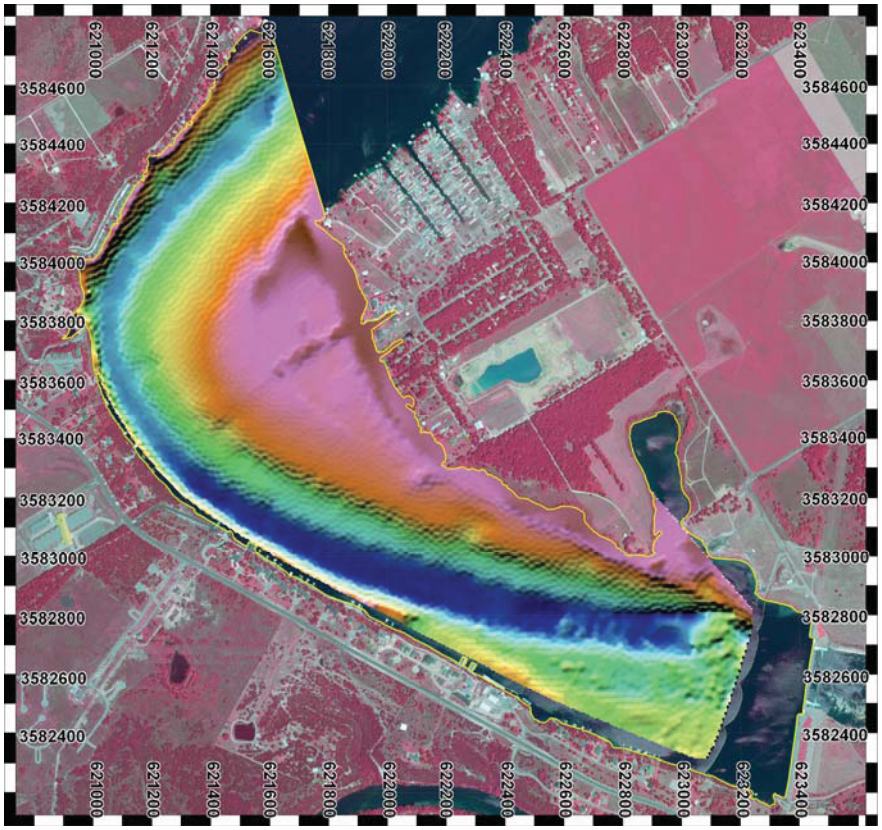
BATHYMETRY AND VOLUME STORAGE OF A PORTION OF LAKE GRANBURY,

HOOD COUNTY, TEXAS



Color shaded relief map of Lake Granbury, Hood County, Texas

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EXECUTIVE SUMMARY

A dual frequency (28/200 kHz) echo sounding system linked to a global positioning system (GPS) receiver was used to map lowermost Lake Granbury, Hood County, Texas during April-May 2007. A total 74.3 miles (120.4 km) of trackline echo sounder data were acquired over 507 acres of lower Lake Granbury. Echo sounder tracks extended from the floating safety boom near the dam site upstream approximately 1.9 miles (3.1 km). Raw bathymetric soundings were processed to remove outliers or incorrect soundings and smooth filtered to yield high-resolution bathymetric grids across mapped surface waters. Bathymetric data were then processed using geographic information systems (GIS) software to generate detailed gridded bathymetric maps of surface water bodies. Echo sounder data were supplemented with elevation data extracted from a USGS 30-m digital elevation model (DEM) of Acton, Texas 7.5-minute quadrangle. Gridded bathymetric maps were resampled to 2m resolution and grid nodes were extracted to yield 508,408 individual soundings within the mapped area. Gridded bathymetric data were contoured at 1-ft interval and estimates of surface area and volume storage within the mapped area were derived from contoured data using the GIS. The following report summarizes data derived from bathymetric mapping at Lake Granbury and provides a catalog of data files included on the accompanying DVD disc.

INTRODUCTION

Lake Granbury is an impoundment of the Brazos River in Hood County, Texas. In December 1966, the Brazos River Authority commenced construction of the De Cordova Bend Dam in order to provide flood control, a water conservation reservoir, drinking water, and recreation for nearby communities. The dam was completed in September 1969 creating Lake Granbury. The reservoir presently provides multiple uses, serving both its original functions as well as supplying industrial water for a TXU natural gas-fired steam electric power plant at the lake and cooling water for the Comanche Peak nuclear power generating facility near Glen Rose, Texas (approximately 8 miles southwest of De Cordova Bend Dam; Brazos River Authority, 2007, http://www.brazos.org/gbHome.asp).

In April 2007, Enercon Services, Inc. conducted bathymetric mapping over 507 acres of lower Lake Granbury (Fig 1). The mapped area extended from the floating safety boom near the De Cordova Bend Dam upstream approximately 1.9 miles to an area locally referred to as Walters Bend (U.SG.S 7.5-minute Acton, TX quadrangle map), the location of the TXU electric power generating facility. Enercon Services, Inc. contracted with Dr. Stephen K. Boss, University of Arkansas to process bathymetric data, develop detailed bathymetric maps of the mapped areas of Lake Granbury, and estimate area-elevation-volume relationships within the mapped area. The following report documents analytical methods and results obtained from this mapping project.

Fig. 1. Aerial photograph of lower Lake Granbury, Hood County, Texas. The yellowsborder along the lake represents the area mapped for this study. Aerial photography obtained from Texas Natural Resources Information System (http://www.tnris.state.tx.us/); Color IR image acquired as part of National Agriculture Imagery Program (NAIP), 2004. De Cordova Bend Dam is located at the southeast corner of the image. The floating safety boom upstream of the dam is clearly visible in this image. Grid on image border is 100m; grid numbers on image are UTM coordinates, 200m spacing. North at top of image.

METHODS

All bathymetric data were acquired using a Knudsen Engineering, Ltd. Model KEL B/P 320 echo sounding system. The Model 320 B/P echo sounder transmits acoustic energy with two distinct frequencies, 200 kHz and 28 kHz (Anonymous, 1998). The 200 kHz (high frequency) band had sufficient energy to penetrate the water column but reflected from the water/sediment interface (Fig. 2). Data from this frequency were used to generate maps depicting present-day bathymetry of the reservoir within the study area. The theoretical vertical resolution of the 200 kHz pulse (i.e. one-quarter λ; Sherrif, 1985) is 1.85 mm, though in practice vertical resolution is typically only 1 – 2 cm because theoretical ideal conditions are not achievable in the field.

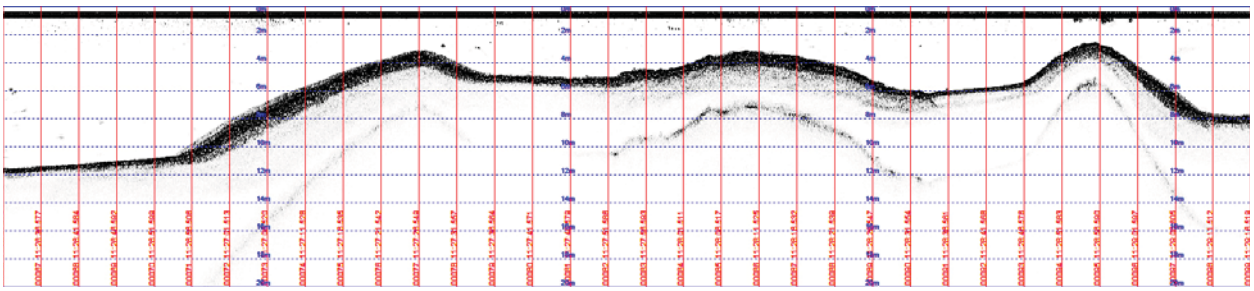

Fig. 2. Example of echo sounder profile from Granbury Lake project area. Heavy dark like with irregular relief represents echo from lake bottom. Vertical scale on image is 66 ft (20 m). Horzontal width of image is approximately 1,083 ft (330 m).

Bathymetry

Echo sounder mapping of lower Lake Granbury was conducted 3 – 12 April 2007. The Knudsen 320 B/P echo sounder system was mounted on the survey vessel which was then steered in an overlapping grid pattern to ensure maximum areal coverage while minimizing acquisition time at the site (Fig. 3). For all mapped areas, echo sounder operations were limited to water depths greater than approximately 5 ft. A total of 74.3 trackline miles were acquired over 507 acres of lower Lake Granbury during the field interval of this study.

Navigation data were acquired using a Trimble Pathfinder Pro XRS Global Positioning System (GPS) receiver. Location and time reported by the GPS were automatically logged every 5 seconds during the survey. All GPS data appear to have been differentially corrected in real time using differential GPS beacons located nearby each mapped site. Differentially corrected GPS data typically have horizontal position accuracy of 1 - 3 m.

Following the field data acquisition, echo sounder data and GPS navigation were merged using spreadsheet software, and geographic positions were interpolated between 5-second navigation fixes to yield a database with navigation data merged to echo profile data at 0.1-second intervals (estimated to be approximately 0.1 to 0.15-m along track). All echo data were reviewed for quality and processed to remove outliers or incorrect values. Incorrect echo 'pings' may be generated by a variety of conditions. Common causes for incorrect 'pings' are submerged aquatic vegetation, schools of fish, submerged trees or other submerged objects, significant turbulence in flowing water, thermal turbulence (as from water discharges from power generating facilities), and wake turbulence generated by either the propulsion system of the survey vessel or wake turbulence generated by the survey vessel itself, or malfunctioning of the

echo sounder system. In addition, echo sounder data were smooth filtered using a maximum-minimum error algorithm based deviation from 10-sounding mean values along each echo sounder profile.

Fig. 3. Map showing distribution of dual frequency echo sounder tracklines (magneta lines) on lower Lake Granbury acquired 3 – 12 April 2007. Note several data gaps resulting from both poor data and corrupted echo sounder files. These data gaps were filled using digital terrain data obtained from USGS 30-m digital elevation model of Acton, TX 7.5 minute quadrangle (see description below). Also note limits of mapped area corresponding to area enclosed by yellow border. Map grid and orientation same as for Fig. 1.

Measured bathymetry was documented in meters and in feet below the surface water level on the date of mapping. Water levels for Lake Granbury during the data acquisition interval were acquired from the Ft. Worth District, United States Army Corps of Engineers. Lake level varied during data acquisition from 692.4 ft above mean sea-level to 692.7 ft above mean sea-level and averaged 692.53 ft above mean sea-level. Lake levels during this time were within nominal levels reported for this reservoir (conservation pool elevation = 693 ft amsl; Texas Parks and Wildlife Dept., 2007; http://www.tpwd.state.tx.us/fishboat/fish/recreational/lakes/granbury/). All processed and corrected echo sounder data were imported to Geographic Information System software where they were gridded to create digital terrain models.

In addition to bathymetric data acquired during April 2007, digital terrain data were obtained from a 30-m digital elevation model (DEM) for the Acton, Texas 7.5-minute topographic quadrangle publicly-available through the Texas Natural Resources Information System on-line geospatial data clearinghouse. This 30-m DEM was originally prepared by the U.S. Geological Survey as part of the National Mapping Program. Interestingly, digital terrain data appear to have been derived from a 7.5-minute topographic quadrangle series pre-dating impoundment of Lake Granbury. As such, pre-impoundment elevations of areas presently inundated were extracted from 30-m DEMs and merged with dual frequency echo sounder data to fill in data gaps within the mapped area. In merging these data, it was assumed the sediment infilling of this portion of the reservoir was minimal since its impoundment in 1969 (almost 40 years ago). Several observations suggest this assumption was valid: 1) the mapped area is near the terminus of the impoundment and sediment infilling of this region would require very long transport of sediments from the upstream head of the impoundment; 2) the maximum depth of Lake Granbury within the Acton quadrangle 30-m DEM was 67 feet; 3) the greatest depth obtained during echo sounder profiling of Lake Granbury was 66.4 ft. Throughout the mapped region where echo sounder data could be co-located with 30-m terrain data from the DEM, the correlation of depths was generally as good or better than 2 feet. Finally, merging of these data did not generate spurious or unusual topographic features on the final gridded bathymetry.

The resulting final terrain model was derived from 508,408 individual soundings within the mapped area. The final terrain model was color-coded by elevation and "illuminated" to create a shaded relief image (Fig. 4). Gridded bathymetric data were then contoured with a 1-foot contour interval using the automated contouring function of the GIS software (Fig. 5). No adjustments to derived contours were made.

Area Calculations

The total area of the mapped portion of lower Lake Granbury was determined by digitizing a polygon of the water body limits observable on digital orthophoto quarter quadrangles (DOQQ) of each site. The dates of the DOQQs were 2004 (Texas Natural Resources Information System, 2007; http://www.tnris.state.tx.us/) and it was assumed the water level observed on each DOQQ was representative or typical for this reservoir. Comparison of the derived digital boundaries to mapped echo data suggests this assumption is valid. The total area (acres) of the polygon bounding the mapped area was determined from the GIS software to be 577.0 acres. The total area covered by survey tracklines (magenta lines on Fig. 3) was 507.0 acres

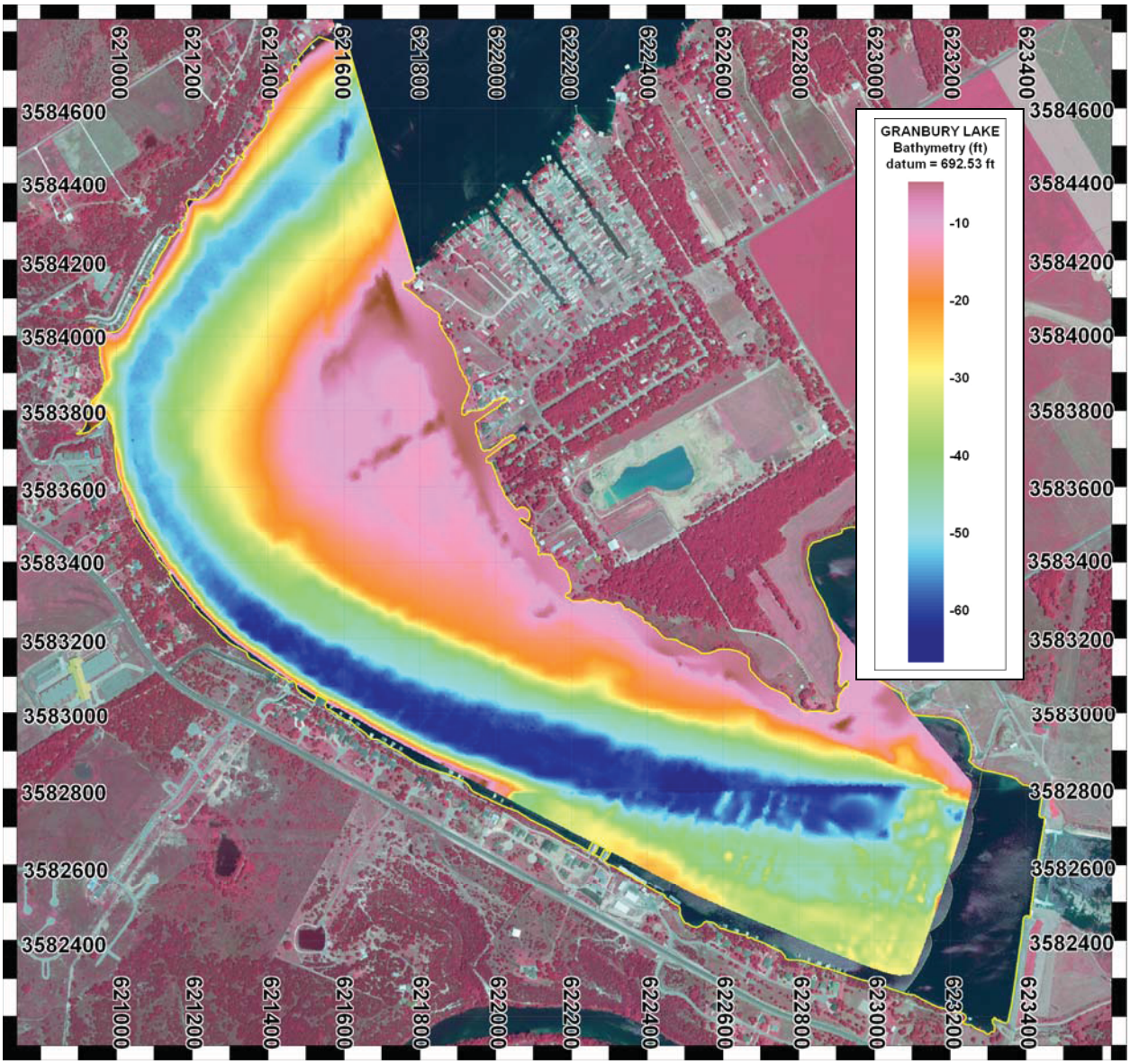

Fig. 4. Colored relief map of lower Lake Granbury derived from merged echo sounder and DEM data.

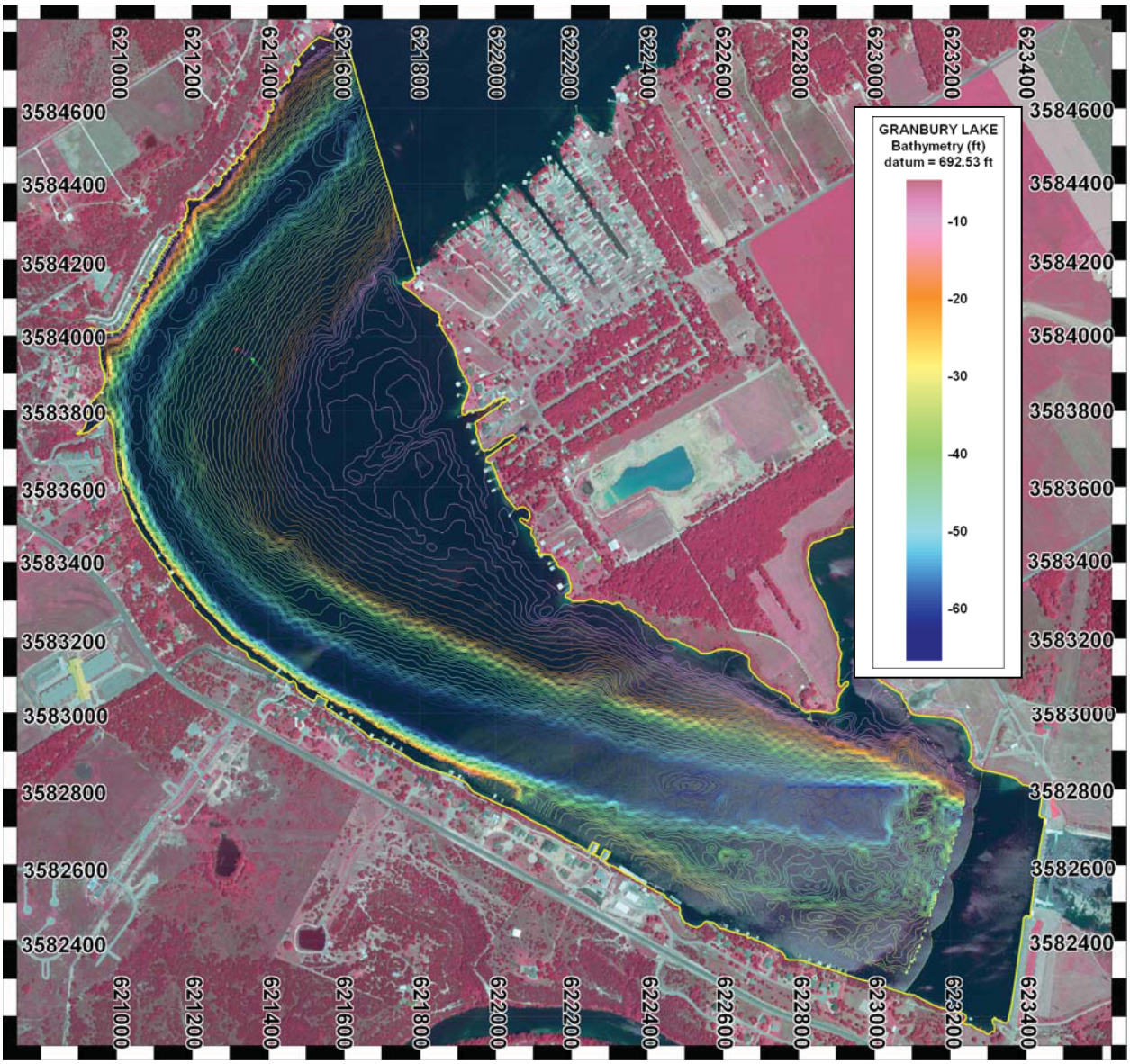

Fig. 5. Contour map of lower Lake Granbury derived from gridded bathymetric data displayed in Fig. 4. Contour interval = 1 ft.

Contour lines (Fig. 5) were converted to polygons bounding upper and lower 1-ft contours (for example, contours depicting -10 foot and -11 foot depths were joined to create a polygon bounding the -10 to -11 foot region of lower Lake Granbury). The area (in acres) of each polygon was derived from the GIS, and all contour-bound areas were summed to determine a total area mapped for each water body. Note that in all areas included in this study, the mapped area (507 acres) was slightly less than the total surface area (577 acres) of the impoundment because very shallow water in some upstream arms and nearshore areas limited navigability and excluded the area between the De Cordova Bend dam and the floating safety boom (Figs. 1,3).

Bathymetry for areas shallower than the operable depths of the echo sounding system were interpolated from the last recorded data point to zero-depth at the shore. For purposes of mapping these areas, the shore was taken as the boundary of the digitized polygon of the water body (yellow bounding line on Figs. 1, 3-5).

Volume Calculations

Volume calculations (acre-feet) for the mapped area were determined by multiplying the areas bound by contours and the mean depth between contours. For example, the area bound by -10 ft. and -11 ft. contours was multiplied by 10.5 ft. to obtain the volume of this parcel. All volume calculations were summed to estimate the maximum volume storage for lower Lake Granbury.

In addition to estimating maximum volume storage using the methods above, volume estimates for varying reservoir levels (elevations) and areas were derived by 'stripping' from the elevation measured on the days of data acquisition to the maximum observed depth at each site. Curves depicting impoundment area versus elevation (Fig. 6), area versus volume (Fig. 7), and elevation versus volume (Fig. 8) were prepared and are included below.

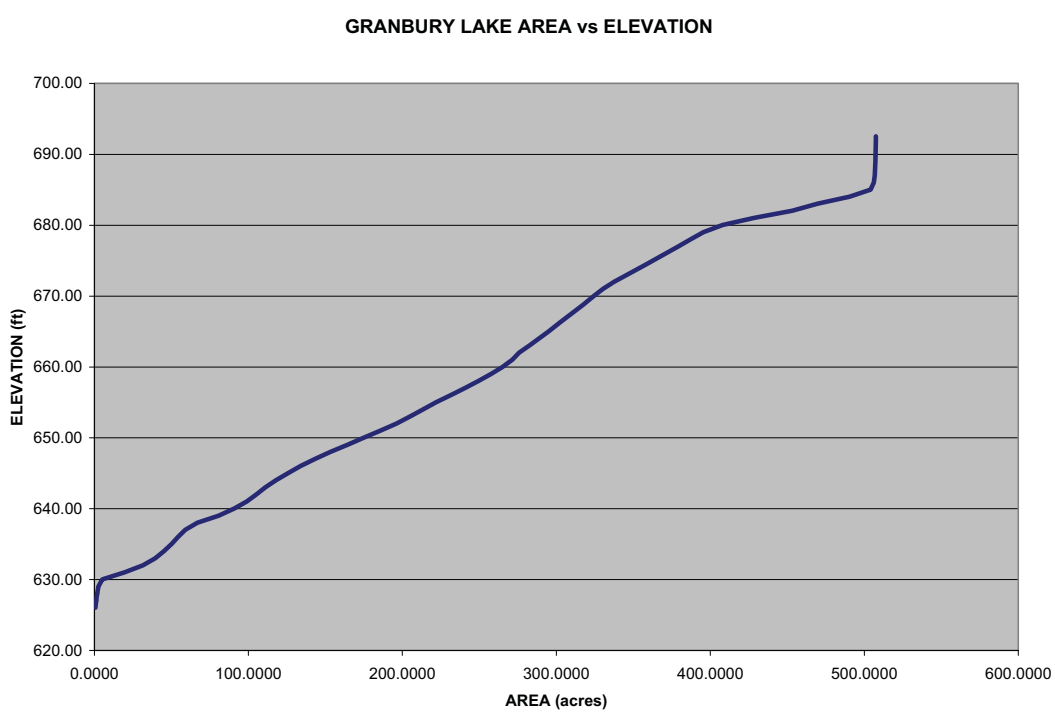

Fig. 6. Plot of surface area versus elevation derived from bathymetric data for lower Lake Granbury.

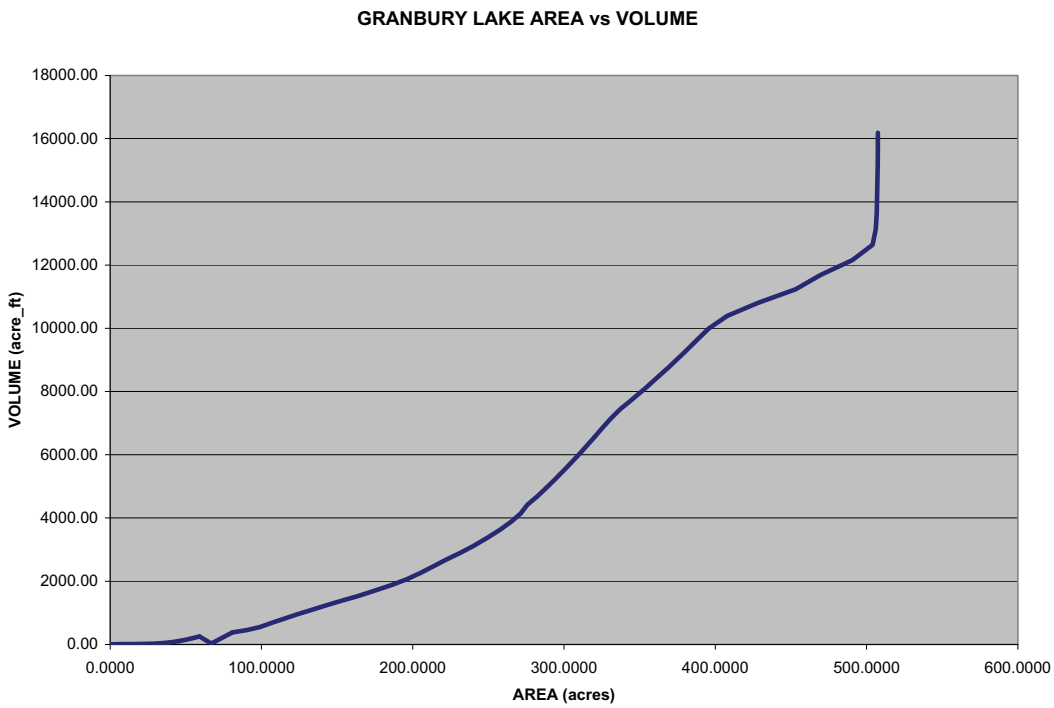

Fig. 7. Plot of surface area versus volume derived from bathymetric data for lower Lake Granbury.

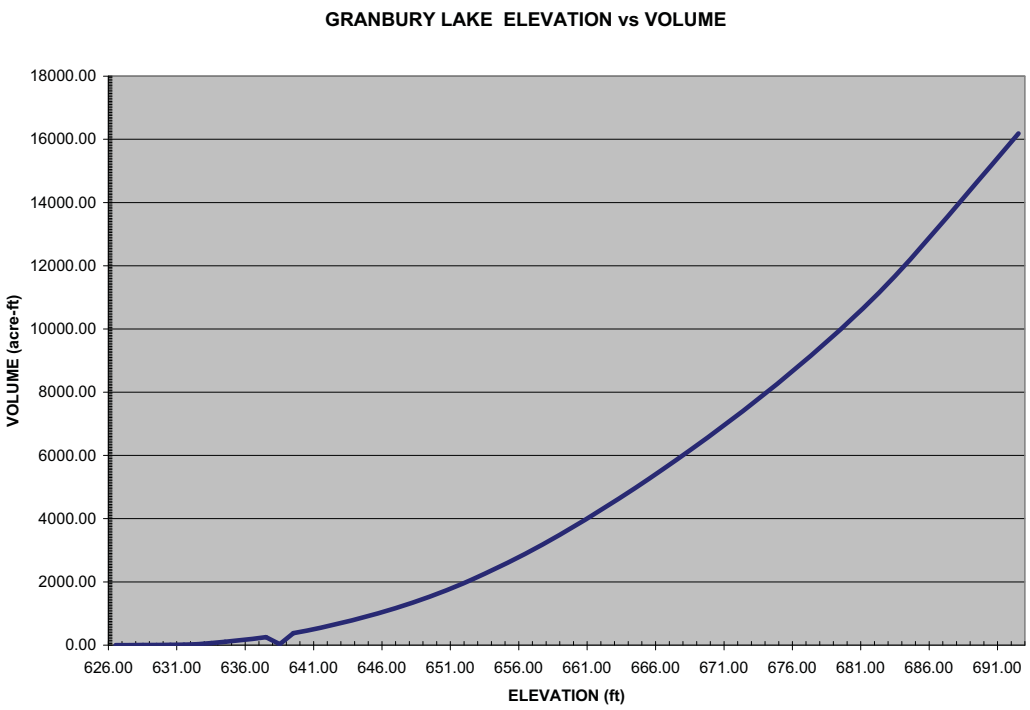

Fig. 8. Plot of elevation versus volume derived from bathymetric data for lower Lake Granbury.

RESULTS

Bathymetry

Overall, the bathymetry of lower Lake Granbury is rather simple, being formed from a broad meander of the Brazos River. Within the mapped area, bathymetry ranged from 0 – 67 ft with an average depth of 32.3 ft (standard deviation 17.2). A colored relief map (Fig. 9) shows the very distinctive former main channel of the Brazos River meander composing the lower reservoir to the dam site. In the northwest portion of the mapped area, a point bar is evident where gently sloping bathymetry eventually merges with the land surface. Along the inside bend of the main channel, a very well developed stream terrace is evident immediately adjacent to the former river channel. Upslope on the point bar itself, there appear to be two and possibly three additional stream terraces reflecting adjustment of the former free-flowing Brazos River to base-level changes.

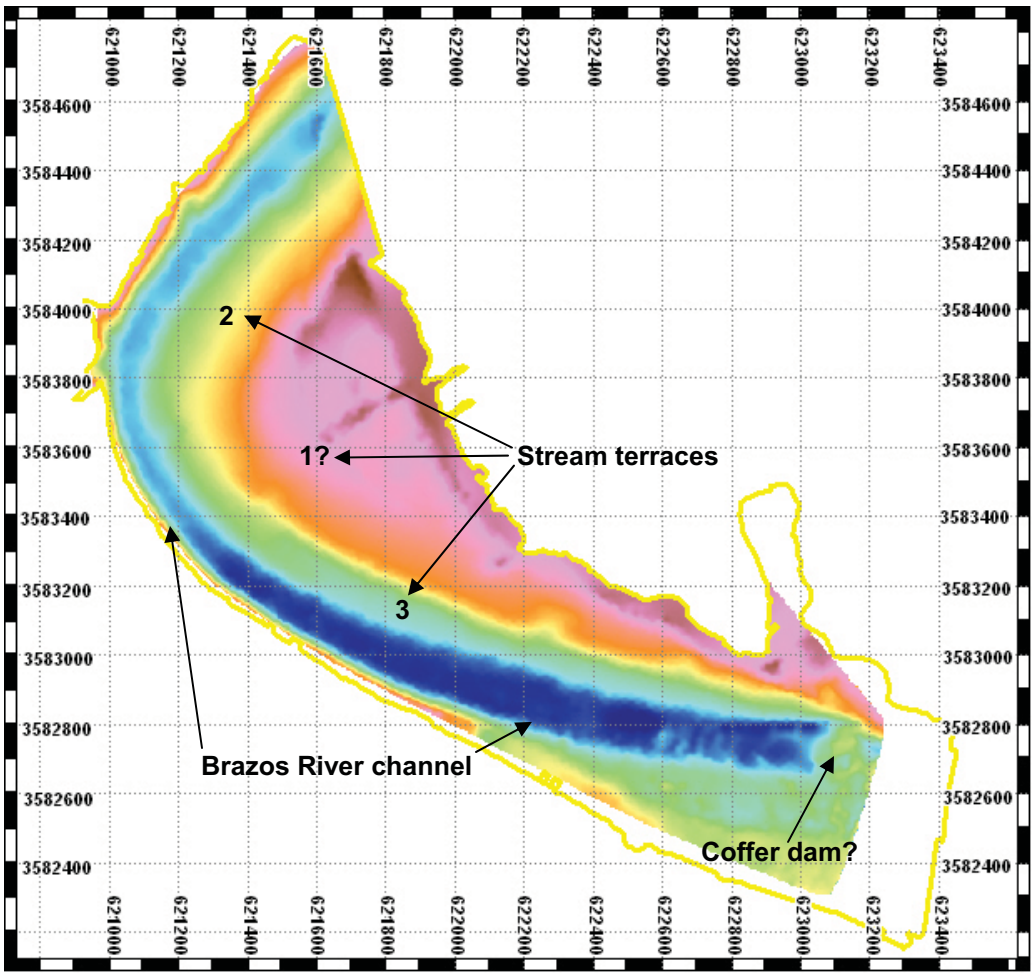

Fig. 9. Bathymetry of the Lake Granbury project area derived from echo sounder profiles and data merged from USGS 30-m digital elevation model of Acton, Texas 7.5-minute quadrangle. Note of this map the main channel of the Brazos River is plainly evident, as are several well-developed stream terraces. The bathymetric anomaly labeled "Coffer dam?" is of unknown origin. This structure abruptly truncates the river channel and may be the remnant of a coffer dam built to divert stream flow during construction of De Cordova Bend dam. Alternatively, this feature could be the remnant of a lock and dam system that was constructed along the Brazos River during the early 20th Century.

The only unusual aspect of bathymetry in the mapped area is located near the southeast corner of the map. Here, the main channel of the Brazos River is abruptly truncated by a structure of unknown origin. Beyond the mapped area, the river channel appears to re-emerge, and is evident on the USGS DEM. The origin of this structure is not known. It is possible that it represents remains of a coffer dam that may have been constructed to divert the river during construction of the De Cordova Bend Dam in the 1960's or it could be the remnant of an early 20th Century lock and dam that was part of a proposed network to promote river commerce along the Brazos water course.

Volume Calculations

The total volume storage within the mapped area was determined from summation of areas between 1-ft contours to be 16,182 acre-feet for lake level of 692.53 ft above mean sea-level. The relation of surface area, elevation, and volume of lower Lake Granbury are presented in Figs. 6-8 above. These curves display forms typical of impoundments along rivers in that they show relatively simple correlations among the parameters area, elevation, and volume.

CONCLUSIONS

Dual frequency echo sounder profiles and publicly available digital terrain data were merged to generate a detailed bathymetric map of lower Lake Granbury, Hood County, Texas. The final bathymetric map was derived from 508,408 individual soundings processed from 74.3 miles of echo sounder profiles merged with digital terrain data from a USGS 30-m DEM of Acton, Texas 7.5-minute quadrangle within the 507 acre study area. The final map shows the former main channel of the Brazos River as well as several well-developed river terraces along the point bar comprising the northern shore of the lake. In addition, a bathymetric anomaly near the De Cordova Bend Dam (southwestern edge of mapped area) abruptly truncates the main Brazos River channel. This appears to be a man-made structure of unknown history or origin. It is known that there was an extensive attempt to establish a lock and dam system along the Brazos River during the early 20th Century for the purpose of promoting river commerce. It is not known if one of these sites existed within the mapped area. Alternatively, the bathymetric anomaly could represent remains of a temporary coffer dam that may have diverted the Brazos River during construction of the De Cordova Bend Dam during the 1960's. Within the mapped area, depths ranged from 0 – 67 feet (average = 32.3 ft). Total volume storage within the mapped area was calculated from areas between 1-ft contours to be 16,182 acre-feet at an elevation of 693.53 ft above mean sea-level.

APPENDIX I:

CONTENTS OF ACCOMPANYING DVD

The DVD disc accompanying this report contains a large number of digital data files derived from the original echo sounding data acquired at each site. The table below documents the contents of each sub-directory (folder) of the DVD using the file name and a brief description of the file contents and data format.

Directory/File Name	**Contents, Format**
Granbury Lake ASCII-DXF Exports	Files related to Granbury Lake mapping project.
/Granbury Bathymetric Data	Directory containing processed bathymetric data from echo sounding survey of lower Lake Granbury in the vicinity of De Cordova Bend Dam, Hood County, Texas; 1 file
/Granbury Lake_Bathy.txt	Bathymetric data (easting, northing, depth) from Lake Granbury mapping project in space-delimited ASCII format; 508,408 total soundings in file.
/Granbury Lake Contours	Directory containing polygons of 1-foot bathymetric intervals exported from GIS to ASCII DXF format; 68 files
/Granbury_*XX*-*YY*_ft.DXF	Individual polygons of 1-foot bathymetric contoured areas from Lake Granbury mapping area. All files are in ASCII DXF format; compatible with AutoCAD v.12.0. File naming convention includes depth of lower (*XX*) and upper (*YY*) contour in feet below water surface (0-depth)
../ Granbury Lake Gridded Data	Directory containing gridded bathymetric data in several common formats suitable for import into GIS software platforms; 5 files
/Granbury Lake Bathy_ASCIIpoint.txt	Gridded bathymetric data in ASCII point format.
/Granbury Lake Bathy_ASCIIgrid.txt	Gridded bathymetric data in ASCII grid format.
/Granbury Lake Bathy_DXFmesh.dxf	Gridded bathymetric data in DXF 'mesh' Grid format compatible with AutoCAD v.12.0..
/Granbury Lake Bathy_DXFpoint.dxf	Gridded bathymetric data in DXF 'point' Grid format compatible with AutoCAD v.12.0..
/Granbury Lake Bathy_USGS.DEM	Gridded bathymetric data in USGS 'DEM' Grid format.
Granbury Lake Maps – JPG Images	Directory containing exported map images from Granbury Lake project area; 7 files
/Granbury Lake Colored Relief.jpg	Large-format JPG image suitable for plotting; colored relief of Granbury Lake area bathymetry.
/Granbury Lake Shaded Relief.jpg	Large-format JPG image suitable for printing; color shaded relief of Granbury Lake area bathymetry.
/Granbury Lake 1 ft Contours.jpg	Large-format JPG image suitable for plotting; color coded contours of Granbury Lake area bathymetry; 1-ft contour interval.
/Granbury Lake Location.jpg	large-format JPG image suitable for printing; aerial image of Granbury Lake project area.
/Granbury Lake Bathy Legend.jpg	JPG image of color coded contour legend for bathymetric map.
/Granbury Lake Tracklines.jpg	JPG image of echo sounder tracklines within Granbury Lake project area
/Granbury Lake Gray Relief.jpg	Hill-shaded relief large format JPG image of Granbury Lake project area bathymetry.

Directory/File Name	**Contents, Format**
Granbury Lake Report	MS-Word document containing final report for Granbury lake project area.
Granbury Lake Elev-Area-Volume Data.xls	MS-Excel spreadsheet with measures and calculations used to estimate volume storage of Granbury Lake project area.
Granbury Lake Map Grid.DXF	DXF file compatiblewith AutoCad v.12.0 containing vectorized map grid and graticule used for border on all Granbury Lake project area maps.
Granbury Lake Map Grid Labels.DXF	DXF file compatiblewith AutoCad v.12.0 containing vectorized UTM coordinates corresponding to grid elements used for all Granbury Lake project area maps.
Granbury Lake Survey Boundary.DXF	DXF file compatiblewith AutoCad v.12.0 containing vectorized boundary of Granbury Lake project area.