1 and 2 penetrated 152 and 109 cm of post-impoundment sediment, respectively, but did not reach the pre-impoundment surface. Physical analysis suggests that both cores penetrated a desiccation surface near their base (Figure 3-2 a and b). The desiccation surface is marked by an isolated zone of low water content and high penetration resistance and is indicative of a time in which the reservoir bottom was subaerially exposed, dried, and compacted. Both cores reach approximately 40 cm below the desiccation surface and end in relatively soft sediment. Friction on the core tube associated with the desiccation interval most likely prevented the cores from penetrating to the base of the post-impoundment layer. Acoustic profiles through the core sites indicate that the full sediment thickness at both locations is approximately 190 cm (Figures 3-3 and 3-4). This is indicated by the 50 and 25 kHz records, but not the 208 kHz records.

Cores 3 and 4 were collected near the middle of the reservoir, about halfway between the main tributary inlet and the dam. Core 3 penetrated 93 cm of post-impoundment mud and 32 cm of compacted sand containing preserved plant roots (Figure 3-2 c). The sharp contact between the mud and sand is interpreted as the pre-impoundment surface. The acoustic profile through the core location shows a close agreement between the thickness of the post-impoundment layer observed in the core and the acoustically determined thickness (Figure 3-5). The base of post-impoundment sediment corresponds to the base of acoustic returns at all three acoustic frequencies (208, 50, and 25 kHz). Core 4 penetrated 150 cm of post-impoundment mud and bottomed in relatively soft sediment, with no indication of pre-impoundment materials. The acoustic profile through the core site indicates that the base of post-impoundment layer is at or near the bottom of the core (Figure 3-6). As was the case at the site of Core 3, the base of Core 4 corresponds to the base of returns at all three signal frequencies. Hence, Cores 3 and 4 are similar in all respects, except that Core 4 did not penetrate the pre-impoundment surface. It is possible that Core 4 happened to be located at a site were the post-impoundment sediment was deposited directly over rock outcrop that cannot be penetrated with the vibracore.

Cores 5 and 6 were the southern-most cores collected. Both cores penetrated thin layers of post-impoundment sediment (15 and 23 cm) and then longer intervals of compacted granitic sand and gravel containing preserved plant roots (Figure 3-2 e and f). Acoustic profiles though the core sites suggest that the base of the post-impoundment layer in this part of the reservoir most closely corresponds to the base of the returns at the 208 kHz signal frequency. However, the correlation between the base of sediment and the base of the 208 kHz returns is not real close (Figures 3-7 and 3-8). It is likely that the discrepancy is caused by a combination of rapidly varying sediment thickness and error in the co-location of the cores and acoustic records. The returns at the 50 and 25 kHz signals penetrate into the underlying sand and gravel and end at the base of the core at both sites. Hence, it is possible that both cores bottomed on solid rock and that is what the 50 and 25 kHz signals track in this part of the reservoir.

Overall, the coring results indicate that the post-impoundment layer is thickest in the northern part of the reservoir, near the main tributary inlet and thins from a thickness of about 2 m in that region to a few tens of centimeters, south of the middle of the reservoir. In the north, the base of the post-impoundment layer appears to coincide with the base of returns of the 50 kHz signal, although this was not directly proven by coring. In the mid-lake region, the base of returns at all three frequencies tracks the base of the post-impoundment layer. South of the mid-lake region, where the sediment is only a few tens of centimeters thick, the base seems to follow the base of returns of the 208 kHz signal.

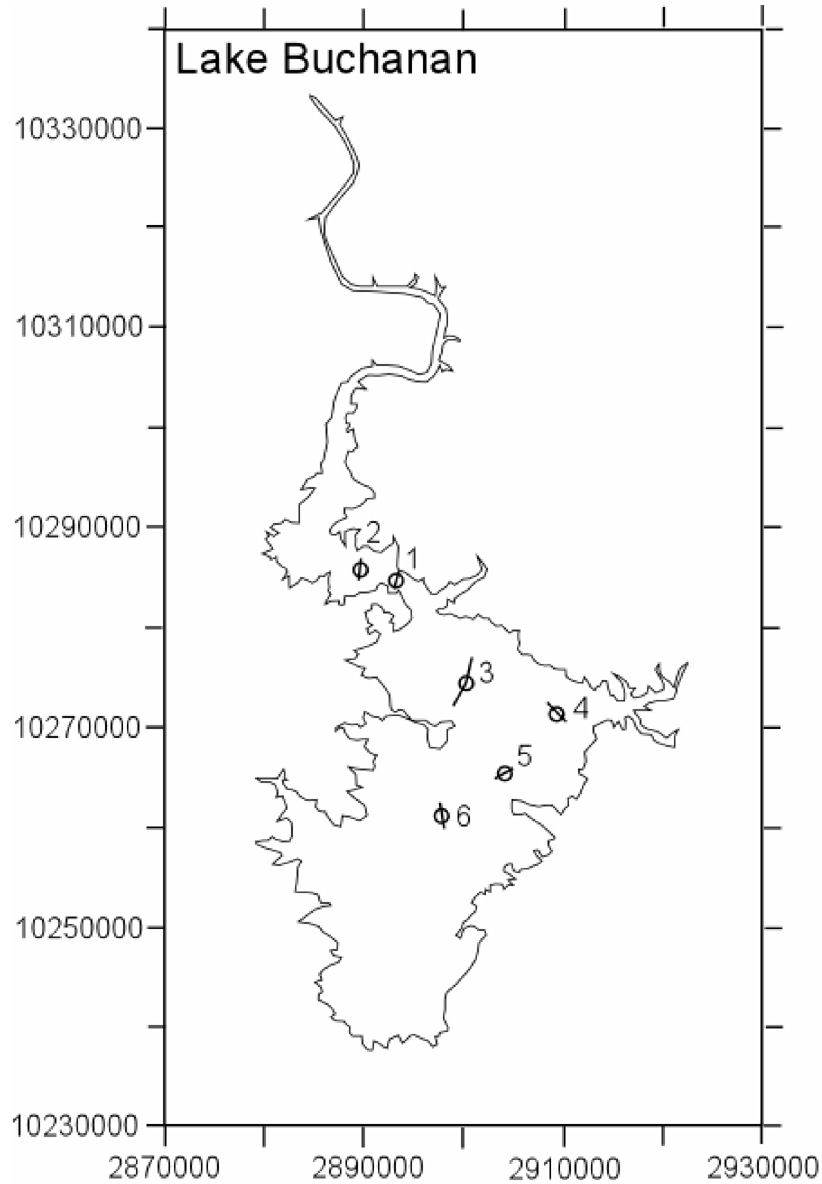
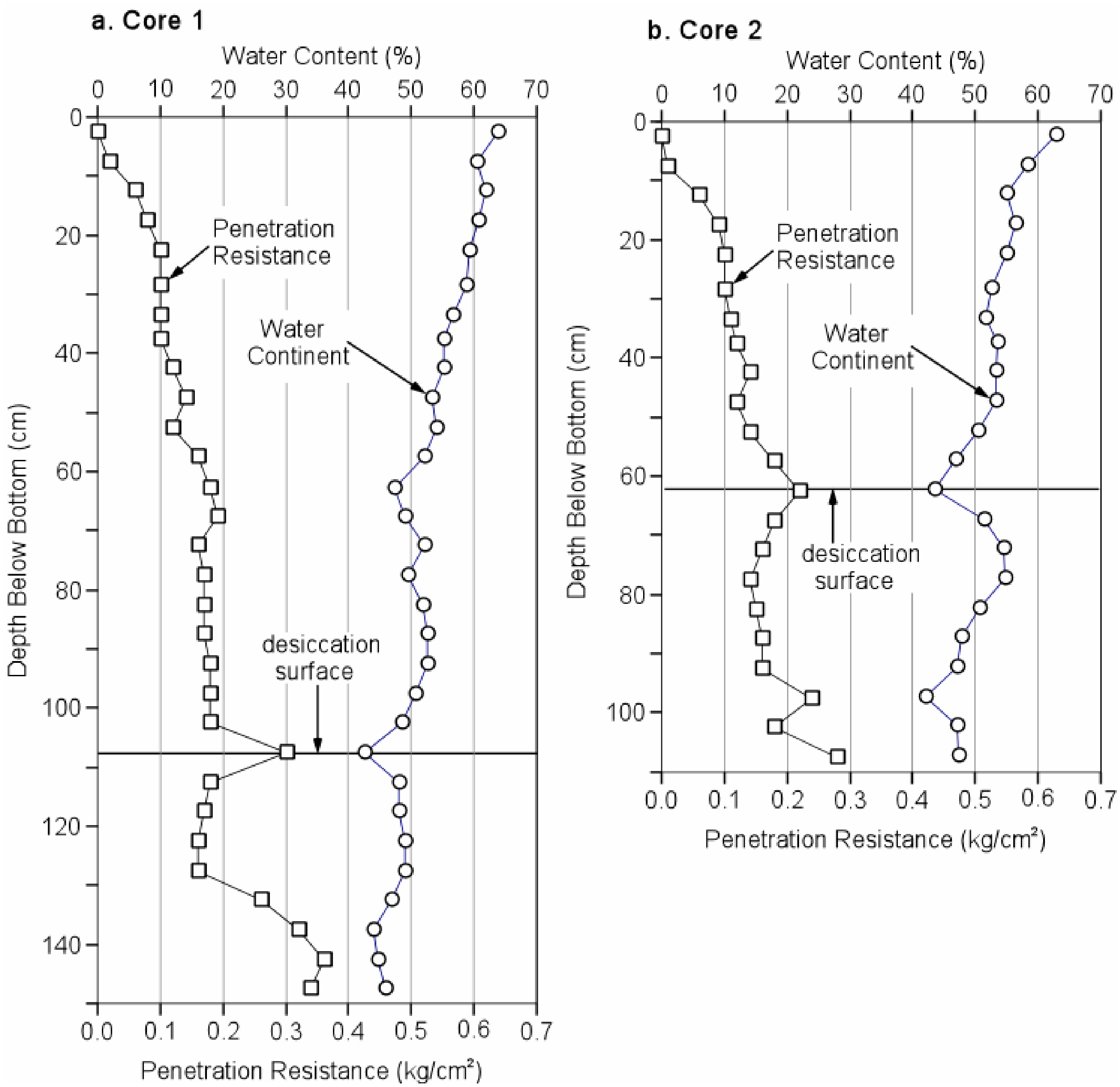
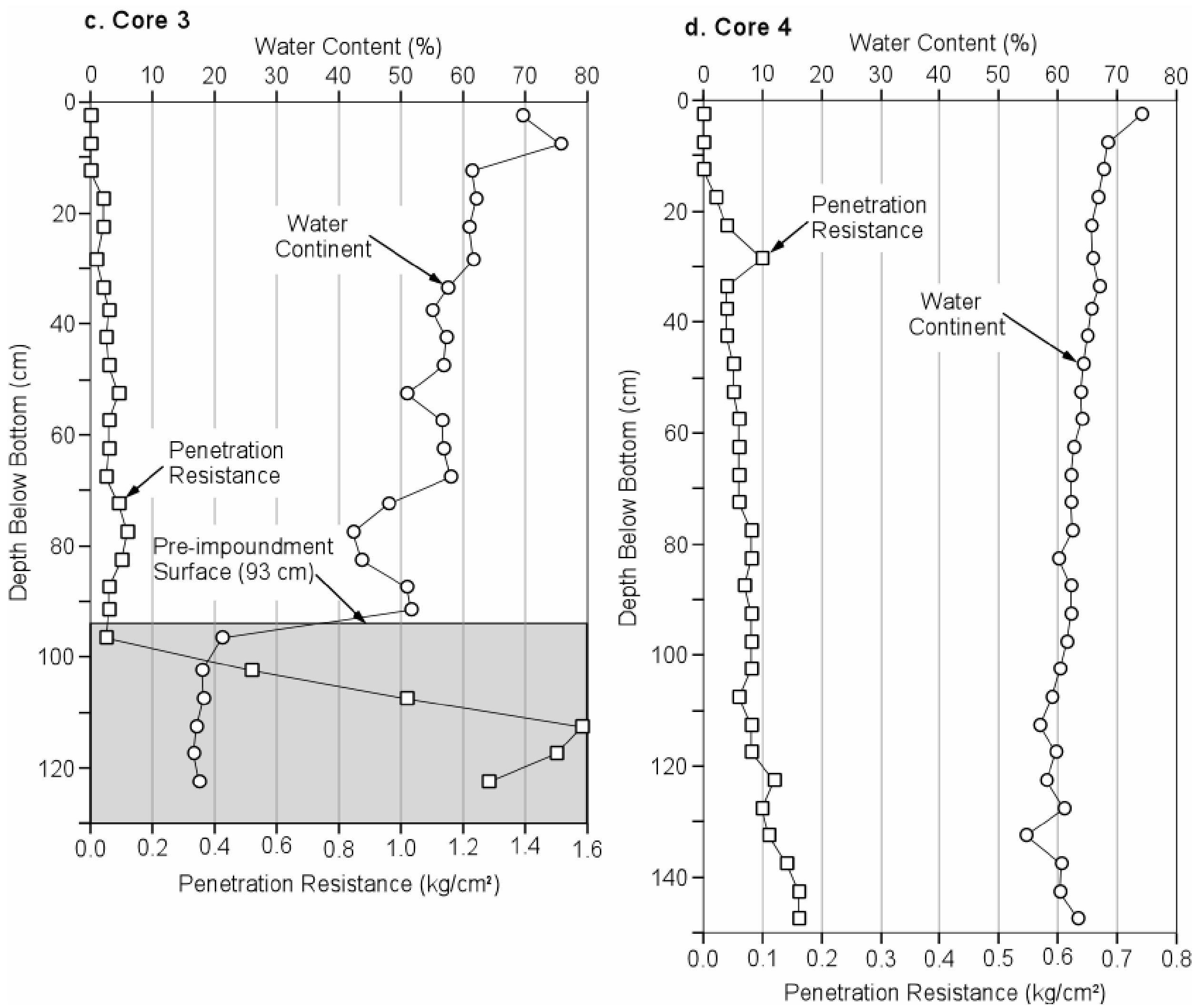



Figure 3-1. Map of core locations in Lake Buchanan (circles). Core numbers are shown adjacent to the corresponding core location. Short acoustic lines (black lines) were collected across each core location. Map coordinates are Texas State Plane, North Central Zone, NAD 83, feet.

Table 3-1. Summary of sediment cores collected in Lake Buchanan. Core locations are given in Texas State Plane, North Central, NAD 83, feet. The length of core and depth to the pre-impoundment surface are given. Estimates of the post impoundment sediment thickness based on acoustic data and not confirmed by direct sampling of the pre-impoundment material are qualified with question marks "?". Survey line numbers refer to acoustic profiles collected during the coring operation.

| Core ID | Easting (ft) | Northing (ft) | Length (cm) | Depth to pre-impoundment (cm) | Line No. |
|---|---|---|---|---|---|
| 1 | 2893542.0 | 10284819.2 | 152 | 193? | 1 |
| 2 | 2889792.5 | 10285809.1 | 109 | 194? | 4 |
| 3 | 2900427.7 | 10274451.2 | 125 | 93 | 6 |
| 4 | 2909525.3 | 10271486.8 | 150 | 150? | 8 |
| 5 | 2904231.1 | 10265503.5 | 72 | 15 | 12 |
| 6 | 2897996.6 | 10261132.3 | 42 | 23 | 11 |


a. Core 1
Water Content (%)
0
10
20
30
40
50
60
70
Depth Below Bottom (cm)
0
20
40
60
80
100
120
140
Penetration
Resistance
Water
Continent
desiccation
surface
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Penetration Resistance (kg/cm²)
b. Core 2
Water Content (%)
0
10
20
30
40
50
60
70
Depth Below Bottom (cm)
0
20
40
60
80
100
Penetration
Resistance
Water
Continent
desiccation
surface
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Penetration Resistance (kg/cm²)



c. Core 3
Water Content (%)
Depth Below Bottom (cm)
Water Continent
Penetration Resistance
Pre-impoundment Surface (93 cm)
Penetration Resistance (kg/cm²)
d. Core 4
Water Content (%)
Depth Below Bottom (cm)
Penetration Resistance
Water Continent
Penetration Resistance (kg/cm²)

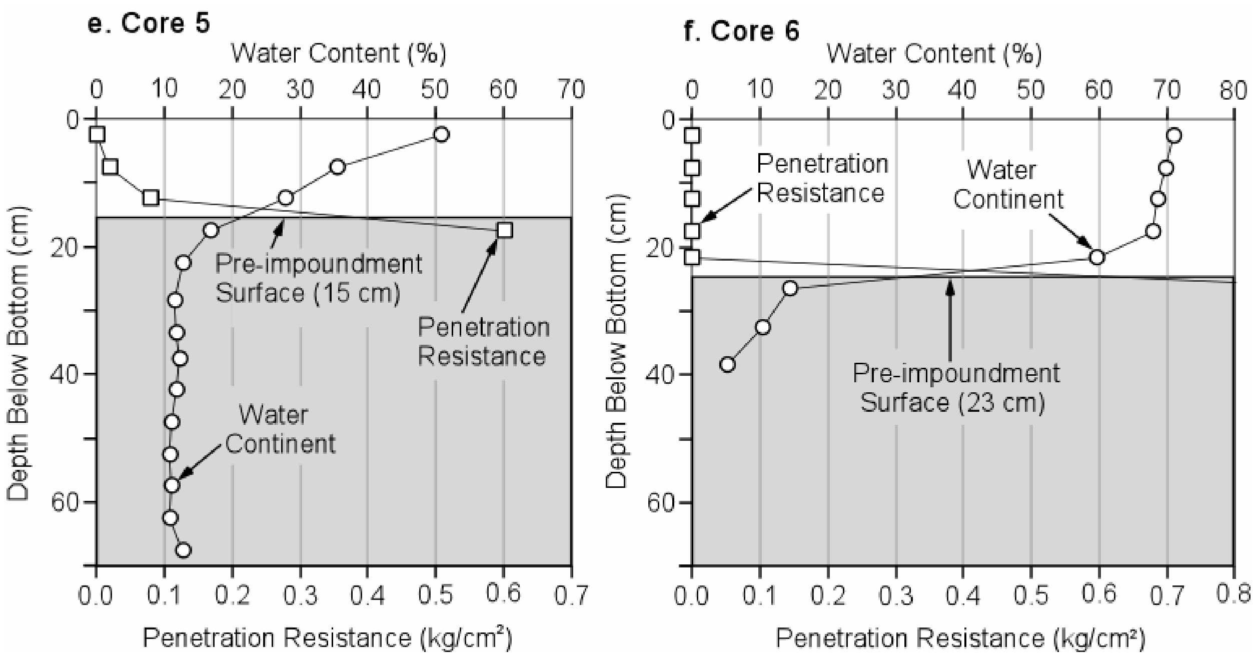



Figure 3-2. Physical analyses of cores collected in Lake Buchanan.

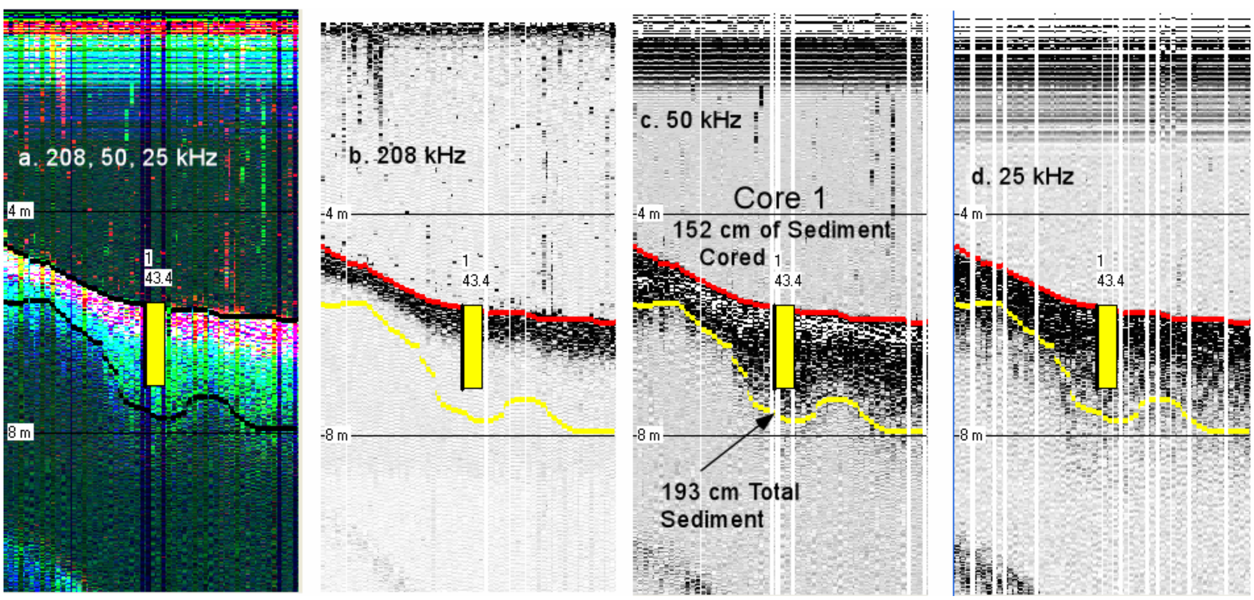



Figure 3-3. Correlation of Core 1 and co-located acoustic records along Line 1. The location of Core Site1 is shown in Figure 3-1. The acoustic record is converted from travel time to depth below the water bottom assuming a speed of sound in sediment of 1460 m/s. (a) Composite display of 208, 50, and 25 kHz. (b) 208 kHz. (c) 50 kHz. (d) 25 kHz. The core did not reach the pre-impoundment surface, which appears to occur at a depth of 193 cm below the bottom and 41 cm below the base of the core.

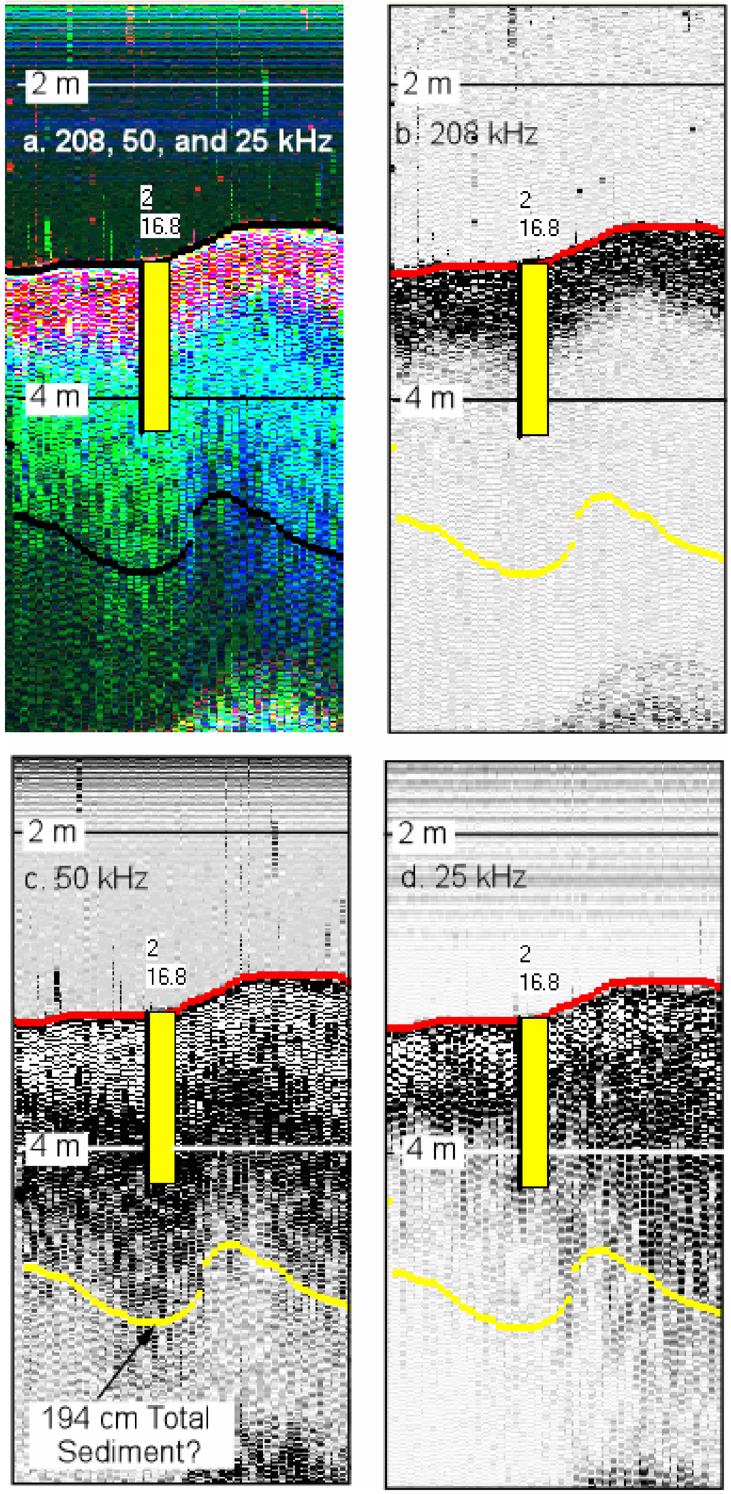



Figure 3-4. Correlation of Core 2 and co-located acoustic records and Line 4. (a) Composite display of 208, 50, and 25 kHz signals. (b) In this location the 208 kHz signal penetrates only 60 cm into the bottom, suggesting a layer of high water content sediment that might normally be interpreted as the post-impoundment layer. However, the core contains post-impoundment material throughout its length to a depth of 109 cm below the bottom. The base of the 208 kHz signal corresponds to an apparent desiccation surface in the core (Figure 3-2b).

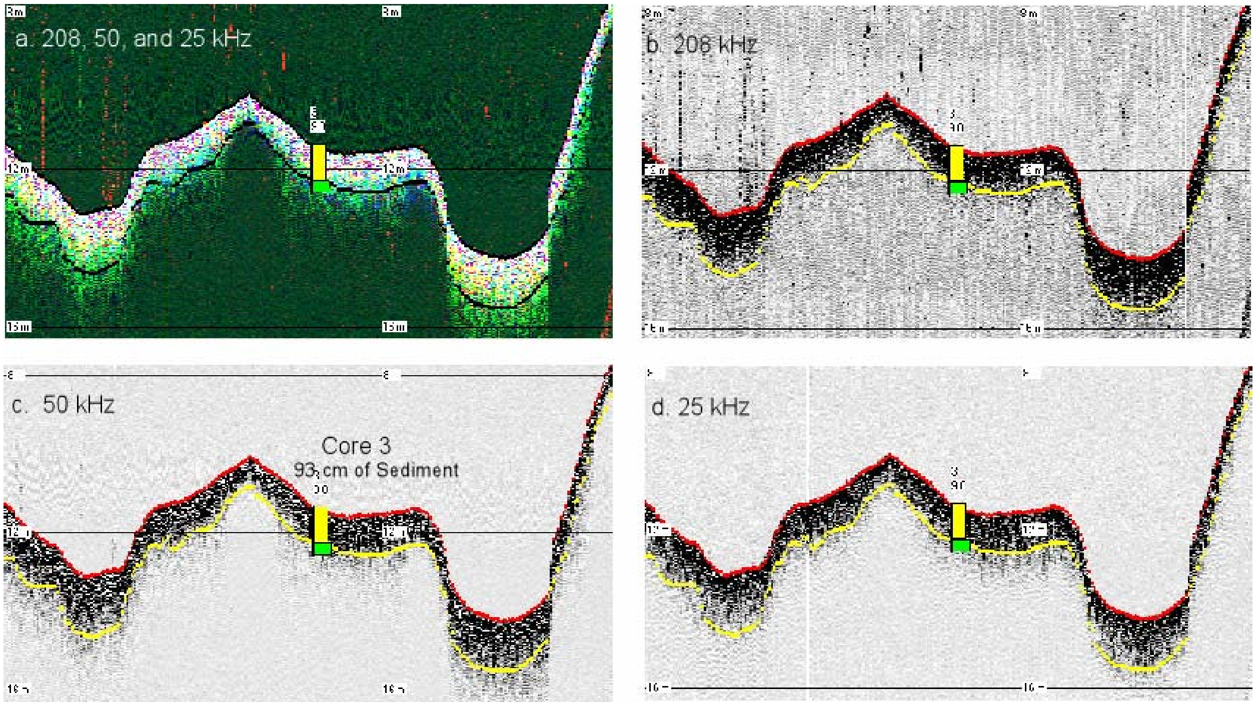



Figure 3-5. Correlation of Core 3 and co-located acoustic records and Line 6. (a) Composite display of 208, 50, and 25 kHz. (b) 208 kHz. (c) 50 kHz. (d) 25 kHz. Core 3 sampled a clear pre-impoundment surface at a depth of 93 cm below bottom. The pre-impoundment material at this location consists of compact, dark brown sand containing plant roots.

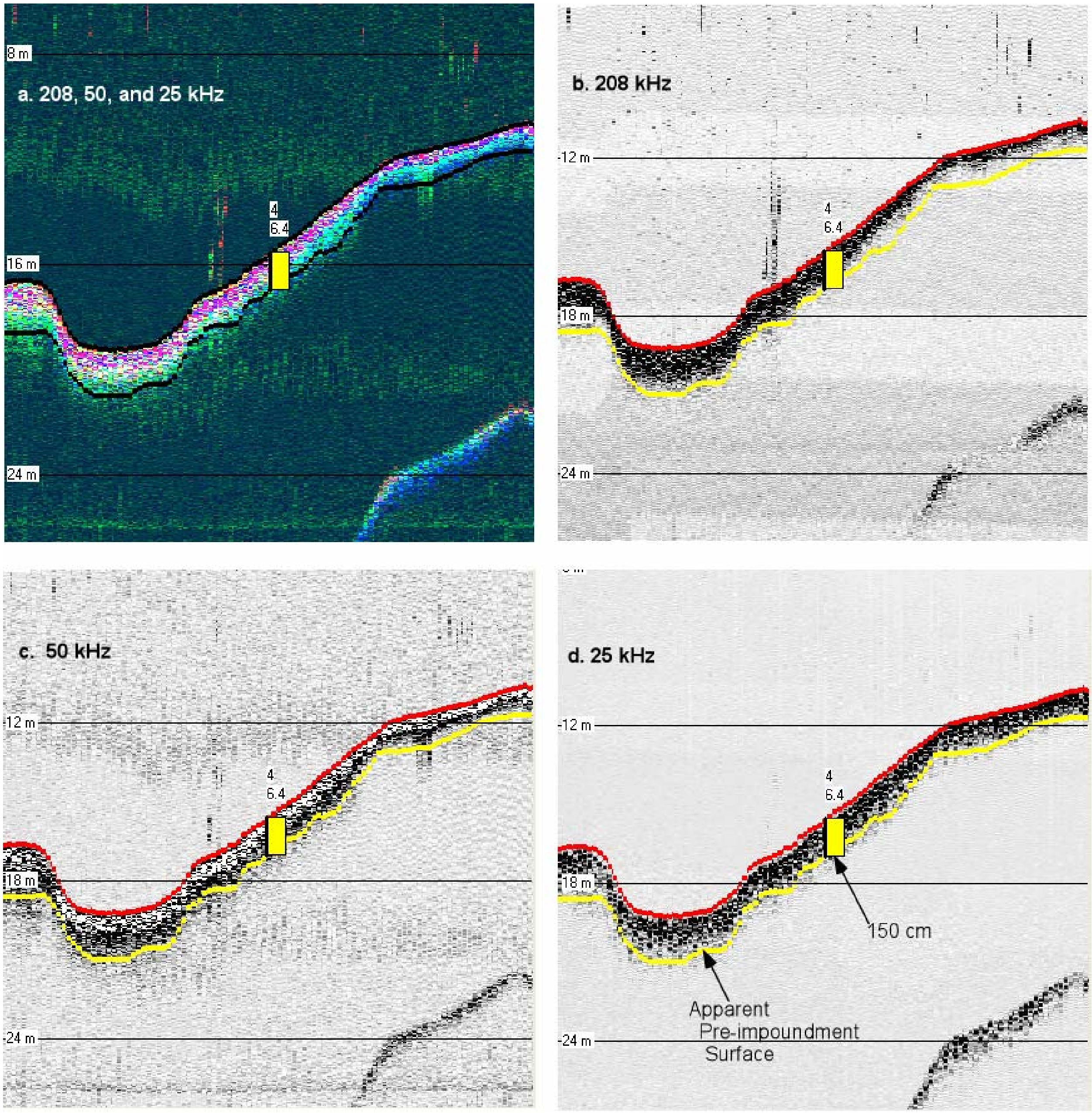



Figure 3-6. Correlation of Buchanan Core 4 and co-located acoustic records and Line 8. (a) Composite display of 208, 50, and 25 kHz. (b) 208 kHz. (c) 50 kHz. (d) 25 kHz. Core 4 did not sample pre-impoundment material. However, acoustically, the pre-impoundment surface appears to occur at or just below the bottom of the core at a depth of 150 cm.

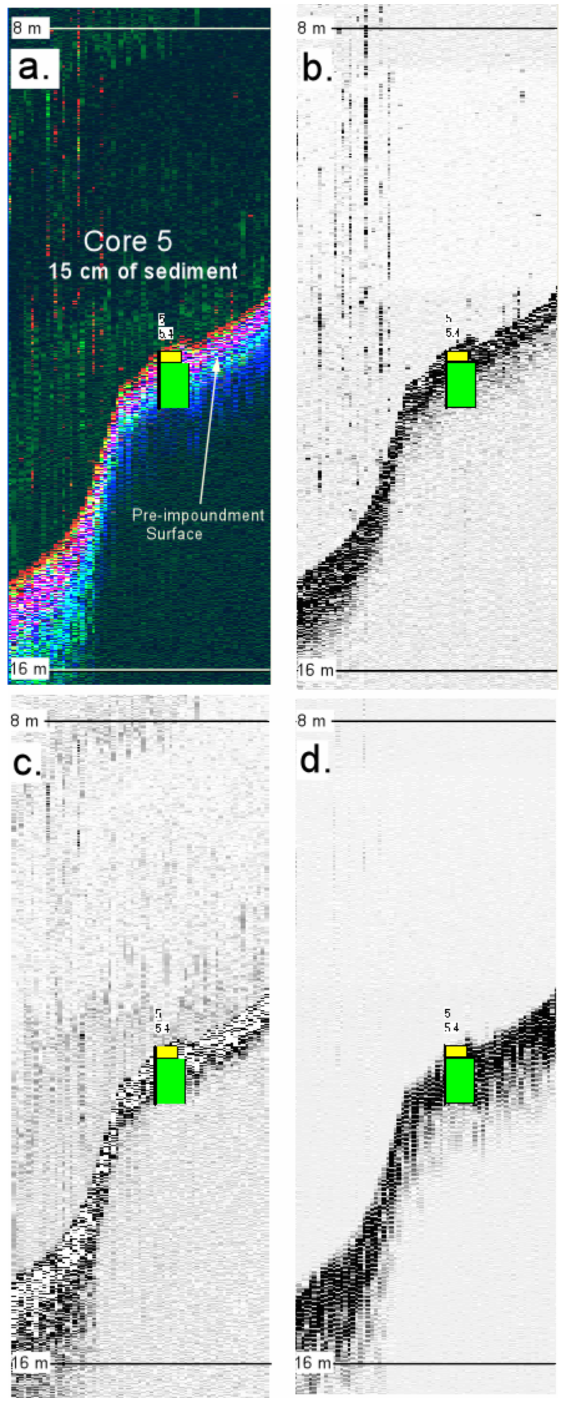



Figure 3-7. Correlation of Core 5 and co-located acoustic records and Line 12. (a) Composite display of 208, 50, and 25 kHz. (b) 208 kHz. (c) 50 kHz. (d) 25 kHz. Core 5 sampled pre-impoundment material at a depth of 15 cm below the bottom consisting of coarse sand and gravel up to ½ cm in diameter. The position of the core was projected 5.4 meters onto the closest point along Line 12. At the point of closest approach on Line 12 the apparent thickness of the post-impoundment sediment is 38 cm (shown in part a.). This discrepancy may be due to the projection distance. Note that the thickness of the post-impoundment layer appears to thin rapidly down slope.

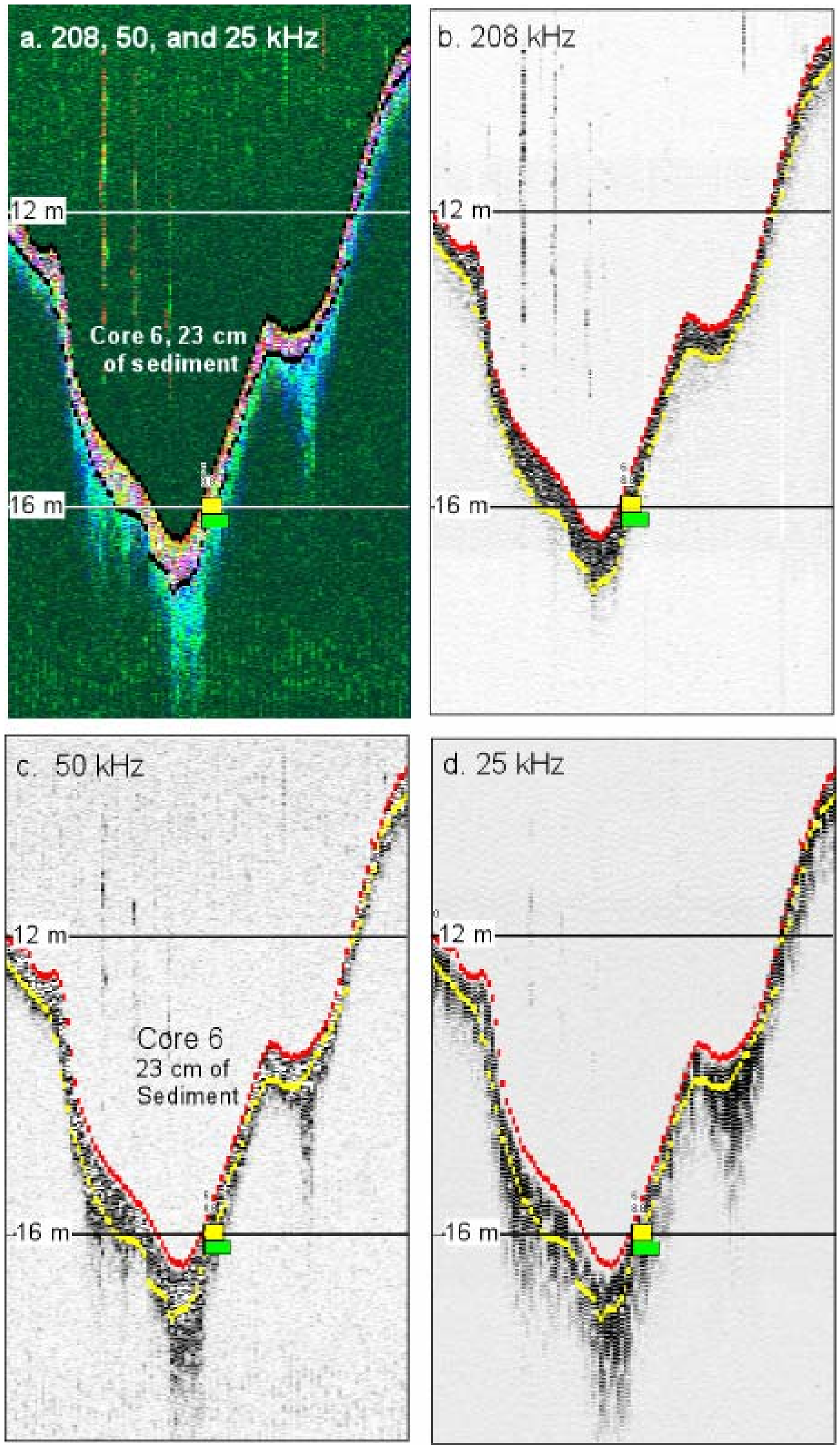



Figure 3-8. Correlation of Core 6 and co-located acoustic records and Line 11. Core 6 sampled pre-impoundment material at a depth of 23 cm below the bottom consisting of coarse sand and granite gravel containing plant roots.

## 4. Discussion

The goal of this study was to collect co-located core and acoustic data to verify the identification of the base of post-impoundment sediment on the acoustic records in the TWDB survey of the reservoir. In spite of the fact that only three of the six cores sampled the pre-impoundment material, the results still provide useful information. However, it would have been better to have had six cores that penetrated the complete post-impoundment layer and sampled at least the top few centimeters of the underlying pre-impoundment material. Part of the problem was likely associated with the large lake-level changes that have occurred over the life of Lake Buchanan and part was likely just the bad luck in selecting a core site underlain by rock outcrop.

To avoid such problems in the future, we suggest the following changes to the coring procedure. When a core is retrieved, we suggest examining the material lodged in the tip of the core. If it appears to be pre-impoundment material, based on the characteristics described in this report, the core can be capped and stored. If it appears to be post-impoundment sediment, a second core should be taken. If the top of the core tube reached the mud line and the pre-impoundment surface was not reached, a longer core tube should be used on the second try. If the top of the core tube did not reach the mud line and the sediment in the tip of core tube seems to be stiff and compacted, more weight should be added to the coring device and/or the vibration should be carried out for a longer period during the second try. If the sediment in the tip of the core is soft and the top of the core did not reach the mud line, it is possible that the pre-impoundment surface at this location is impenetrable. In this case, we suggest moving to a new location for the second try, in the hopes of finding a nearby area where the pre-impoundment material can be sampled.

## 5. CONCLUSIONS

This study was done to to serve as a guide for interpreting sedimentation survey data collected in Lake Buchanan. The main conclusions are listed below.

1. In the northern part of the lake, where the sediment appears to be near 2 m thick, the base of the 50 kHz returns seems to correspond to the base of sediment. Associating the base of 200 kHz returns with the base of sediment in this region would result in a significant underestimate of the amount of sediment present.

2. In the mid-lake region, where the base of returns is the same at all three acoustic frequencies, the base of all the acoustic returns track the base of post-impoundment surface.

3. In the southern part of the lake, where the base of 200 kHz returns is only a few tens of centimeters deep, the base of the 200 kHz signal tracks the base of post-impoundment sediment. Associating the base of 50 or 25 kHz returns with the base of sediment in this region would result in a significant over estimate of the amount of sediment present.

## Appendix A: Physical Analysis of Cores

| Core 1 | x=2893542.0 | y=10284819.2 |
|---|---|---|

| Sample | Top | Bottom | cont wt | wet | dry | water cont | pen | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 5.0 | 8.73 | 135.06 | 52.25 | 65.55 | 0 | |
| 2 | 5 | 10.0 | 8.62 | 111.59 | 53.17 | 56.73 | 0.1 | |
| 3 | 10 | 15.0 | 8.48 | 138.95 | 70.5 | 52.46 | 0.3 | |
| 4 | 15 | 20.0 | 8.69 | 168.19 | 92.37 | 47.54 | 0.4 | |
| 5 | 20 | 25.0 | 8.36 | 169.24 | 86.00 | 51.74 | 0.5 | |
| 6 | 25 | 32.0 | 8.62 | 135.73 | 67.09 | 54.00 | 0.5 | |
| 7 | 32 | 35.0 | 8.48 | 174.37 | 82.3 | 55.50 | 0.5 | Organic-rich mud |
| 8 | 35 | 40.0 | 8.48 | 162.9 | 73.84 | 57.67 | 0.5 | Dark gray |
| 9 | 40 | 45.0 | 8.55 | 177.42 | 82.44 | 56.24 | 0.6 | |
| 10 | 45 | 50.0 | 8.67 | 154.82 | 74.44 | 55.00 | 0.7 | |
| 11 | 50 | 55.0 | 8.63 | 154.95 | 74.42 | 55.04 | 0.6 | |
| 12 | 55 | 60.0 | 8.61 | 150.72 | 72.18 | 55.27 | 0.8 | |
| 13 | 60 | 65.0 | 8.64 | 173.46 | 80.09 | 56.65 | 0.9 | |
| 14 | 65 | 70.0 | 8.64 | 152.14 | 79.67 | 50.50 | 0.95 | |
| 15 | 70 | 75.0 | 8.47 | 175.0 | 94.05 | 48.61 | 0.8 | |
| 16 | 75 | 80.0 | 8.50 | 161.54 | 81.64 | 52.21 | 0.85 | |
| 17 | 80 | 85.0 | 8.68 | 145.95 | 70.64 | 54.86 | 0.85 | |
| 18 | 85 | 90.0 | 8.59 | 162.39 | 82.67 | 51.83 | 0.85 | |
| 19 | 90 | 95.0 | 8.57 | 174.95 | 86.22 | 53.33 | 0.9 | |
| 20 | 95 | 100.0 | 8.71 | 156.98 | 79.10 | 52.53 | 0.9 | |
| 21 | 100 | 105.0 | 8.57 | 150.57 | 77.43 | 51.51 | 0.9 | Shift to brown color |
| 22 | 105 | 110.0 | 8.26 | 145.31 | 79.68 | 47.89 | 1.5 | |
| 23 | 110 | 115.0 | 8.60 | 153.19 | 85.13 | 47.07 | 0.9 | |
| 24 | 115 | 120.0 | 8.54 | 122.28 | 68.85 | 46.98 | 0.85 | |
| 25 | 120 | 125.0 | 8.65 | 143.81 | 79.36 | 47.68 | 0.8 | |
| 26 | 125 | 130.0 | 8.65 | 136.5 | 72.66 | 49.93 | 0.8 | |
| 27 | 130 | 135.0 | 8.70 | 144.22 | 76.28 | 50.13 | 1.3 | |
| 28 | 135 | 140.0 | 8.55 | 165.68 | 91.44 | 47.25 | 1.6 | |
| 29 | 140 | 145.0 | 8.61 | 150.00 | 89.34 | 42.90 | 1.8 | |
| 30 | 145 | 150.0 | 8.64 | 236.06 | 156.91 | 34.80 | 1.7 | No pre-impoundment |

| Core 2 | x=2889792.5 | y=10285809.1 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sample** | **Top** | **Bottom** | **cont wt** | **wet** | **dry** | **water cont** | **pen** | **Comments** |
| 1 | 0 | 5.0 | 8.26 | 76.00 | 33.45 | 62.81 | 0.0 | |
| 2 | 5 | 10.0 | 8.29 | 105.10 | 48.73 | 58.23 | 0.1 | |
| 3 | 10 | 15.0 | 8.25 | 131.99 | 63.86 | 55.06 | 0.3 | |
| 4 | 15 | 20.0 | 8.17 | 117.47 | 55.76 | 56.46 | 0.5 | |
| 5 | 20 | 25.0 | 8.32 | 113.92 | 55.79 | 55.05 | 0.5 | |
| 6 | 25 | 32.0 | 8.34 | 146.38 | 73.84 | 52.55 | 0.5 | |
| 7 | 32 | 35.0 | 8.64 | 154.13 | 78.88 | 51.72 | 0.6 | Organic-rich mud |
| 8 | 35 | 40.0 | 8.23 | 144.47 | 71.57 | 53.51 | 0.6 | Dark gray |
| 9 | 40 | 45.0 | 8.62 | 143.53 | 71.80 | 53.17 | 0.7 | |
| 10 | 45 | 50.0 | 8.21 | 119.73 | 60.28 | 53.31 | 0.6 | |
| 11 | 50 | 55.0 | 8.47 | 152.89 | 80.26 | 50.29 | 0.7 | |
| 12 | 55 | 60.0 | 8.26 | 161.40 | 89.83 | 46.74 | 0.9 | |
| 13 | 60 | 65.0 | 8.23 | 155.12 | 91.20 | 43.52 | 1.1 | |
| 14 | 65 | 70.0 | 8.11 | 131.18 | 68.06 | 51.29 | 0.9 | |
| 15 | 70 | 75.0 | 8.20 | 142.62 | 69.46 | 54.43 | 0.8 | |
| 16 | 75 | 80.0 | 8.19 | 103.24 | 51.31 | 54.63 | 0.7 | |
| 17 | 80 | 85.0 | 8.13 | 124.72 | 65.68 | 50.64 | 0.8 | |
| 18 | 85 | 90.0 | 8.15 | 136.40 | 75.23 | 47.70 | 0.8 | |
| 19 | 90 | 95.0 | 8.13 | 132.07 | 73.88 | 46.95 | 0.8 | |
| 20 | 95 | 100.0 | 8.14 | 159.05 | 95.57 | 42.06 | 1.2 | |
| 21 | 100 | 105.0 | 8.15 | 65.95 | 38.68 | 47.18 | 0.9 | |
| 22 | 105 | 110.0 | 8.17 | 62.83 | 36.95 | 47.35 | 1.4 | No pre-impoundment |

| Core 3 | x=2900427.7 | | | y=10274451.2 | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sample** | **Top** | **Bottom** | **cont wt** | **wet** | **dry** | **water cont** | **pen** | **Comments** |
| 1 | 0 | 5.0 | 8.13 | 69.61 | 26.88 | 69.50 | 0.0 | |
| 2 | 5 | 10.0 | 8.18 | 94.80 | 29.31 | 75.61 | 0.0 | Dark gray - black |
| 3 | 10 | 15.0 | 8.16 | 106.42 | 46.15 | 61.34 | 0.0 | |
| 4 | 15 | 20.0 | 8.11 | 111.64 | 47.46 | 61.99 | 0.2 | |
| 5 | 20 | 25.0 | 8.12 | 117.63 | 51.02 | 60.83 | 0.2 | |
| 6 | 25 | 32.0 | 8.54 | 114.92 | 49.36 | 61.63 | 0.1 | |
| 7 | 32 | 35.0 | 8.25 | 108.72 | 50.97 | 57.48 | 0.2 | Brown |
| 8 | 35 | 40.0 | 8.18 | 124.58 | 60.61 | 54.96 | 0.3 | Clay-rich |
| 9 | 40 | 45.0 | 8.37 | 96.35 | 46.03 | 57.19 | 0.3 | |
| 10 | 45 | 50.0 | 8.28 | 133.79 | 62.43 | 56.86 | 0.3 | |
| 11 | 50 | 55.0 | 8.22 | 139.78 | 72.66 | 51.02 | 0.5 | |
| 12 | 55 | 60.0 | 8.20 | 135.57 | 63.37 | 56.69 | 0.3 | |
| 13 | 60 | 65.0 | 8.12 | 78.59 | 38.52 | 56.86 | 0.3 | |
| 14 | 65 | 70.0 | 8.14 | 117.43 | 54.19 | 57.86 | 0.3 | |
| 15 | 70 | 75.0 | 8.19 | 147.60 | 80.76 | 47.94 | 0.5 | |
| 16 | 75 | 80.0 | 8.20 | 129.19 | 77.98 | 42.33 | 0.6 | |
| 17 | 80 | 85.0 | 8.10 | 144.57 | 85.07 | 43.60 | 0.5 | |
| 18 | 85 | 90.0 | 8.14 | 129.68 | 67.85 | 50.87 | 0.3 | |
| 19 | 90 | 93.0 | 8.19 | 90.67 | 48.13 | 51.58 | 0.3 | |
| 20 | 93 | 100.0 | 8.13 | 149.47 | 119.62 | 21.12 | 0.3 | Pre-impoundment |
| 21 | 100 | 105.0 | 8.16 | 199.49 | 165.11 | 17.97 | 2.6 | surface |
| 22 | 105 | 110.0 | 8.16 | 171.16 | 141.63 | 18.12 | 5.1 | Dark brown |
| 23 | 110 | 115.0 | 8.67 | 156.39 | 131.15 | 17.09 | 7.9 | sand, with roots |
| 24 | 115 | 120.0 | 8.19 | 164.17 | 138.16 | 16.68 | 7.5 | |
| 25 | 120 | 125.0 | 8.47 | 146.20 | 122.24 | 17.40 | 6.4 | |

| Core 4 | x=2909525.3 | | | y=10271486.8 | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sample** | **Top** | **Bottom** | **cont wt** | **wet** | **dry** | **water cont** | **pen** | **Comments** |
| 1 | 0 | 5.0 | 8.18 | 109.14 | 34.31 | 74.12 | 0.00 | |
| 2 | 5 | 10.0 | 8.19 | 61.52 | 25.07 | 68.35 | 0.00 | |
| 3 | 10 | 15.0 | 8.19 | 84.71 | 32.92 | 67.68 | 0.00 | |
| 4 | 15 | 20.0 | 8.13 | 91.04 | 35.81 | 66.61 | 0.10 | |
| 5 | 20 | 25.0 | 8.15 | 95.96 | 38.48 | 65.46 | 0.20 | |
| 6 | 25 | 32.0 | 8.78 | 107.75 | 42.63 | 65.80 | 0.50 | |
| 7 | 32 | 35.0 | 8.30 | 101.31 | 39.05 | 66.94 | 0.20 | Organic-rich mud |
| 8 | 35 | 40.0 | 8.16 | 100.02 | 39.80 | 65.56 | 0.20 | Dark gray-black |
| 9 | 40 | 45.0 | 8.35 | 116.20 | 46.27 | 64.84 | 0.20 | |
| 10 | 45 | 50.0 | 8.30 | 109.36 | 44.62 | 64.06 | 0.25 | |
| 11 | 50 | 55.0 | 8.31 | 105.96 | 43.72 | 63.74 | 0.25 | |
| 12 | 55 | 60.0 | 8.30 | 108.70 | 44.45 | 63.99 | 0.30 | |
| 13 | 60 | 65.0 | 8.14 | 117.61 | 49.19 | 62.50 | 0.30 | |
| 14 | 65 | 70.0 | 8.16 | 108.82 | 46.42 | 61.99 | 0.30 | Brown |
| 15 | 70 | 75.0 | 8.25 | 126.60 | 53.13 | 62.08 | 0.30 | |
| 16 | 75 | 80.0 | 8.29 | 111.35 | 47.21 | 62.24 | 0.40 | |
| 17 | 80 | 85.0 | 8.36 | 117.17 | 51.81 | 60.07 | 0.40 | |
| 18 | 85 | 90.0 | 8.17 | 109.65 | 46.68 | 62.05 | 0.35 | Brown |
| 19 | 90 | 95.0 | 8.21 | 100.38 | 43.19 | 62.05 | 0.40 | Gray |
| 20 | 95 | 100.0 | 8.18 | 98.96 | 43.15 | 61.48 | 0.40 | |
| 21 | 100 | 105.0 | 8.17 | 94.58 | 42.50 | 60.27 | 0.40 | |
| 22 | 105 | 110.0 | 8.16 | 82.02 | 38.55 | 58.85 | 0.30 | |
| 23 | 110 | 115.0 | 8.64 | 82.44 | 40.53 | 56.79 | 0.40 | |
| 24 | 115 | 120.0 | 8.18 | 77.11 | 36.03 | 59.60 | 0.40 | |
| 25 | 120 | 125.0 | 8.43 | 97.83 | 46.11 | 57.85 | 0.60 | |
| 26 | 125 | 130.0 | 8.24 | 94.76 | 42.13 | 60.83 | 0.50 | |
| 27 | 130 | 135.0 | 8.22 | 89.60 | 45.27 | 54.47 | 0.55 | |
| 28 | 135 | 140.0 | 8.22 | 103.54 | 45.92 | 60.45 | 0.70 | |
| 29 | 140 | 145.0 | 8.23 | 89.07 | 40.47 | 60.12 | 0.80 | |
| 30 | 145 | 150.0 | 8.22 | 169.61 | 67.73 | 63.13 | 0.80 | No pre-impoundment |

| **Core 5** | x=2904231.1 | | | y=10265503.5 | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sample** | **Top** | **Bottom** | **cont wt** | **wet** | **dry** | **water cont** | **pen** | **Comments** |
| 1 | 0 | 5.0 | 8.51 | 74.31 | 41.05 | 50.55 | 0 | 0-8 cm, organic rich |
| 2 | 5 | 10.0 | 8.36 | 119.41 | 80.22 | 35.29 | 0.2 | 8-15, light gray |
| 3 | 10 | 15.0 | 8.26 | 144.91 | 107.10 | 27.67 | 0.8 | |
| 4 | 15 | 20.0 | 8.19 | 133.37 | 112.45 | 16.71 | 6 | Pre-impoundment |
| 5 | 20 | 25.0 | 8.22 | 133.88 | 117.85 | 12.76 | | Coarse sand to |
| 6 | 25 | 30.0 | 8.62 | 169.23 | 150.63 | 11.58 | | gravel (1/2 cm max) |
| 7 | 30 | 35.0 | 8.30 | 176.89 | 157.16 | 11.70 | | |
| 8 | 35 | 40.0 | 8.21 | 173.03 | 152.94 | 12.19 | | |
| 9 | 40 | 45.0 | 8.38 | 188.65 | 167.57 | 11.69 | | |
| 10 | 45 | 50.0 | 8.30 | 136.42 | 122.36 | 10.97 | | |
| 11 | 50 | 55.0 | 8.10 | 188.11 | 168.91 | 10.67 | | |
| 12 | 55 | 60.0 | 8.36 | 147.72 | 132.56 | 10.88 | | |
| 13 | 60 | 65.0 | 8.17 | 148.15 | 133.19 | 10.69 | | Gravel |
| 14 | 65 | 70.0 | 8.18 | 183.66 | 161.37 | 12.70 | | |

| Core 6 | x=2897996.6 | | | y=10261132.3 | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | Top | Bottom | cont wt | wet | dry | water cont | pen | |
| 1 | 0 | 5.0 | 8.57 | 64.44 | 24.72 | 71.09 | 0 | 0-8 cm, organic rich |
| 2 | 5 | 10.0 | 8.69 | 112.05 | 39.98 | 69.73 | 0 | 8-15, light gray |
| 3 | 10 | 15.0 | 8.69 | 99.30 | 37.04 | 68.71 | 0 | |
| 4 | 15 | 20.0 | 8.64 | 112.30 | 41.82 | 67.99 | 0 | Pre-impoundment |
| 5 | 20 | 23.0 | 8.54 | 103.24 | 46.75 | 59.65 | 0 | Grus with plant |
| 6 | 23 | 30.0 | 8.72 | 225.72 | 194.19 | 14.53 | 10 | roots, poorly sortedl |
| 7 | 30 | 35.0 | 8.46 | 225.32 | 202.79 | 10.39 | | sand and gravel |
| 8 | 35 | 42.0 | 8.74 | 254.45 | 241.52 | 5.26 | | |

# Appendix I

Historical Area and Volume Data and Sources

## DATA SET A: 1950

**Original as Built Data - 1950, Based on USGS 7.5 min quad maps and 20-ft contour interval [TWDB Report, 1971]**

| Elevation (MSL ft.) | Surface Area (acres) | Volume (acre-feet) |
|---|---|---|
| 914.00 | 600 | 7,000 |
| 920.00 | 900 | 11,931 |
| 924.00 | 1,110 | 15,000 |
| 930.00 | 1,550 | 23,968 |
| 934.00 | 1,900 | 30,000 |
| 938.00 | 2,300 | 39,000 |
| 940.00 | 2,525 | 43,853 |
| 944.00 | 3,100 | 52,500 |
| 948.00 | 3,750 | 70,000 |
| 950.00 | 4,100 | 76,439 |
| 954.00 | 4,900 | 95,000 |
| 960.00 | 6,200 | 127,169 |
| 964.00 | 7,150 | 154,000 |
| 968.00 | 8,150 | 185,000 |
| 970.00 | 8,650 | 200,989 |
| 974.00 | 9,675 | 240,000 |
| 978.00 | 10,800 | 280,000 |
| 980.00 | 11,350 | 301,031 |
| 984.00 | 12,550 | 350,000 |
| 988.00 | 13,700 | 400,000 |
| 990.00 | 14,328 | 429,414 |
| 995.50 | 15,820 | 505,000 |
| 1,000.00 | 17,306 | 587,625 |
| 1,005.50 | 18,770 | 678,000 |
| 1,010.00 | 20,230 | 777,000 |
| 1,018.00 | 22,345 | 939,667 |
| **1,020.35** | **23,020** | **988,929** |
| 1,020.50 | 23,060 | 992,000 |

Note: Original Data for Elevation 1018 & 1020.35 are interpolated

**Source: River Op Center, LCRA and also LP-60 Report by TWDB 1978**

| DATA SET B: 1991 & 1997 | | | |
|---|---|---|---|
| Based on Hydro Survey by LCRA 1991 & mass points from aerial mapping 1997 | | | Percent Diff Betn Original Data and 1991 Survey |
| **Elevation** | **Surface Area** | **Volume** | **Volume** |
| **(MSL ft.)** | **(acres)** | **(acre-feet)** | **(%)** |
| 914.00 | 54 | 45 | |
| 920.00 | 321 | 1,190 | |
| 924.00 | 550 | 2,908 | |
| 930.00 | 979 | 7,474 | |
| 934.00 | 1,338 | 12,093 | |
| 938.00 | 1,751 | 18,232 | |
| 940.00 | 1,972 | 21,956 | |
| 944.00 | 2,459 | 30,786 | |
| 948.00 | 3,040 | 41,771 | |
| 950.00 | 3,331 | 48,137 | |
| 954.00 | 4,002 | 62,745 | |
| 960.00 | 5,171 | 90,204 | |
| 964.00 | 6,005 | 112,531 | |
| 968.00 | 6,912 | 138,338 | |
| 970.00 | 7,422 | 152,663 | |
| 974.00 | 8,472 | 184,443 | |
| 978.00 | 9,528 | 220,457 | |
| 980.00 | 10,045 | 240,029 | |
| 984.00 | 11,094 | 282,308 | |
| 988.00 | 12,175 | 328,852 | |
| 990.00 | 12,692 | 353,719 | |
| 995.00 | 14,094 | 420,750 | |
| 1,000.00 | 15,529 | 494,606 | |
| 1,005.00 | 17,250 | 576,506 | |
| 1,010.00 | 19,487 | 668,534 | |
| 1,018.00 | 21,660 | 833,836 | |
| **1,020.35** | **22,333** | **885,507** | **-10.5%** |
| 1,020.00 | 22,208 | 877,674 | |
| 1,021.00 | 22,565 | 900,055 | |

Note: Survey Data for Elevation 1020.35 is interpolated

Source: River Op Center, LCRA

Currently used for Daily Allocation purpose

| DATA SET C: 1987 | | | |
|---|---|---|---|
| Based on Contour Maps Interpolated in 1987, | | Percent Diff Between Original Data and 1987 Data | Percent Diff Between 1991 and 1987 Data |
| **Elevation** | **Volume** | **Volume** | **Volume** |
| **(MSL ft.)** | **(acre-feet)** | **(%)** | **(%)** |
| 914 | 466 | | |
| 920 | 2253 | | |
| 924 | 4475 | | |
| 930 | 10105 | | |
| 934 | 15756 | | |
| 938 | 23086 | | |
| 940.00 | 27356 | | |
| 944.00 | 37660 | | |
| 948.00 | 50751 | | |
| 950.00 | 58416 | | |
| 954.00 | 75943 | | |
| 960.00 | 107514 | | |
| 964.00 | 132533 | | |
| 968.00 | 161369 | | |
| 970.00 | 177232 | | |
| 974.00 | 211782 | | |
| 978.00 | 249986 | | |
| 980.00 | 270436 | | |
| 984.00 | 314142 | | |
| 988.00 | 361666 | | |
| 990.00 | 386860 | | |
| 995.00 | 454142 | | |
| 1000.00 | 527634 | | |
| 1005.00 | 609227 | | |
| 1010.00 | 700823 | | |
| 1018.00 | 866128 | | |
| **1020.35** | **918807** | **-7.1%** | -3.6% |

Note: Survey Data for Elevation 1020.35 is interpolated

**Source: From ROC, LCRA Report: "Highland Lakes Capacities, August 1999". Originally found in David Murdoch's office**

The Lake Buchanan Area-Capacity-Elevation data was compiled from the following sources:

Currently Available Data Sets:

1. Original as built data - dated 1950 in DATA SET A

· Source: Report LP 60 as Hard Copy

2. Capacity table - dated 1987 in DATA SET C

Source: ROC, LCRA Report "Highland Lakes Capacities, August 1999"

3. Recent Survey Data 1991 and 1997 in DATA SET B

Source: ROC, LCRA as electronic format

Notes:

1991 survey data from bottom of the lake to the top of water level and mass points from aerial mapping projection in 1997 from the top of the water level to above.

Data Set B is currently used for daily allocation by the ROC

Related Information:

1. 1984 Lake Travis Cross Sections & Lake Buchanan Cross Sections

Source: Report on the History of the Highland Lakes Capacity Tables" by Coleen Johnson, June 1999, as Exhibit B

The calculations were performed at UT, based on a combination of cross sections from hydrographic surveys by the Corps of Engineers and USGS topographic surveys. No capacity tables were found with this information.

2. Report "Colorado River Sediment Reduction Study" by USDA and LCRA in November 1990

The study has determined the origin and cause of the sediment accumulation immediately above Lake LBJ and Lake Travis. Not in Lake Buchanan?

3. Copy of Fax signed by Wes Birdwell: Report on "Lake Sedimentation Analysis" faxed on 03/04/1996. The Corps of Engineers surveyed Highland Lakes in 1983. Cross sectional Area-elevation graphs are available for 3 x-sections for Lake Buchanan. Capacity data from this survey is not available.

From the Report: "Survey locations were not monumented, making their relocation for the purpose of the comparison very inaccurate. Use of this data therefore provides only a rough estimate of sediment accumulation"

## Appendix J

LIDAR Data Processing Methods

### Summary

To supplement the data collected by TWDB during the 2006 volumetric and sedimentation survey of Lake Buchanan, LCRA provided high-resolution LIDAR data for the land areas adjacent to each of the Highland Lakes. This appendix outlines how TWDB processed the LIDAR data provided by LCRA, and describes how this data was incorporated into the TIN models used in representing the bathymetric surface of Lake Buchanan.

The LCRA LIDAR data was collected on December 31, 2006 and January 1, 2007 when the approximate water surface elevation in Lake Buchanan was 998.05 ft above mean sea level. LIDAR points were processed in a series of steps in order to reduce the number of points used in creating bathymetric TIN models. The processing steps used in dataset reduction were:

1. Excluding any point more than 1 km outside the 1,040 ft elevation contour boundary about Lake Buchanan
2. Excluding any point with an elevation greater than elevation 1,041.0 ft.
3. Excluding any point with an elevation less than elevation 999.0 ft.
4. Removing any wayward points located in the lake interior where elevations are known not to exceed 999.0 ft.
5. Adjusting LiDAR point elevations from the NAVD88 to NGVD29 datum by subtracting 0.25 ft (per conversion provided by LCRA).

The resulting LIDAR dataset contained 36,202,279 data points. TWDB sounding & interpolated points (with elevations less than 999.0 ft) were added to the LIDAR data set in order to create the Lake Buchanan bathymetric TIN models. Due to the large number of sounding points, two individual TIN models had to be created.

### Introduction

The LIDAR data provided by LCRA to TWDB for use in assessing the volume of Lake Buchanan was obtained in the form of LAS text files. Each file contained numerous lines of data, with each individual line containing an X coordinate, a Y coordinate, an elevation above mean sea level, and an unknown data value (This value was not readily identifiable and LCRA did not provide metadata describing this value). The X- and Y- coordinates were in the UTM Zone 14N coordinate system, and the elevation value was given in feet above mean sea level (NAVD 88). Per LCRA provided conversion factors, LiDAR point elevations were converted to the NGVD29 datum. TWDB was provided with 157 LAS files covering all of the Highland Lakes area (including the vicinity of Lakes Buchanan, Inks, LBJ, Marble Falls, and Travis), and consisting of 23.3 GB.

**LIDAR Data Processing**

To process the LAS text files, TWDB created the program "read_lidar.exe" using the FORTAN computer programming language and the Lahey Fujitsu Fortran (V5.6) compiler. This program performed the following operations:

1. Opened each individual LAS file and read the file contents
2. Removed any line of data that corresponded to a point outside a 1 km distance from the boundary of Lake Buchanan (as defined by the 1040-ft contour from available hypsography datasets).
3. Removed any line of data with elevations less than 999.0 ft or greater than 1,041 ft.
4. Output the data in CSV format, suitable for importation as a shapefile in the ArcGIS software system.

The output was then converted into ArcGIS shapefiles and manually reviewed to assure data quality. In this step, wayward points (i.e. those with incorrectly edited coordinates) were manually removed.

TWDB chose to ignore all points greater than 1 km outside of the 1,040 ft contour surrounding Lake Buchanan in order to assure that the 1,040 ft contour was well-represented in the TIN model created from the LIDAR data. The 1,040 ft contour was considered important as it would be used as the clipping polygon for the final bathymetric TIN model. The 1-km distance was deemed sufficient such that the LIDAR data would contain all points around the 1,040 ft contour. This contour was derived from other, less-accurate datasets, and including LIDAR data around this contour would ensure that any contours derived strictly from the LIDAR data would accurately depict the actual 1,040 ft contour about Lake Buchanan.

In order to reduce the number of points in the LIDAR dataset, all points with elevations above 1,041 ft were excluded. Such points would not be included in any TIN model of the Lake Buchanan bathymetry, as LCRA only requested that the final TIN model extend at least to the 1,035 ft elevation. Also points with elevation values between 1,041 ft and 1,040 ft were deemed necessary in order to properly compute a 1,040 ft contour based on the LIDAR datapoints.

The LIDAR system used in collecting the LIDAR data was a standard LIDAR system without water-penetrating capabilities. Therefore the LIDAR datasets had to be filtered to remove any data point corresponding to a "wet" location (i.e. where the LIDAR sound wave reflected off the Lake Buchanan water surface). Elevation values in these areas will not be elevations of the bathymetric surface of the lake, and will also not correspond to the elevation of the lake water surface at the time of the LIDAR flight. This makes it difficult to distinguish between sounding points corresponding to "wet" locations and those corresponding to dry locations with elevations just above the water surface elevation at the times of the LIDAR flights. This LIDAR data was collected when the Lake Buchanan water surface elevation was an average of 998.05 ft MSL. Through inspection of the data, it was found that eliminating any LIDAR data point with an elevation less than 999.0 ft removed the vast majority of "wet" points within the dataset. It is likely that some dry points with elevations between 998 ft and 999 ft were also removed, however their removal is unlikely to affect the overall accuracy of the resulting TIN model.

Figure J1 depicts the results of the LIDAR data filtering for a portion of Lake Buchanan. In Figure J1-A, the TIN model derived from TWDB sounding data shows the bathymetric elevations in the vicinity of a confluence between two arms of the reservoir. Water depths in this area reach up to 50 ft when the water surface elevation is at CPE (1,020.50 ft). In Figure J1-B, all 98,000 LIDAR raw data points located within this area are shown (black dots), and it is obvious that most of these points correspond to "wet" points and should be eliminated. In Figure J1-C, points with elevations less than 998.50 ft are excluded, leaving 15,000 points. It is evident, however, that some of the remaining points are still "wet" points and need to be removed. In Figure J1-D, all points with elevations less than 999.0 ft have been removed. This resulted in a clustering of points along the boundary of the reservoir, as would be expected based on the TWDB collected bathymetry. There exist relatively few remaining "wayword points" in the center of the reservoir, and these points were manually removed from the LIDAR dataset.

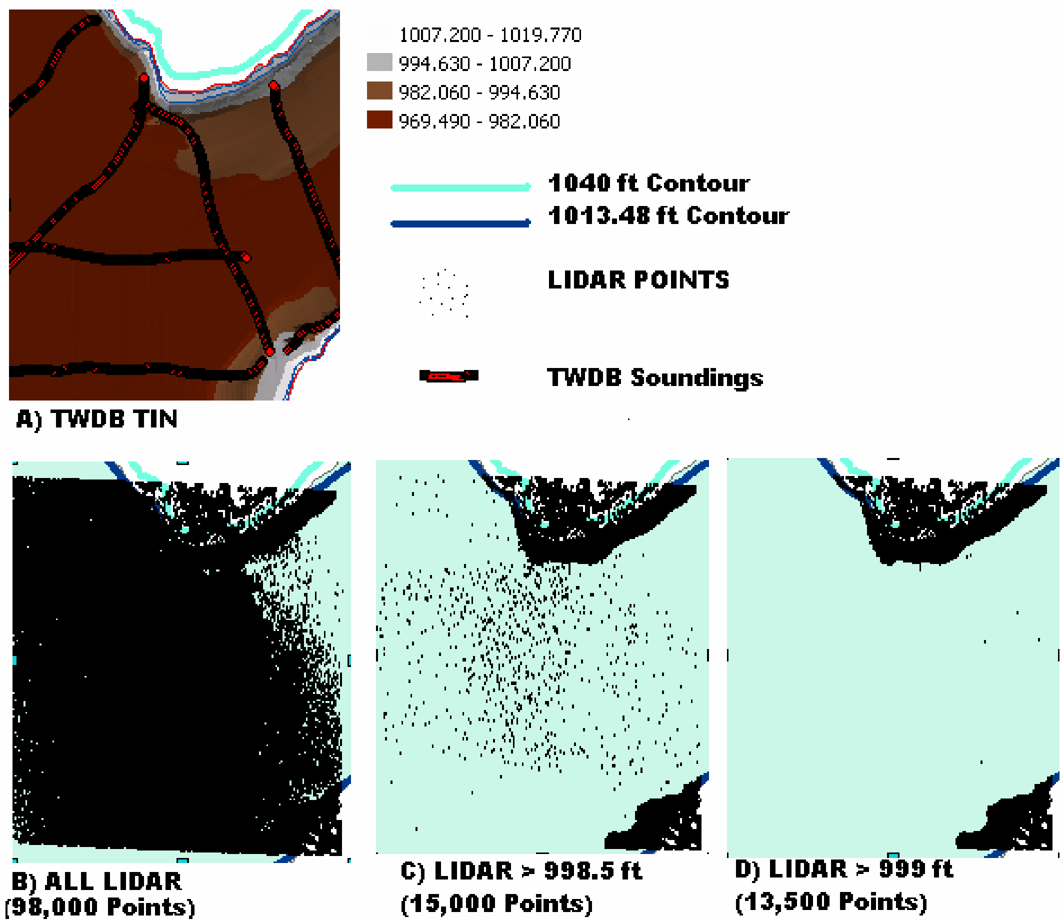



*Figure J1 – LIDAR data processing Steps for Lake Buchanan – A) TIN model showing bathymetric surface from TWDB data. B) Unfiltered LIDAR data, C) Partially filtered LIDAR data with numerous "wet" points still included, D) Fully filtered LIDAR data with few wayward points.*

A second set of “wet” points, those corresponding to LIDAR sounding reflections off of the Colorado River as it flows into the upper-reaches of Lake Buchanan, also had to be identified and removed. These wet points were identified through visual inspection of the LIDAR data points and TWDB-collected sounding points upstream of Willow Slough (Figure J2). When comparing the TWDB-collected soundings with the LIDAR soundings in this area, it was observed that the TWDB bathymetric surfaces were generally below the surfaces suggested by the LIDAR data. This trend diminished in the downstream direction (Figure J2 A-C), suggesting that the LIDAR and TWDB surfaces were reaching greater agreement closer to the boundary of the lake at the time of the LIDAR flights. In order to capture the true bathymetric surface of the Colorado River channel in the lake Buchanan TIN model, all LIDAR points within a “River Channel polygon” bounding the TWDB sounding points in the area upstream of Willow Slough were excluded. LIDAR data was used to better describe the lake margins between the 1,040 ft contour and the River Channel Polygon. The River Channel polygon used in this assessment is shown in Figure J2.

The LIDAR data filtering process resulted in over 36 million data points suitable for use in the Lake Buchanan TIN model. These points were combined with all of the TWDB sounding points and only the interpolated points whose elevations were less than elevation 999.0 ft or within the River Channel polygon used to define the river channel in the upper reaches of the lake. The spatial location of data points used computing the Lake Buchanan TIN model is shown in Figure J3.

It should be noted that TWDB collected survey data when the water surface elevation ranged from 1,012.2 to 1,011.75 ft, with the interpolated points extending to elevation 1,013.5 ft. Therefore there is a portion of the reservoir where the TWDB data and the LIDAR data overlap (i.e. for elevations less than 1,013.5 and greater than 999.0 ft). Comparisons of the TWDN and LIDAR data in this “overlap region” are provided at the end of this Appendix. Greater accuracy in the bathymetric surface model will be derived when using a higher density of sounding points. TWDB assumes that the vertical accuracy of the LCRA-provided LIDAR data is comparable to the vertical accuracy of the TWDB sounding data (approximately ± 0.1 ft). Therefore to obtain the most accurate TIN model, both LIDAR and TWDB sounding data within the overlap region were used. Interpolated data was used only where the interpolated elevations were less than 999.0 ft. Interpolated points with elevations above 999.0 ft were excluded, as TWDB has yet to determine the accuracy of the interpolated elevations (which must be achieved through comparison with the TIN model derived from LIDAR data). Such a comparison is currently underway at TWDB, and will be documented in TWDB reports released in 2008, documenting the activities of the HydroGraphic Survey program.

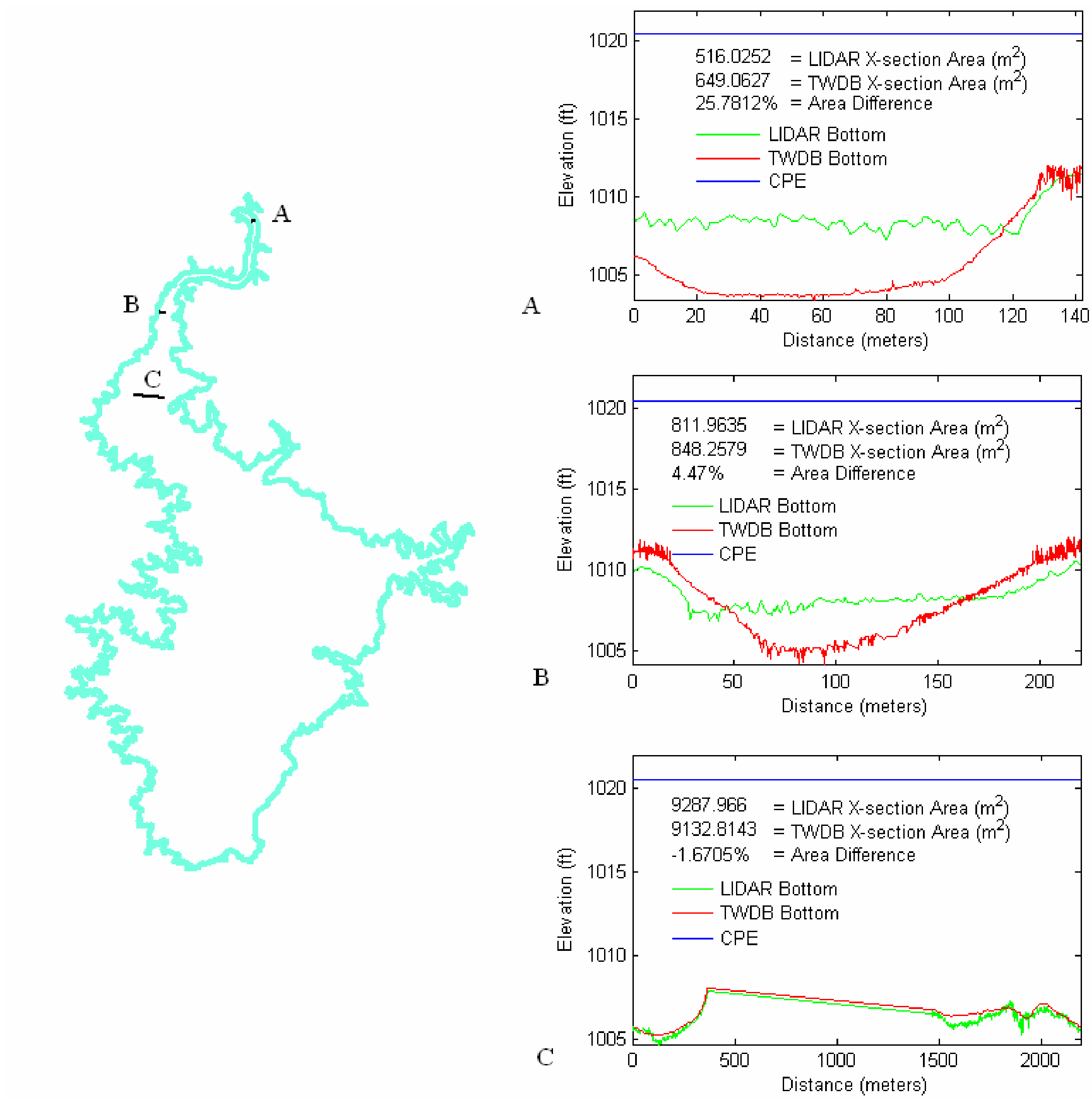



*Figure J2 – LIDAR & TWDB Cross Sections upstream of Willow Slough – differences between LIDAR & TWDB cross sections diminish in the downstream direction. TWDB suspects the LIDAR data is reflecting off the surface of the Colorado River as in flows into Lake Buchanan, thereby preventing the LIDAR cross-sections from representing the channel bathymetry evident in the TWDB data.*

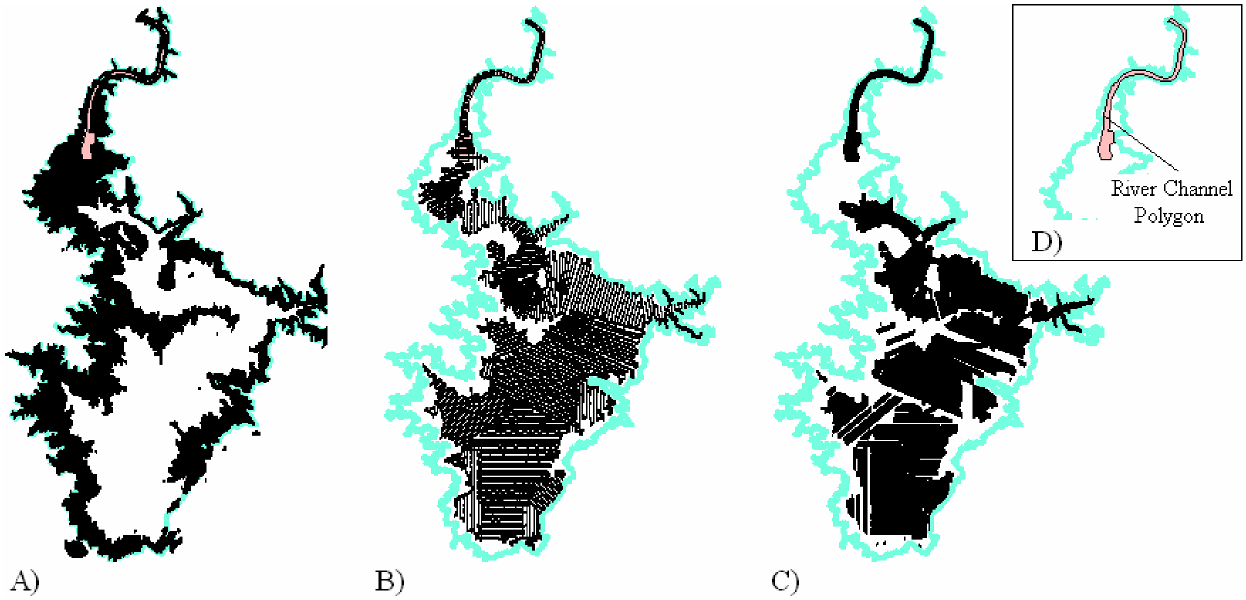


*Figure J3 – Lake Buchanan Maps – A) LIDAR points, B) TWDB sounding points, C) TWDB Interpolated Points, D) River Channel Polygon (orange). Note: TWDB interpolated points are located between adjacent TWDB cross sections, and not all adjacent cross-sections required interpolation.*

**TIN Model Generation**

Due to the large number of LIDAR points to be included in representing the bathymetric surface of Lake Buchanan, it was computationally impossible to create a single TIN model with elevations ranging from 906.6 ft (the lowest elevation based on the TWDB sounding data) to elevation 1,041 ft. Instead, multiple TIN models were constructed, each covering a portion of this elevation range. All point data were queried and separated into individual shapefiles, with each shapefile containing datapoints with elevations within a 1-ft increment (e.g. file_GE_1012_LT_1013.shp contained all points with elevations greater than or equal to 1,012 ft and less than 1,013 ft). Point shapefiles were then added individually to a TIN model using the "Edit TIN" command in ArcCatalog. With each added point shapefile, the resulting TIN model was clipped using the 1,040 ft contour polygon derived from available hypsography. The two TIN models created in this process were:

1. "TIN A" contains all points with elevations less than or equal to 1,025 ft except LIDAR points in the river channel upstream from Willow Slough.
2. "TIN B" contains all non-LIDAR points and all LIDAR points with elevations above 1,015 ft.

These TIN models are depicted in Figure J4. Calculations of the reservoir area and volume for each elevation were performed separately on each of the TIN models, with the volumes summed in Microsoft Excel.

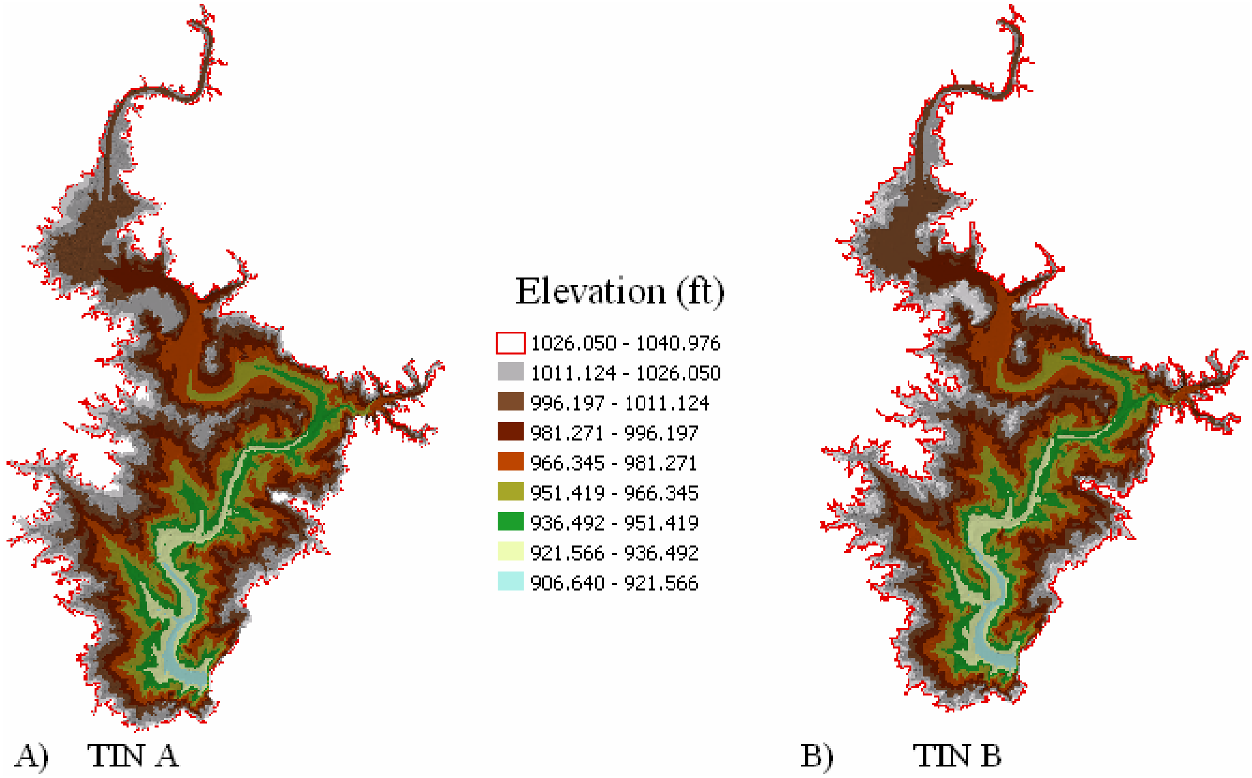



*Figure J4 TIN Model Representation of Lake Buchanan Bathymetry –A) TIN A, B) TIN B. Both TINs were clipped using a 1,040-ft contour polygon. TINs shown at differing scales.*

As shown in Figure J4, the most noticeable differences between TIN A and TIN B are how each surface model depicts the lake bathymetry in the shallow upper reaches of the reservoir. Specifically, TIN A contains a more detailed representation of the river channel (Figure J4A), where as TIN B contains a more detailed representation of the upper banks along the rim of the reservoir (Figure J4B). The distinction between each TIN is more evident in close-up views (Figure J5) containing the upper portions of TIN A and the lower portions of TIN B. As shown in Figure J5A, submerged river-channels are evident in high resolution, whereas the terrain for higher-elevations is not well resolved. In Figure J5B, the river channels are poorly resolved, however the higher terrain is well represented, with roadways clearly discernible within the TIN model.

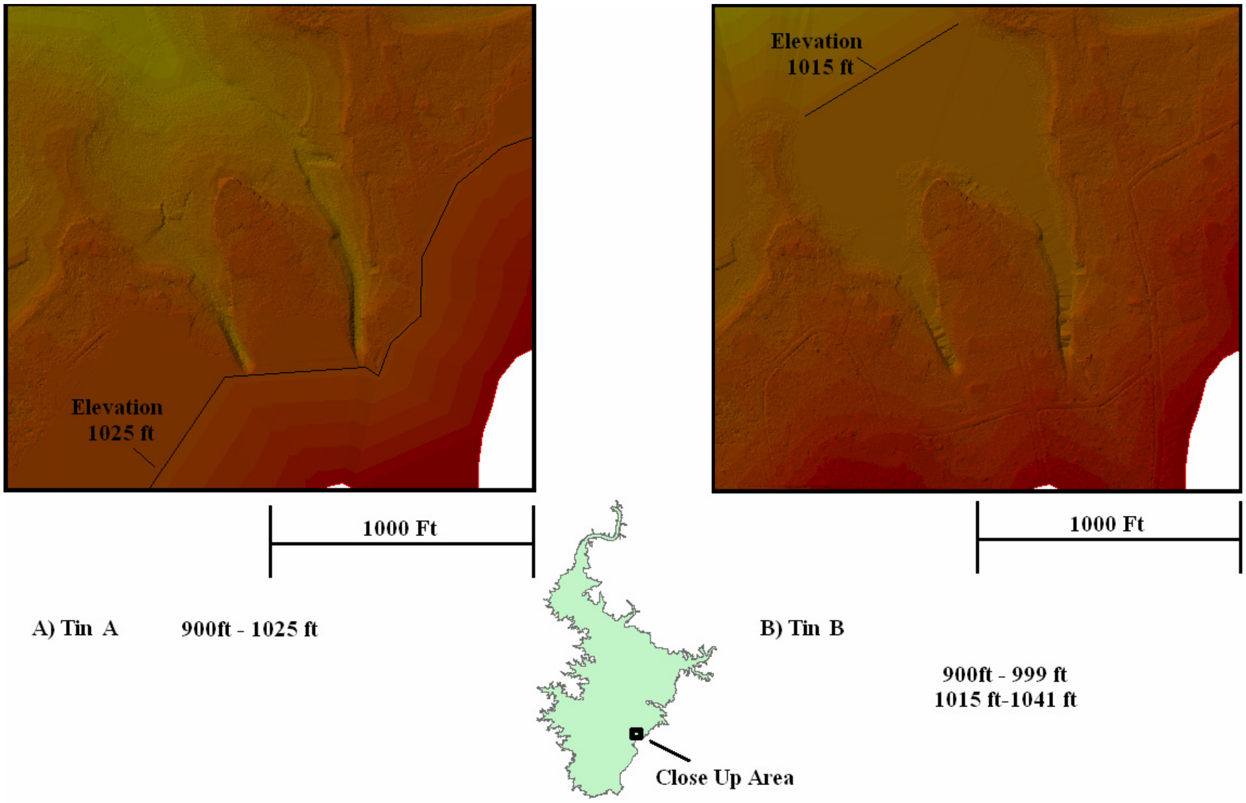



*Figure J5 – Terrain Representation using LIDAR data – A) TIN A, showing detailed terrain up to elevation 1,025 ft, B) TIN B, showing detailed elevations above elevation 1,015 ft. By combining data from each TIN, a detailed representation of the complete Lake Buchanan bathymetry would be achieved.*

When combined, these two TINs fully describe the Lake Buchanan bathymetry from elevation 906.6 ft to 1,041.0 ft. The 10-ft of vertical overlap between these two TINs (i.e. from elevations 1,015 ft to 1,025 ft) is used in the summation of the volumes derived from each TIN. Specifically, the volume values for each elevation (in 0.1 ft intervals) are computed for each TIN. These values are combined to compute the total volume of the lake, however the values from the TIN B (elevations 1,015 ft to 1,041 ft) need to be adjusted since this TIN was not derived from all of the datapoints with elevations less than 1,015 ft. Therefore the volumes computed at such elevations from TIN B will not be accurate. However, incremental volumes (ie the volume increase due to the 0.1 ft increase in elevation) will be accurate as long as the TIN model contains all sounding points within the elevation increase. In theory, the incremental change in volume computed for each TIN in the overlap elevations should be identical, as both TIN models contain all of the appropriate datapoints. As shown in Figure J6, when the incremental change in volume for each TIN is identical, then the volumes may be added. In practice, the incremental volumes of TIN B were slightly less than those from TIN A in the overlap region (Figure J6), however the difference is a small percentage of the lake volume and increment volume. The difference is due to the lack of LIDAR datapoints in the vicinity of the Lake Buchanan dam (Figure J3). To create a proper representation of the bathymetry in this area, TWDB sounding and interpolated points had to be added to TIN B (Figure J4B) – this avoided large errors in the TIN surface in the vicinity of the dam and minimized errors in the volume calculation. The minimized errors resulted in a 4 acre-ft difference in incremental volumes between the two TIN models near the elevation 1,022.0 ft. Based on this small difference, the final volumes and areas for Lake Buchanan (as reported in Appendix A, B) were derived from TIN A up to elevation 1,022.0 ft, and from TIN B for elevations above and including 1,022.0 ft.

| Elevation | TIN A Volume | TIN B Volume | TIN A Increment | TIN B Increment | Increment Difference | Report Volume | | |
|---|---|---|---|---|---|---|---|---|
| 1015.1 | 769,761 | 767,440 | 2,107 | 2,093 | 14 | 769,761 | TIN A VOLUME | |
| 1015.2 | 771,872 | 769,540 | 2,111 | 2,100 | 12 | 771,872 | | |
| 1015.3 | 773,985 | 771,642 | 2,113 | 2,102 | 10 | 773,985 | | |
| 1015.4 | 776,101 | 773,749 | 2,116 | 2,107 | 9 | 776,101 | | |
| 1015.5 | 778,219 | 775,858 | 2,117 | 2,109 | 9 | 778,219 | | |
| 1015.6 | 780,338 | 777,970 | 2,120 | 2,112 | 8 | 780,338 | | |
| 1015.7 | 782,462 | 780,086 | 2,123 | 2,116 | 8 | 782,462 | | |
| 1021.3 | 904,430 | 901,771 | 2,236 | 2,232 | 4 | 904,430 | | |
| 1021.8 | 915,661 | 912,982 | 2,252 | 2,248 | 4 | 915,661 | | |
| 1021.9 | 917,918 | 915,235 | 2,257 | 2,253 | 4 | 917,918 | | |
| 1022.0 | 920,177 | 917,490 | 2,259 | 2,255 | 4 | 920,173 | | <- Base Volume |
| 1022.1 | 922,439 | 919,748 | 2,262 | 2,258 | 4 | 922,431 | Base Volume + TIN B Increments | |
| 1022.2 | 924,706 | 922,011 | 2,267 | 2,263 | 4 | 924,694 | | |
| 1022.9 | 940,660 | 937,936 | 2,290 | 2,285 | 4 | 940,619 | | |
| 1023.0 | 942,951 | 940,223 | 2,291 | 2,287 | 4 | 942,906 | | |
| 1024.5 | 977,738 | 974,891 | 2,355 | 2,331 | 24 | 977,574 | | |
| 1024.6 | 980,112 | 977,224 | 2,374 | 2,333 | 41 | 979,907 | | |
| 1024.7 | 982,525 | 979,561 | 2,413 | 2,336 | 77 | 982,244 | | |
| 1024.8 | 984,987 | 981,902 | 2,462 | 2,342 | 121 | 984,585 | | |
| 1024.9 | 987,453 | 984,244 | 2,465 | 2,342 | 123 | 986,927 | | |
| 1025.0 | 989,919 | 986,588 | 2,467 | 2,344 | 122 | 989,271 | | |
| 1025.1 | | 988,935 | | 2,347 | | 991,618 | | |
| 1025.2 | | 991,285 | | 2,350 | | 993,968 | | |
| 1025.3 | | 993,640 | | 2,355 | | 996,323 | | |
| 1025.4 | | 995,995 | | 2,355 | | 998,678 | | |
| 1025.5 | | 998,353 | | 2,358 | | 1,001,036 | | |

*Figure J6 – Combining Volume Calculations between TIN models – volumes reported in Appendix A were computed from TIN A up until elevation 1,022.0 ft. Volumes for elevations greater than 1,022.0 ft were computed as the TIN A volume at elevation 1022.0 ft (Base Volume) plus the incremental change in volumes from TIN B for all elevation increments above elevation 1,022.0 ft. Calculations were made in Microsoft Excel. Rows are hidden for clarity.*

To create the elevation relief (Figure 4), Depth Range (Figure 5), and 10-ft contour maps (Figure 6), TIN A was converted into a raster gird with elevations assigned at the centers of 10 ft x 10 ft grid cells. The raster grid was masked to elevation 1,020.5 (conservation pool elevation), with all cells containing elevations greater than this value converted to NODATA cells.

**Comparing LIDAR and TWDB Sounding Data**

With the LIDAR data points ranging in elevation from 999.0 ft to 1,041.0 ft and the survey points collected by TWDB ranging in elevation from 906.6 ft to 1012.0 ft, there exists an overlap in elevations captured within each dataset. This overlap, specifically from 999.0 ft to 1012.0 ft, allows for the comparison of the LIDAR data and TWDB surveyed data. Datasets were compared by creating a TIN model ("TIN LIDAR") using the LIDAR datapoints, and then determining the elevation from TIN LIDAR at the exact coordinates of each TWDB surveyed datapoint within the area spanned by the TIN LIDAR surface. In order to avoid incorrect elevation assessments near the border of the TIN LIDAR surface, only TWDB surveyed points within 5 ft of at least 3 LIDAR datapoints were used in the comparison. All comparisons were made using MATLAB scripts and the MATLAB “Delaunay” triangulation function. This function is identical to the function used in ArcGIS for creating TIN models, and no differences between the MATLAB- created and ArcGIS-created TINS were observed.

Exactly 116,878 comparisons between the LIDAR surface and the TWDB sounding points, with the $R^2$ value between the two datasets equal to 0.94343 (Note: $R^2 = 1$ indicates a perfect correlation between datasets). The RMS difference between the LIDAR elevations and the TWDB elevations is 0.90 ft, which is significantly larger than the expected accuracy of either the LIDAR or TWDB datasets. Figure J7 demonstrates the correspondence between the two datasets, where equal elevations would plot on the 1:1 line (black). As shown, deviations from the 1:1 line are similar to both the left and right. Causes for the elevation differences are indiscernible from the data and may be identified through detailed analyses of the data collection/processing methods of both TWDB and the LIDAR data providers. One outlier is not shown in Figure J7, with its LIDAR elevation of 1004.8 ft and its TWDB elevation of 987.9 ft. This outlier is highlighted in Figure J8.

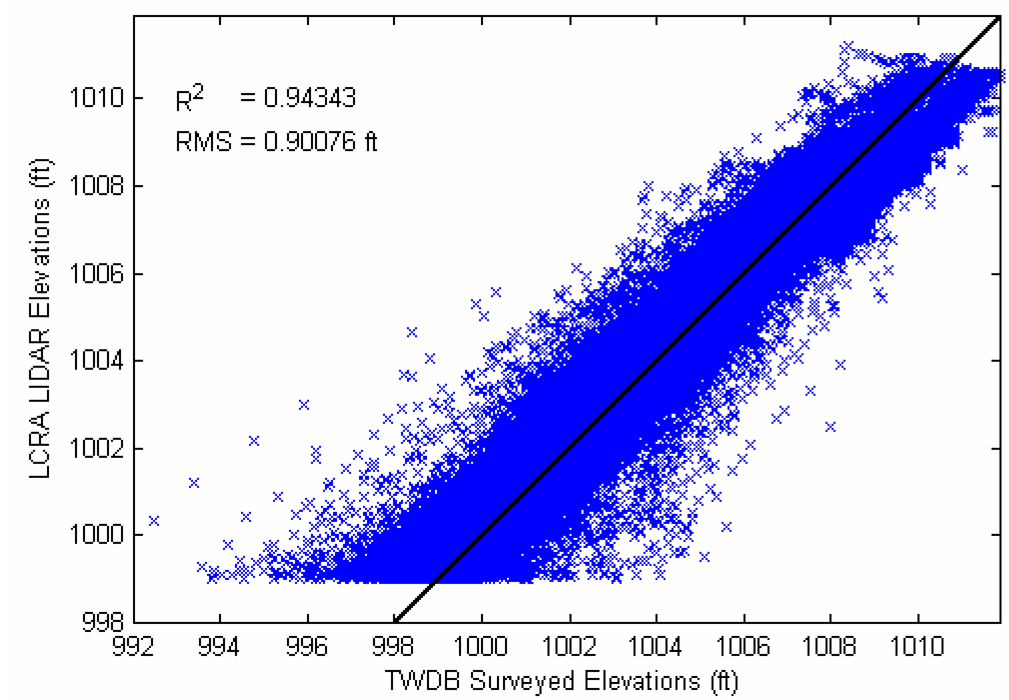



*Figure J7 – Comparison of TWDB sounding elevations and LIDAR surface elevations. Note: 1 outlier not shown (LIDAR Elevation = 1,004.8 ft, TWDB Elevation = 987.9 ft).*

Of the 116,878 elevation comparisons, the 6-largest differences are between elevations are shown in Figure J8. This figure presents the location of the LIDAR points (dots) and TWDB soundings (crosses). The LIDAR elevation at each TWDB sounding location is computed by first creating a TIN model out of the LIDAR points, then identifying the triangle in the TIN that contains the TWDB point, and then computing the TIN elevation at the point location based on the point location and the known locations/elevations of the TIN triangle’s vertices. For the TWDB soundings shown in Figure J8A, the corresponding LIDAR surface elevations range from 1,003 ft to 1,000 ft and are all approximately 8 ft higher than the TWDB sounding elevations.

This elevation difference is not due to the LIDAR soundings reflecting off a dock or other structure floating on the lake surface – as evidenced by the similar LIDAR elevations in the vicinity of the sounding points. The difference in elevations shown in Figure J8B is similarly unexplainable as the LIDAR points about the TWDB sounding are all of approximately the same elevation nearly 15 ft higher than the TWDB sounding elevation. This point is the outlier point not shown in Figure J7. Figure J8C also shows an un-explainable 6+ ft elevation difference between the TWDB soundings and LIDAR elevations.

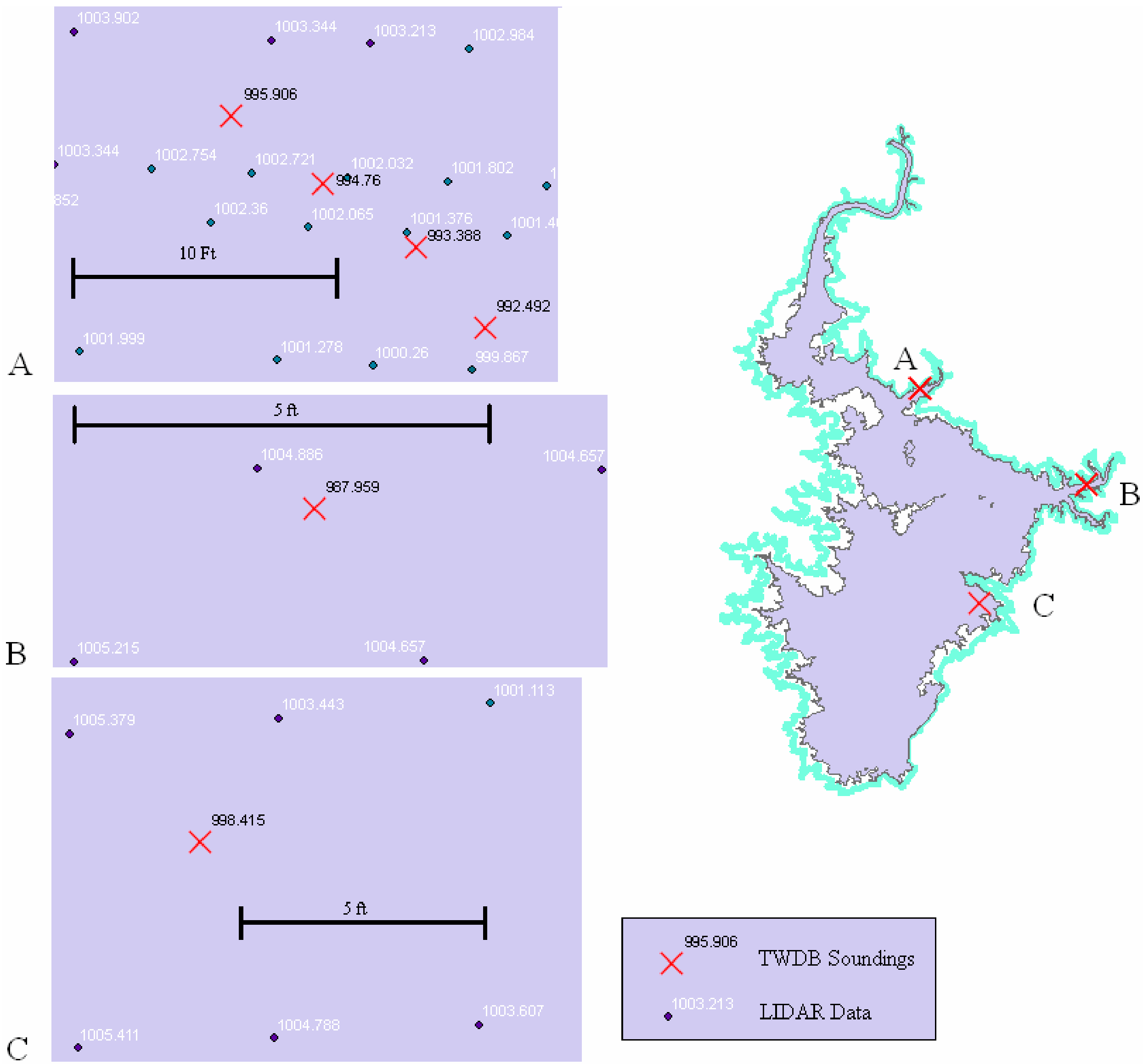


*Figure J8 – Large Differences in TWDB Sounding & LIDAR elevations – LIDAR points shown as dots with elevations in white, TWDB Soundings shown as crosses with elevations in black. Point "B" is the outlier point not shown on Figure J7.*

As shown in Figure J9, there does not appear to be a spatial correlation between larger differences in elevations from the LIDAR and TWDB data. The areas where the elevations from each dataset differ by at least 2 ft (Figure J9 B, C) are found throughout the lake and are not distinct, meaning that areas where the LIDAR data is 2 ft higher than the TWDB data are immediately adjacent to areas where the opposite elevation difference was measured. The overwhelming majority of comparisons between LIDAR and TWDB data showed that the elevations between the two sets differed by less than 2 ft (Figure J9A). For this reason, all TWDB sounding data was included in the final TIN model representations of the Lake Buchanan bathymetry.

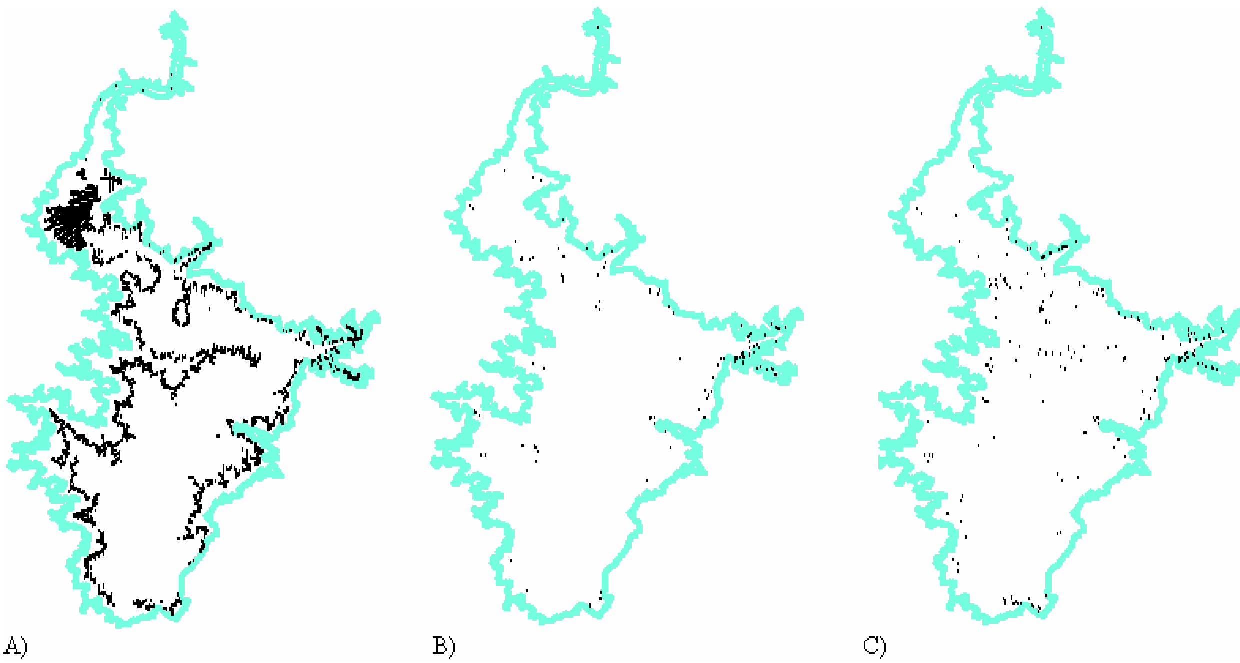


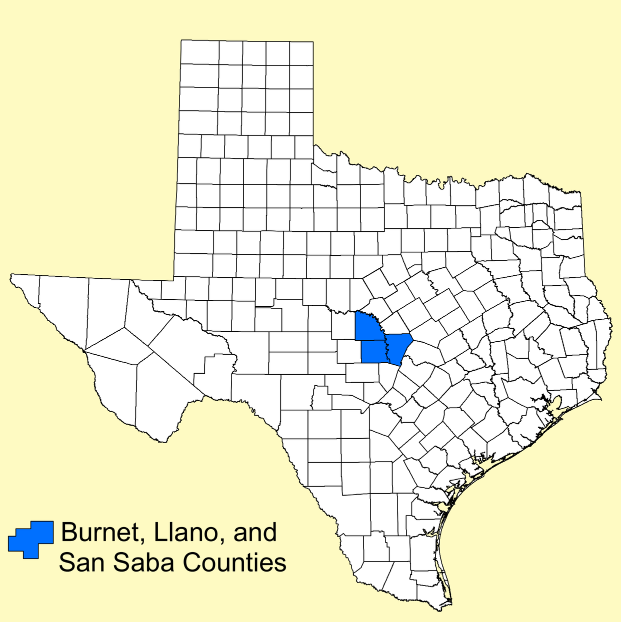

*Figure J9 – Spatial clustering of differences between TWDB sounding elevations and LIDAR surface elevations. A) Elevations differences of less than 2 ft, B) Elevations differences greater than 2 ft, with the TWBD elevations less than the LIDAR elevations, C) Elevations differences greater than 2 ft, with the TWBD elevations greater than the LIDAR elevations. Lake boundary shown at E = 1,040.0 ft.*

# Figure 6

## CONTOURS

- 910
- 920
- 930
- 940
- 950
- 960
- 970
- 980
- 990
- 1000
- 1010

Lake Buchanan Conservation Pool Elevation 1020.5 ft




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