VOLUMETRIC SURVEY
OF
BELTON LAKE

Prepared for:

BRAZOS RIVER AUTHORITY

Prepared by:

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INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Belton Lake in September, 1994. The purpose of the survey was to determine the capacity of the lake at the normal pool elevation and to establish baseline information for future surveys. From this information, future surveys will be able to determine sediment deposition locations and rates over time. Survey results are presented in the following pages in both graphical and tabular form. All elevations presented in this report will be reported in feet above mean sea level based on the National Geodetic Vertical Datum of 1929 (NGVD '29) unless noted otherwise. The results will be compared to the information from the latest sedimentation survey performed by the U. S. Army Corps of Engineers in 1966. At the normal pool elevation of 594.0 feet, they reported a surface area of 12,423 acres and a capacity of 441,984 acre-feet.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Belton Lake is located on the Leon River in Bell County, three miles north of Belton, Texas. The estimated drainage area of the lake is 3,531 square miles and includes Cowhouse, Owl, Cedar, and Stampede Creeks. The lake and dam facility are owned by the United States Government, and maintained and operated by the U. S. Army Corps of Engineers, Fort Worth District (COE). The water rights are allocated to the U. S. Government and the Brazos River Authority. Dam construction commenced in July 1949. Deliberate impoundment of water began March 8, 1954 and the facility was completed December 15 of the same year. The project was designed by the COE and the general contractor was J. W. Moorman and Son of Snyder, Texas. The estimated project cost was $13,804,000.

Belton Dam consists of a rolled-earthfill embankment, 5,524 feet long, with a 1,300 foot uncontrolled broad-crested spillway. The controlled outlet works consists of a 22-foot-diameter conduit that is controlled by three 7-by-22-foot broome-type gates. The service outlet consists of a 36-by-36-inch gated outlet that discharges into the controlled outlet conduit.

Belton Lake was authorized to be built under the Federal Flood Control Act of July 24, 1946, modified on September 3, 1954. Water Rights were granted by the State Board of Water Engineers under Permit No. 1689, dated October 29, 1953, to the U. S. Government to divert 10,000 acre-feet of water per year for use at Fort Hood. This volume of water was later increased to 12,000 acre-feet per year by Permit No.1725 dated October 27, 1954. A Certificate of Adjudication No. 2936 for the same amount of water was issued by the Texas Water Commission on April 30, 1984 to the COE.

Additional water rights from Belton Lake were granted to the Brazos River Authority (BRA) under Permit No. 2108, July 24, 1964. The permit authorized the permittee to impound not to exceed 457,600 acre-feet of water in Belton Lake. BRA could divert and use not to exceed 95,000 acre-feet of water per annum for municipal purposes, 150,000 acre-feet of water per annum for industrial purposes and 150,000 acre-feet per annum for irrigation purposes with a priority right of 110,000 acre-feet of water per annum. Permit No. 2108 was amended by the Texas Water Commission on September 4, 1979. It expanded the rights of the BRA at Belton Lake to include the use of impounded waters for non-consumptive recreational purposes. The permit was further amended on November 30, 1980. It authorized the BRA to use 500 acre-feet for mining purposes out of the 150,000 acre-feet of water allotted for irrigation. Certificate of Adjudication No. 5160 was issued to the BRA on December 14, 1987. It stated the BRA had entered into a contractual agreement with the United States Government for the storage of 457,600 acre-feet of water in Belton Lake between elevation 540 and elevation 594 under the same conditions as previously stated in the amended Permit No. 2108.

The BRA has additional authority to use waters from the Brazos River Basin system. Certificate of Adjudication No. 5167 (issued December 14, 1987) allows the BRA to divert and use not to exceed 30,000 acre-feet of water for municipal purposes and 170,000 acre-feet for industrial purposes in the San Jacinto-Brazos Coastal Basin. These waters are to be released from Belton Lake and other reservoirs owned and operated by the Brazos River Authority.

Belton Lake, at the normal pool elevation of 594.0 feet, was originally estimated when built by the COE to have a capacity of 457,600 acre-feet with a surface area of 12,300 acres. These original records were adjusted by the COE in 1963 after reviewing information from a 1953 range system consisting of 71 monumented sedimentation and 11 degradation ranges. The revised storage at the normal pool elevation was estimated to be 456,884 acre-feet with a surface area of 12,416 acres. In 1961 a resurvey of Belton Lake was performed by the COE in which 26 of the sedimentation range lines were surveyed. The storage volume was calculated at elevation 594.0 to be 447,500 acre-feet with a surface area of 12,420 acres. In 1966 a re-survey was performed by the COE in which 37 of the original 71 sedimentation ranges and 3 of the 11 degradation ranges were surveyed. The storage volume was calculated at elevation 594.0 to be 441,984 acre-feet with a surface area of 12,423 acres.

HYDROGRAPHIC SURVEYING TECHNOLOGY

The following sections will describe the equipment and methodology used to conduct this hydrographic survey. Some of the theory behind Global Positioning System (GPS) technology and its accuracy are also addressed.

GPS Information

The following is a brief and simple description of Global Positioning System (GPS) technology. GPS is a new technology that uses a network of satellites, maintained in precise orbits around the earth, to determine locations on the surface of the earth. GPS receivers continuously monitor the broadcasts from the satellites to determine the position of the receiver. With only one satellite being monitored, the point in question could be located anywhere on a sphere surrounding the satellite with a radius of the distance measured. The observation of two satellites decreases the possible location to a finite number of points on a circle where the two spheres intersect. With a third satellite observation, the unknown location is reduced to two points where all three spheres intersect. One of these points is obviously in error because its location is in space, and it is ignored. Although three satellite measurements can fairly accurately locate a point on the earth, the minimum number of satellites required to determine a three dimensional position within the required accuracy is four. The fourth measurement compensates for any time discrepancies between the clock on board the satellites and the clock within the GPS receiver.

GPS technology was developed in the 1960s by the United States Air Force and the defense establishment. After program funding in the early 1970s, the initial satellite was launched on February 22, 1978. A four year delay in the launching program occurred after the Challenger space shuttle disaster. In 1989, the launch schedule was resumed. Full operational capability will be reached when the NAVSTAR (NAVigation System with Time And Ranging) satellite constellation is composed of 24 Block II satellites. At the time of the survey, the system had achieved initial operational capability. A full constellation of 24 satellites, in a combination of Block I (prototype) and Block II satellites, was fully functional. The NAVSTAR satellites provide data based on the World Geodetic System (WGS '84) spherical datum. WGS '84 is essentially identical to NAD '83.

The United States Department of Defense (DOD) is currently responsible for implementing and maintaining the satellite constellation. In an attempt to discourage the use of these survey units as a guidance tool by hostile forces, the DOD has implemented means of false signal projection called Selective Availability (S/A). Positions determined by a single receiver when S/A is active result in errors to the actual position of up to 100 meters. These errors can be reduced to centimeters by performing a static survey with two GPS receivers, one of which is set over a point with known coordinates. The errors induced by S/A are time-constant. By monitoring the movements of the satellites over time (one to three hours), the errors can be minimized during post processing of the collected data and the unknown position computed accurately.

Differential GPS (DGPS) can determine positions of moving objects in real-time or "on-the-fly." One GPS receiver was set up over a benchmark with known coordinates established by the hydrographic survey crew. This receiver remained stationary during the survey and monitored the movements of the satellites overhead. Position corrections were determined and transmitted via a radio link once per second to a second GPS receiver located on the moving boat. The boat receiver used these corrections, or differences, in combination with the satellite information it received to determine its differential location. The large positional errors experienced by a single receiver when S/A is active are greatly reduced by utilizing DGPS. The reference receiver calculates satellite corrections based on its known fixed position, which results in positional accuracies within three meters for the moving receiver. DGPS was used to determine horizontal position only. Vertical information was supplied by the depth sounder.

Equipment

The equipment used in the performance of the hydrographic survey consisted of a 23-foot aluminum tri-hull SeaArk craft with cabin, equipped with twin 90-Horsepower Johnson outboard motors. Installed within the enclosed cabin are an Innerspace Helmsman Display (for navigation), an Innerspace Technology Model 449 Depth Sounder and Model 443 Velocity Profiler, a Trimble Navigation, Inc. 4000SE GPS receiver, a Motorola Radius radio with an Advanced Electronic Applications, Inc. packet modem, and an on-board computer. The computer was supported by a dot matrix printer and a

B-size plotter. Power was provided by a water-cooled generator through an in-line uninterruptible power supply. Reference to brand names does not imply endorsement by the TWDB.

The shore station included a second Trimble 4000SE GPS receiver, Motorola Radius radio and Advanced Electronic Applications, Inc. packet modem, and an omni-directional antenna mounted on a modular aluminum tower to a total height of 40 feet. The combination of this equipment provided a data link with a reported range of 25 miles over level to rolling terrain that does not require that line-of-sight be maintained with the survey vessel in most conditions, thereby reducing the time required to conduct the survey.

As the boat traveled across the lake surface, the depth sounder gathered approximately ten readings of the lake bottom each second. The depth readings were averaged over the one-second interval and stored with the positional data to an on-board computer. After the survey, the average depths were corrected to elevation using the daily lake elevation. The set of data points logged during the survey were used to calculate the lake volume. Accurate estimates of the lake volume can be quickly determined using these methods to produce an affordable survey. The level of accuracy is equivalent to or better than previous methods used to determine lake volumes, some of which are discussed below.

Previous Survey Procedures

Originally, reservoir surveys were conducted with a rope stretched across the reservoir along pre-determined range lines. A small boat would manually pole the depth at selected intervals along the rope. Over time, aircraft cable replaced the rope and electronic depth sounders replaced the pole. The boat was hooked to the cable, and depths were again recorded at selected intervals. This method, used mainly by the Soil Conservation Service, worked well for small reservoirs.

Larger bodies of water required more involved means to accomplish the survey, mainly due to increased size. Cables could not be stretched across the body of water, so surveying instruments were utilized to determine the path of the boat. Monumentation was set for the end points of each line so the same lines could be used on subsequent surveys. Prior to a survey, each end point had to be located (and sometimes reestablished) in the field and vegetation cleared so that line of sight could be maintained. One surveyor monitored the path of the boat and issued commands via radio to insure that it remained on line while a second surveyor determined depth measurement locations by turning angles. Since it took a major effort to determine each of the points along the line, the depth readings were spaced quite a distance apart. Another major cost was the land surveying required prior to the reservoir survey to locate the range line monuments and clear vegetation.

Electronic positioning systems were the next improvement. If triangulation could determine the boat location by electronic means, then the boat could take continuous depth soundings. A set of microwave transmitters positioned around the lake at known coordinates would allow the boat to receive data and calculate its position. Line of site was required, and the configuration of the transmitters had to be such that the boat remained within the angles of 30 and 150 degrees in respect to the shore stations. The maximum range of most of these systems was about 20 miles. Each shore station had to be accurately located by survey, and the location monumented for future use. Any errors in the land surveying resulted in significant errors that were difficult to detect. Large reservoirs required multiple shore stations and a crew to move the shore stations to the next location as the survey progressed. Land surveying was still a major cost.

Another method used mainly prior to construction utilized aerial photography to generate elevation contours which could then be used to calculate the volume of the reservoir. Fairly accurate results could be obtained, although the vertical accuracy of the aerial topography was generally one-half of the contour interval or $\pm$ five feet for a ten-foot contour interval. This method could be quite costly and was only applicable in areas that were not inundated.

PRE-SURVEY PROCEDURES

The reservoir's surface area was determined prior to the survey by digitizing with AutoCad software the lake's normal pool boundary from six USGS quad sheets. The names of the quad sheets are as follows: Belton, TX, 1965 (Revised 1993); Bland TX, 1958 (Photo-revised 1978); Eagle Springs, TX, 1965 (Revised 1993); Leon Junction, TX, 1957 (Photo-revised 1978); Moffat, TX, 1965 (Revised 1993) and Nolanville, TX, 1958 (Photo-revised 1974).

The survey layout was designed by placing survey track lines at 500 foot intervals across the lake. The survey design for this lake required approximately 360 survey lines to be placed along the length of the lake. Survey setup files were created using Innerspace Technology Inc. software for each group of track lines that represented a specific section of the lake. The setup files were copied onto diskettes for use during the field survey.

SURVEY CONTROL SETUP

The first task of the Hydrographic Survey field staff after arriving at Belton Lake was to establish a horizontal reference control point. Due to the length of the lake, two control points were deemed necessary. Figure 3 shows the locations of the control points established. These locations were chosen due to their close proximity to the reservoir and the security of the areas.

Prior to the field survey, TWDB staff had researched locations of known first-order benchmarks and requested Brazos River Authority employees to physically locate the associated monuments. Of the monuments found, the one chosen to provide horizontal control for the survey was a United States Geological Survey first-order monument named BELTON 1943 located on the campus of the University of Mary Hardin Baylor in Belton, Texas. The coordinates for the monument are published as Latitude 31° 04' 04.19687"N and Longitude 97° 27' 53.89148"W.

On September 12, 1994 at the location for the first control point, staff set a standard surveying brass cap labeled TWDB #15 in concrete, flush to the ground. A static survey was performed from the BELTON 1943 monument to the control point using two Trimble 4000SE GPS receivers. The GPS receivers were setup on tripods over each point and satellite data were gathered for approximately one hour, with up to six satellites visible at the same time to the receivers. While maintaining the receiver at the BELTON 1943 monument, this procedure was repeated at the second control point labeled TWDB #16.

Once data collection ended, the data were retrieved and processed from both receivers, using Trimble Trimvec software, to determine coordinates for the control points. The WGS' 84 coordinates for TWDB #15 were determined to be North latitude 31° 07' 36.10491", West longitude 97° 31' 03.95891", with an ellipsoid height of 192.2163 meters. The approximate NGVD '29 elevation was 720.55 feet. The WGS' 84 coordinates for TWDB #16 were determined to be North latitude 31° 11' 49.98929", West longitude 97° 27' 32.68782", with an ellipsoid height of 189.2313 meters. The approximate NGVD '29 elevation was 711.17 feet.

Using the newly determined coordinates, a shore station was setup at TWDB #15 to provided DGPS control during the survey. The coordinates from the static survey were entered into the GPS receiver located over the control point to fix its location. Data received during the survey could then be corrected and broadcast to the GPS receiver on the moving boat during the survey.

SURVEY PROCEDURES

The following procedures were followed during the hydrographic survey of Belton Lake performed by the TWDB. Information regarding equipment calibration and operation, the field survey, and data processing is presented.

Equipment Calibration and Operation

During the survey, the GPS receivers were operated in the following DGPS modes. The reference station receiver was set to a horizontal mask of 0°, to acquire information on the rising satellites. A horizontal mask of 10° was used on the roving receiver for the purpose of calculating better horizontal positions. A PDOP (Position Dilution of Precision) limit of 7 was set for both receivers. The DGPS positions are known to be within acceptable limits of horizontal accuracy when the PDOP is seven (7) or less. An internal alarm sounds if the PDOP rises above seven to advise the field crew that the horizontal position has degraded to an unacceptable level.

Prior to the survey, TWDB staff verified the horizontal accuracy of the DGPS used during the Belton Lake survey to be within the specified accuracy of three meters by the following procedure. The shore station was set up over a known United States Geological Service (USGS) first order monument and placed in differential mode. The second receiver, directly connected to the boat with its interface computer, was placed over another known USGS first order monument and data was collected for 60 minutes in the same manner as during a survey. Based on the differentially-corrected coordinates obtained and the published coordinates for both monuments, the resulting positions fell within a three-meter radius of the actual known monument position.

At the beginning of each surveying day, the depth sounder was calibrated with the Innerspace Velocity Profiler. The Velocity Profiler calculates an average speed of sound through the water column of interest for a designated draft value of the boat (draft is the vertical distance that the boat penetrates the water surface). The draft of the boat was previously determined to average 1.2 ft. The velocity profiler probe is placed in the water to moisten and acclimate the probe. The probe is then raised to the water surface where the depth is zeroed. The probe is lowered on a cable to just below the maximum depth set for the water column, and then raised to the surface. The unit displays an average speed of sound for a given water depth and draft, which is entered into the depth sounder. The depth value on the depth sounder was then checked manually with a measuring tape to ensure that the depth sounder was properly calibrated and operating correctly. During the survey of Belton Lake , the speed of sound in the water column varied daily between 4,916 and 4,926 feet per second. Based on the measured speed of sound for various depths, and the average speed of sound calculated for the entire water column, the depth sounder is accurate to within ±0.2 feet, plus an estimated error of ±0.3 feet due to the plane of the boat for a total accuracy of ±0.5 feet for any instantaneous reading. These errors tend to be minimized over the entire survey, since some are plus readings and some are minus readings. Further information on these calculations is presented in Appendix A.

Field Survey

Data was collected on Belton Lake during the period of September 12-22, 1994. Approximately 105,920 data points were collected over the 215 miles traveled along the pre-planned survey lines and the random data-collection lines. These points were stored digitally on the boat's computer in 355 data files. Data were not collected in areas of shallow water (depths less than 3.0 ft.) or with significant obstructions unless these areas represented a large amount of water. Random data points were collected when determined necessary by the field crew by manually poling the depth and entering the depth value into the data file. As each point was entered, the DGPS horizontal position was stored automatically with each return keystroke on the computer. The boat was moving slowly during this period so positions stored were within the stated accuracy of ± 3 meters to the point poled. Figure 2 shows the actual location of the data collection points.

Analog charts were printed for each survey line as the data were collected. The gate mark, which is a known distance above the actual depth, was also printed on the chart. Each chart was labeled with the date and data file ID for future reference. The depth sounder was set to record bad depth readings as 0.

The collected data were stored in individual data files for each pre-plotted range line or random data collection events. These files were downloaded to diskettes at the end of each day for further processing.

Data Processing

All collected data were down-loaded from diskettes onto the TWDB's computer network. The diskettes were then stored in a secured, safe location for future reference as needed. A Fortran program stripped the data collection files of non-essential data and created a Temporary data file. This data file consists of latitude, longitude and depth readings for each data point. The depth readings consist of instantaneous, average and auxiliary readings. The data files were edited manually by comparing the analog charts to the gate mark. Where the gate mark indicated that the recorded depth was other than the bottom, the depths were modified to reflect the recorded bottom. The Temporary files were then saved as Output files after editing was completed. The Output files were run through another Fortran program to delete all zero depth readings and to replace the average reading with the spot reading when the average reading was zero and the spot reading was greater then zero. The resulting file was saved as the final data file. Each of the individual data files were then combined into a single data-collection file that represented the date of data collection. The depths were then transformed to elevations with a simple Unix command based on the water surface elevation of each day. The elevations were rounded to the nearest tenth of a foot since the depth sounder records in tenths. The water surface ranged from 594.06 to 594.16 feet during the survey. Each of the daily files were then combined into a single edited data file to be used to develop a model of the lake's bottom surface.

The resulting DOS data file was imported into the UNIX operating system used to run Environmental Systems Research Institutes's (ESRI) Arc/Info GIS software. The latitude and longitude coordinates of each point were then converted to decimal degrees by a UNIX awk command. The awk command manipulates the data file format into a MASS points format for use by the GIS software. The graphic boundary file used for guidance along the pre-plotted survey lines was then transformed from NAD '27 datum to NAD '83, using Environmental Systems Research Institutes's (ESRI) Arc/Info project command with the NADCOM parameters. The area of the lake boundary was checked to verify that the area was the same in both datums. Once this was accomplished successfully, the boundary and the edited data file were in the same datum.

The two files are edited using the Arc/Edit module. The MASS points are converted into a point coverage and plotted on top of the boundary file. If data points were collected outside the boundary file, the boundary was modified to include the data points. The boundary near the edges of the lake in areas of significant sedimentation was down-sized to reflect the observations of the field crew. The resulting boundary shape was considered to be the acreage at the normal pool elevation of the lake. This was calculated as 12,385 acres for Belton Lake. The Board does not represent the boundary, as depicted in this report, to be a detailed actual boundary. Instead, it is a graphical approximation of the actual boundary used solely to compute the volume and area of the lake. The boundary does not represent the true land versus water boundary of the lake. An aerial topo of the upper four feet of the lake or an aerial photo taken when the lake is at the normal pool elevation would more closely define the present boundary. However, the minimal increase in accuracy does not appear to offset the cost of those services at this time.

The edited MASS points and modified boundary file were used to create a Digital Terrain Model (DTM) of the reservoir's bottom surface using Arc/Info's TIN module. The module builds an irregular triangulated network from the data points and the boundary file. This software uses a method known as Delauney's criteria for triangulation. A triangle is formed between three non-uniformly spaced points, including all points along the boundary. If there is another point within the triangle, additional triangles are created until all points lie on the vertex of a triangle. All of the data points are preserved for use in determining the solution of the model by using this method. The generated network of three-dimensional triangular planes represents the actual bottom surface. Once the triangulated irregular network (TIN) is formed, the software then calculates elevations along the triangle surface plane by solving the equations for elevation along each leg of the triangle. Areas that were too shallow for data collection or obstructed by vegetation were estimated by the Arc/Info's TIN product using this method of interpolation.

There were some areas where values could not be calculated by interpolation because of a lack of information along the boundary of the reservoir. "Flat triangles" were drawn at these locations. Arc/Info does not use flat triangle areas in the volume or contouring features of the model. These areas were determined to be insignificant on Belton Lake. Therefore no additional points were required for interpolation and contouring of the entire lake surface. The TIN product calculated the surface area and volume of the entire reservoir at one-tenth of a foot intervals from the three-dimensional triangular plane surface representation. The computed reservoir volume table is presented in Appendix B and the area table in Appendix C. An elevation-area-volume graph is presented in Appendix D.

Other presentations developed from the model include a shaded relief map and a shaded depth range map. To develop the shaded relief map, the three-dimensional triangular surface was modified by a GRIDSHADE command. Colors were assigned to different elevation values of the grid. Using the command COLORRAMP, a set of colors that varied from navy to yellow was created. The lower elevation was assigned the color of navy, and the lake normal pool elevation was assigned the color of yellow. Different color shades were assigned to the different depths in between. Figure 4 presents the resulting depth shaded representation of the lake. Figure 5 presents a similar version of the same map, using bands of color for selected depth intervals. The color increases in intensity from the shallow contour bands to the deep water bands.

The DTM was then smoothed and linear smoothing algorithms were applied to the smoothed model to produce smoother contours. The resulting contour map of the bottom surface at ten-foot intervals is presented in Figure 6.

RESULTS

Staff of the TWDB collected hydrographic data on Belton Lake during the period September 12-22, 1994. The survey crew observed that the widest area of the lake was at the confluence of Cowhouse Creek and the Leon River. The Leon River segment of Belton Lake was observed to have river characteristics with major relief along the perimeter. As the river meandered through the limestone rock terrain, the survey crew observed shallow silt deposit banks on one side and a deep cut channel on the opposite side. The width of the river channel varied between 1/4 and 1/2 mile from the confluence of Cowhouse Creek to the Highway 36 bridge on the Leon River. Upstream of the Highway 36 bridge, the terrain became more gentle with rolling hills and a wider flood plain. The Cowhouse Creek arm exhibited similar characteristics to the terrain above the Highway 36 bridge.

Results from the survey indicate Belton Lake now encompasses around 12,385 surface acres and contains a volume of 434,500 acre-feet at the normal pool elevation of 594.0 feet. The lowest elevation encountered during the field survey was 481.46 feet, or 112.54 feet of depth and was found near the dam.

The storage volume calculated by this survey is approximately 1.7 percent less than the 1966 previous record information for the lake. The lowest gated outlet invert elevation is at elevation 483.0 feet. There is no dead storage volume in the lake below this elevation. Therefore, the conservation storage capacity is calculated to be 434,500 acre-feet. Since the maximum depth of the lake is within 1.5 ft of the lowest gated outlet, the potential for the outlet to become silted in exists in the near future.

Operational procedures should be considered and implemented to maintain the functionality of the outlet.

SUMMARY

When Belton Lake was built in 1954, it was estimated to contain 457,000 acre-feet of water at the normal pool elevation of 594.0 ft. This original estimate was revised to 456,884 acre-feet after a sedimentation range line network was established in 1953-54. In 1961, a sedimentation survey of Belton Lake performed by US Army Corps of Engineers (COE) reported the new volume of the lake to be 447,500 acre-feet at the normal pool elevation. In 1966, the lake was again surveyed by the COE and the volume was revised to 441,984 acre-feet. The COE estimated that Belton Lake had accumulated 9,733 acre-ft of sediment between 1949 and 1961, and an additional 5,122 acre-feet of sediment between 1961 and 1966. The average annual sediment accumulation rate for the period 1949-61 was estimated at 1,269 acre-feet. The average annual sediment accumulation rate for the period 1961-66 was estimated at 1,024 acre-feet.

In September 1994, a hydrographic survey of Belton Lake was performed by the Texas Water Development Board's Hydrographic Survey Program. The 1994 survey used technological advances such as differential global positioning system and geographical information system technology to build a model of the reservoir's bathemetry. These advances allowed a survey to be performed quickly and to collect significantly more data of the bathemetry of Belton Lake than the previous surveys. Results from the survey indicate that the lake's capacity and conservation storage capacity at the normal pool elevation of 594.0 feet was 434,500 acre-feet. The estimated reduction in storage capacity, if compared to the 1966 survey information, was 7,484 acre-feet, or 1.7 percent. This equates to an estimated loss of 267.29 acre-feet per year during the 28 years between the TWDB's survey and the last survey performed by the COE.

It is difficult to compare the surveys performed by the TWDB and the COE because the methods and procedures used were very different. However, the TWDB considers the 1994 survey to be a significant improvement over previous survey procedures and recommend that the same methodology be used to re-surveyed Belton Lake in five to ten years or after major flood events. A second survey will remove any noticeable error due to improved calculation techniques and will isolate current sedimentation rates and the storage losses occurring in Belton Lake.

CALCULATION OF DEPTH SOUNDER ACCURACY

This methodology was extracted from the Innerspace Technology, Inc. Operation Manual for the Model 443 Velocity Profiler.

For the following examples, $t = (D - d)/V$

where: t_D = travel time of the sound pulse, in seconds (at depth = D)
D = depth, in feet
d = draft = 1.2 feet
V = speed of sound, in feet per second

To calculate the error of a measurement based on differences in the actual versus average speed of sound, the same equation is used, in this format:

$$D = [t(V)]+d$$

For the water column from 2 to 30 feet: V = 4832 fps

$t_{30} = (30-1.2)/4832$
$= 0.00596$ sec.

For the water column from 2 to 45 feet: V = 4808 fps

$t_{45} = (45-1.2)/4808$
$= 0.00911$ sec.

For a measurement at 20 feet (within the 2 to 30 foot column with V = 4832 fps):

$D_{20} = [((20-1.2)/4832)(4808)]+1.2$
$= 19.9'$ (-0.1')

For a measurement at 30 feet (within the 2 to 30 foot column with V = 4832 fps):

$D_{30} = [((30-1.2)/4832)(4808)]+1.2$
$= 29.9'$ (-0.1')

For a measurement at 50 feet (within the 2 to 60 foot column with V = 4799 fps):

$D_{50} = [((50-1.2)/4799)(4808)]+1.2$
$= 50.1'$ (+0.1')

For the water column from 2 to 60 feet: V = 4799 fps   Assumed V_{80} = 4785 fps

t_{60} =(60-1.2)/4799
=0.01225 sec.

For a measurement at 10 feet (within the 2 to 30 foot column with V = 4832 fps):

D_{10} = [((10-1.2)/4832)(4799)]+1.2
= 9.9'   (-0.1')

For a measurement at 30 feet (within the 2 to 30 foot column with V = 4832 fps):

D_{30} = [((30-1.2)/4832)(4799)]+1.2
= 29.8'   (-0.2')

For a measurement at 45 feet (within the 2 to 45 foot column with V = 4808 fps):

D_{45} = [((45-1.2)/4808)(4799)]+1.2
= 44.9'   (-0.1')

For a measurement at 80 feet (outside the 2 to 60 foot column, assumed V = 4785 fps):

D_{80} = [((80-1.2)/4785)(4799)]+1.2
= 80.2'   (+0.2')

TEXAS WATER DEVELOPMENT BOARD
RESERVOIR VOLUME TABLE

Dec 1 1994

BELTON LAKE SEPTEMBER 1994 SURVEY

VOLUME IN ACRE-FEET — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
481										
482										
483										1
484	1	1	1	1	1	1	1	1	1	1
485	2	2	2	2	2	2	3	3	3	3
486	3	4	4	4	5	5	5	6	6	7
487	7	8	9	10	10	11	12	13	14	15
488	16	17	18	19	20	22	23	24	26	27
489	29	31	32	34	36	38	40	42	44	47
490	49	51	54	56	59	61	64	66	69	72
491	75	78	81	84	87	90	93	97	100	104
492	107	111	114	118	122	126	130	134	138	142
493	147	151	156	161	166	171	176	181	186	192
494	197	203	209	215	221	228	234	241	248	255
495	262	269	276	284	291	299	307	315	324	332
496	341	350	359	369	378	388	397	407	417	428
497	438	448	459	470	481	492	503	514	526	538
498	549	561	573	586	598	611	624	637	650	663
499	676	690	704	718	732	747	761	776	791	807
500	822	838	854	870	887	904	921	938	955	973
501	991	1010	1028	1048	1067	1087	1107	1128	1149	1170
502	1192	1214	1237	1260	1283	1307	1331	1355	1380	1405
503	1431	1457	1483	1510	1537	1564	1591	1619	1648	1676
504	1705	1735	1764	1794	1824	1855	1886	1917	1949	1981
505	2013	2045	2078	2112	2145	2179	2214	2249	2284	2319
506	2355	2391	2427	2464	2501	2539	2577	2615	2654	2693
507	2733	2772	2813	2853	2894	2936	2977	3020	3062	3105
508	3148	3192	3236	3281	3325	3371	3416	3462	3509	3555
509	3603	3650	3698	3747	3795	3845	3894	3944	3995	4046
510	4097	4149	4201	4254	4307	4361	4415	4469	4524	4580
511	4636	4692	4749	4807	4865	4924	4983	5043	5103	5164
512	5226	5288	5350	5414	5477	5542	5606	5672	5738	5804
513	5871	5939	6007	6075	6145	6214	6285	6356	6427	6499
514	6572	6645	6719	6794	6869	6944	7021	7097	7175	7253
515	7332	7411	7491	7572	7653	7735	7817	7901	7985	8070
516	8156	8242	8330	8419	8508	8598	8690	8782	8875	8969
517	9064	9160	9256	9354	9452	9551	9652	9753	9855	9957
518	10061	10166	10271	10377	10484	10592	10701	10811	10922	11033
519	11145	11258	11372	11486	11602	11718	11835	11953	12072	12192
520	12312	12433	12555	12678	12802	12926	13052	13178	13305	13433
521	13562	13691	13822	13953	14085	14218	14352	14486	14622	14758
522	14895	15033	15172	15311	15451	15592	15734	15876	16019	16163
523	16307	16452	16598	16745	16892	17040	17188	17338	17488	17638
524	17790	17942	18095	18248	18403	18558	18713	18870	19027	19185
525	19343	19502	19662	19822	19983	20145	20307	20470	20633	20797
526	20962	21128	21294	21461	21628	21796	21965	22135	22306	22477
527	22649	22821	22994	23168	23342	23517	23693	23870	24047	24224
528	24403	24582	24762	24943	25124	25306	25488	25672	25856	26041
529	26227	26413	26601	26789	26978	27168	27358	27550	27742	27935

BELTON LAKE SEPTEMBER 1994 SURVEY

VOLUME IN ACRE-FEET

ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
580	282880	283820	284760	285710	286660	287610	288560	289510	290470	291420
581	292380	293350	294310	295280	296240	297210	298190	299160	300140	301110
582	302090	303080	304060	305050	306040	307030	308020	309010	310010	311010
583	312010	313010	314010	315020	316030	317040	318050	319070	320080	321100
584	322120	323140	324170	325190	326220	327250	328290	329320	330360	331400
585	332440	333480	334520	335570	336620	337670	338720	339780	340830	341890
586	342950	344010	345080	346150	347210	348280	349360	350430	351510	352590
587	353670	354750	355830	356920	358010	359100	360190	361290	362380	363480
588	364580	365680	366790	367900	369010	370120	371230	372350	373470	374590
589	375710	376840	377960	379090	380220	381360	382490	383630	384770	385910
590	387050	388200	389340	390490	391640	392800	393950	395110	396270	397430
591	398600	399770	400940	402120	403290	404470	405650	406830	408010	409200
592	410390	411580	412770	413960	415150	416350	417550	418750	419950	421150
593	422350	423560	424770	425980	427190	428400	429620	430830	432050	433270
594	434500									

TEXAS WATER DEVELOPMENT BOARD

RESERVOIR AREA TABLE

Dec 1 1994

BELTON LAKE SEPTEMBER 1994 SURVEY

AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
481										
482										
483								1	1	1
484	1	1	1	1	1	1	1	1	1	1
485	1	1	2	2	2	2	2	2	2	2
486	3	3	3	3	4	4	4	5	5	6
487	6	7	7	8	8	8	9	9	10	10
488	10	11	11	12	12	13	14	14	15	15
489	16	17	18	19	19	20	21	21	22	22
490	23	24	24	25	25	26	27	27	28	28
491	29	30	30	31	32	32	33	34	34	35
492	36	36	37	38	39	40	41	41	42	43
493	44	46	47	48	49	50	52	53	55	56
494	57	59	60	61	63	64	66	67	68	70
495	71	73	74	76	78	79	81	83	85	86
496	88	90	92	94	95	97	98	100	101	103
497	104	106	107	109	110	111	113	114	116	117
498	119	120	122	124	125	127	129	130	132	134
499	136	138	140	142	144	146	148	150	152	154
500	157	159	161	164	166	169	171	174	177	180
501	182	186	189	192	196	201	205	209	213	216
502	220	223	227	231	235	238	242	246	250	254
503	257	261	265	268	271	275	278	281	285	288
504	291	294	298	301	304	307	311	314	318	321
505	325	328	332	335	338	342	345	349	352	356
506	359	363	367	370	374	378	381	385	389	393
507	397	401	404	408	412	416	420	423	427	431
508	435	439	443	446	450	454	458	462	466	470
509	474	478	482	486	490	495	499	503	508	512
510	516	520	525	529	533	538	543	547	552	557
511	562	568	573	578	584	590	596	601	607	612
512	618	624	629	635	640	646	651	656	662	667
513	673	678	684	689	695	700	706	712	718	724
514	731	737	742	748	753	759	765	771	778	784
515	790	797	803	810	816	823	830	837	844	853
516	863	873	881	890	900	908	917	926	935	944
517	953	962	971	980	988	997	1006	1015	1024	1033
518	1041	1050	1059	1067	1076	1084	1093	1101	1109	1118
519	1126	1134	1142	1150	1159	1167	1175	1183	1192	1200
520	1208	1216	1224	1233	1241	1249	1258	1267	1275	1284
521	1292	1300	1308	1317	1325	1334	1342	1350	1358	1366
522	1374	1383	1391	1398	1406	1413	1420	1427	1434	1441
523	1448	1455	1462	1469	1475	1482	1489	1496	1503	1510
524	1517	1525	1532	1539	1546	1554	1561	1568	1575	1581
525	1588	1594	1600	1607	1613	1619	1625	1631	1638	1644
526	1651	1658	1665	1672	1679	1687	1694	1701	1708	1715
527	1721	1728	1734	1741	1748	1754	1761	1768	1775	1782
528	1789	1796	1802	1809	1816	1823	1830	1838	1846	1854
529	1862	1870	1878	1886	1894	1901	1909	1917	1925	1933

BELTON LAKE SEPTEMBER 1994 SURVEY

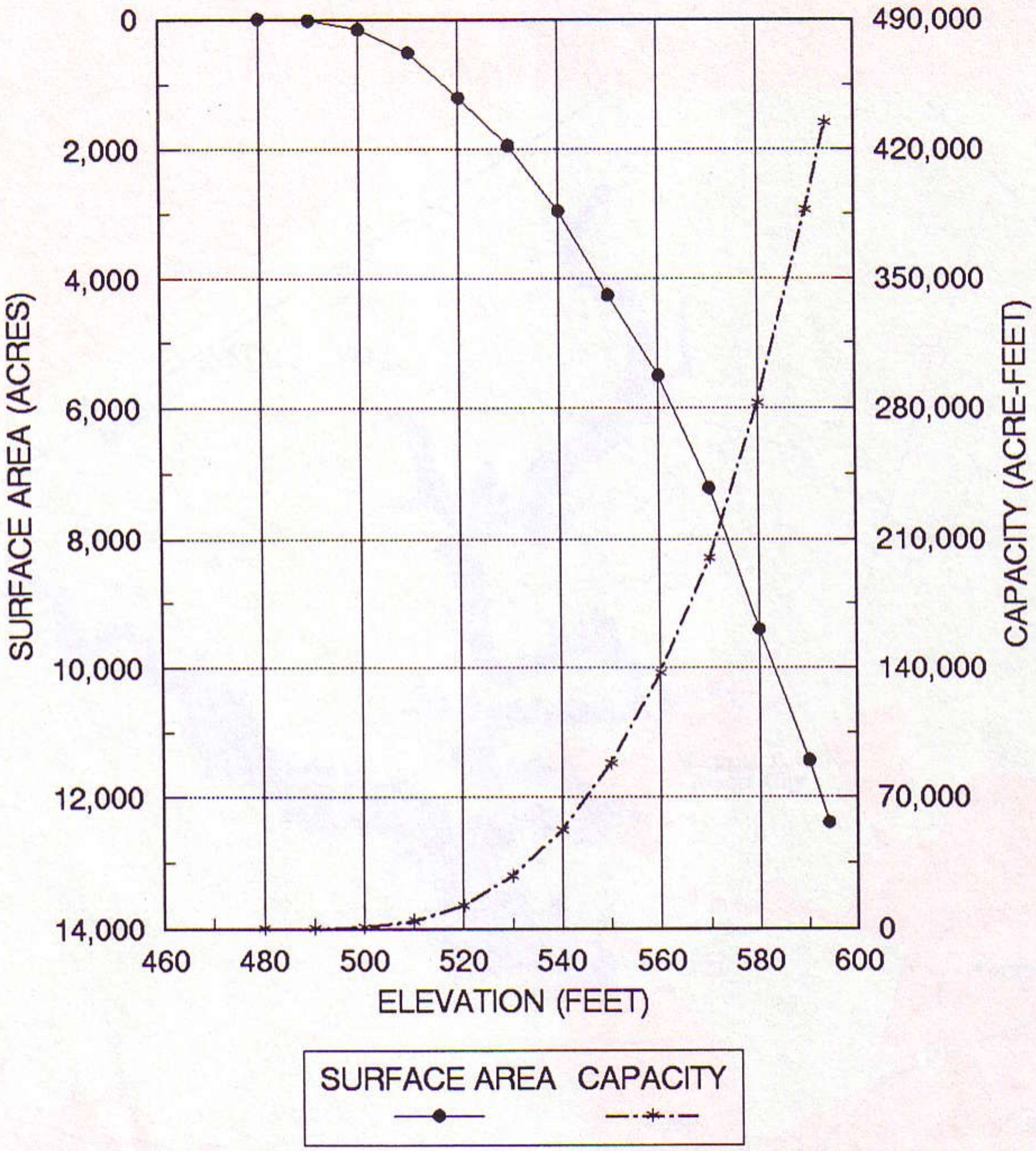
AREA IN ACRES — ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
530	1941	1949	1956	1964	1972	1980	1988	1996	2005	2013
531	2021	2030	2038	2047	2056	2065	2074	2083	2092	2101
532	2110	2119	2129	2138	2148	2157	2167	2176	2186	2197
533	2207	2218	2228	2239	2249	2259	2270	2280	2291	2301
534	2312	2324	2335	2347	2358	2370	2381	2393	2404	2417
535	2428	2439	2450	2461	2471	2482	2491	2501	2512	2522
536	2533	2543	2554	2566	2576	2586	2597	2607	2617	2627
537	2637	2646	2656	2665	2675	2685	2694	2704	2714	2724
538	2734	2745	2755	2765	2775	2786	2797	2808	2819	2831
539	2842	2854	2866	2878	2889	2901	2913	2924	2936	2949
540	2961	2973	2984	2997	3009	3020	3033	3045	3057	3068
541	3080	3091	3102	3114	3125	3136	3147	3159	3171	3183
542	3194	3205	3216	3227	3242	3254	3266	3278	3290	3302
543	3313	3325	3337	3349	3361	3373	3384	3396	3407	3419
544	3431	3443	3455	3467	3480	3492	3504	3516	3528	3539
545	3551	3564	3577	3590	3602	3615	3628	3641	3655	3668
546	3683	3698	3713	3727	3741	3755	3768	3782	3796	3810
547	3824	3838	3852	3866	3881	3894	3909	3924	3939	3954
548	3969	3984	4000	4015	4031	4046	4060	4075	4089	4103
549	4118	4133	4148	4163	4178	4192	4207	4221	4234	4248
550	4262	4276	4290	4304	4318	4331	4344	4358	4371	4385
551	4399	4412	4425	4437	4450	4464	4477	4491	4506	4523
552	4539	4555	4569	4583	4596	4609	4622	4634	4646	4658
553	4669	4681	4692	4703	4714	4725	4736	4747	4758	4768
554	4779	4790	4801	4812	4823	4833	4844	4855	4865	4875
555	4886	4896	4908	4920	4933	4945	4959	4972	4984	4996
556	5008	5019	5031	5043	5054	5065	5075	5086	5096	5107
557	5118	5130	5142	5153	5165	5177	5188	5201	5213	5225
558	5238	5250	5262	5273	5285	5297	5310	5323	5335	5348
559	5361	5374	5386	5399	5412	5426	5440	5454	5469	5483
560	5497	5511	5524	5538	5552	5565	5579	5592	5605	5618
561	5632	5645	5659	5673	5688	5702	5718	5733	5748	5764
562	5779	5794	5810	5826	5842	5858	5875	5891	5907	5925
563	5947	5969	5992	6010	6026	6041	6057	6072	6087	6102
564	6116	6129	6143	6156	6168	6180	6192	6204	6216	6228
565	6241	6253	6265	6277	6290	6302	6316	6329	6343	6357
566	6370	6384	6398	6413	6430	6448	6465	6482	6499	6517
567	6536	6556	6578	6600	6624	6646	6666	6686	6706	6728
568	6750	6772	6795	6817	6839	6861	6883	6903	6924	6946
569	6968	6991	7015	7042	7068	7093	7119	7146	7172	7195
570	7217	7237	7257	7277	7297	7319	7342	7368	7395	7425
571	7455	7482	7506	7530	7553	7576	7598	7618	7638	7658
572	7678	7698	7719	7741	7763	7787	7809	7831	7851	7871
573	7890	7910	7929	7948	7966	7985	8004	8024	8043	8062
574	8081	8100	8119	8138	8157	8178	8199	8220	8242	8265
575	8289	8313	8336	8358	8379	8400	8420	8440	8461	8483
576	8506	8528	8551	8575	8600	8625	8650	8673	8695	8719
577	8741	8765	8787	8811	8834	8860	8885	8909	8932	8954
578	8976	8998	9022	9045	9067	9089	9112	9135	9159	9185
579	9209	9232	9254	9274	9294	9312	9331	9349	9367	9386

BELTON LAKE SEPTEMBER 1994 SURVEY

AREA IN ACRES ELEVATION INCREMENT IS ONE TENTH FOOT

ELEV. FEET	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
580	9407	9429	9448	9467	9487	9506	9526	9547	9567	9587
581	9608	9629	9650	9670	9690	9710	9730	9749	9768	9788
582	9809	9831	9852	9873	9893	9913	9933	9952	9973	9993
583	10014	10034	10054	10074	10094	10115	10135	10156	10176	10197
584	10216	10237	10257	10277	10296	10316	10335	10355	10374	10394
585	10414	10435	10455	10475	10495	10516	10536	10556	10575	10595
586	10615	10635	10655	10674	10694	10714	10735	10755	10775	10794
587	10814	10834	10854	10874	10894	10915	10936	10957	10978	10998
588	11019	11040	11062	11083	11106	11132	11155	11177	11198	11219
589	11239	11259	11279	11299	11319	11338	11358	11379	11399	11419
590	11439	11459	11480	11501	11523	11547	11571	11596	11621	11645
591	11671	11701	11735	11755	11773	11790	11808	11826	11843	11861
592	11878	11896	11913	11931	11948	11966	11984	12002	12020	12037
593	12055	12072	12090	12107	12125	12142	12159	12177	12194	12212
594	12385									



BELTON LAKE

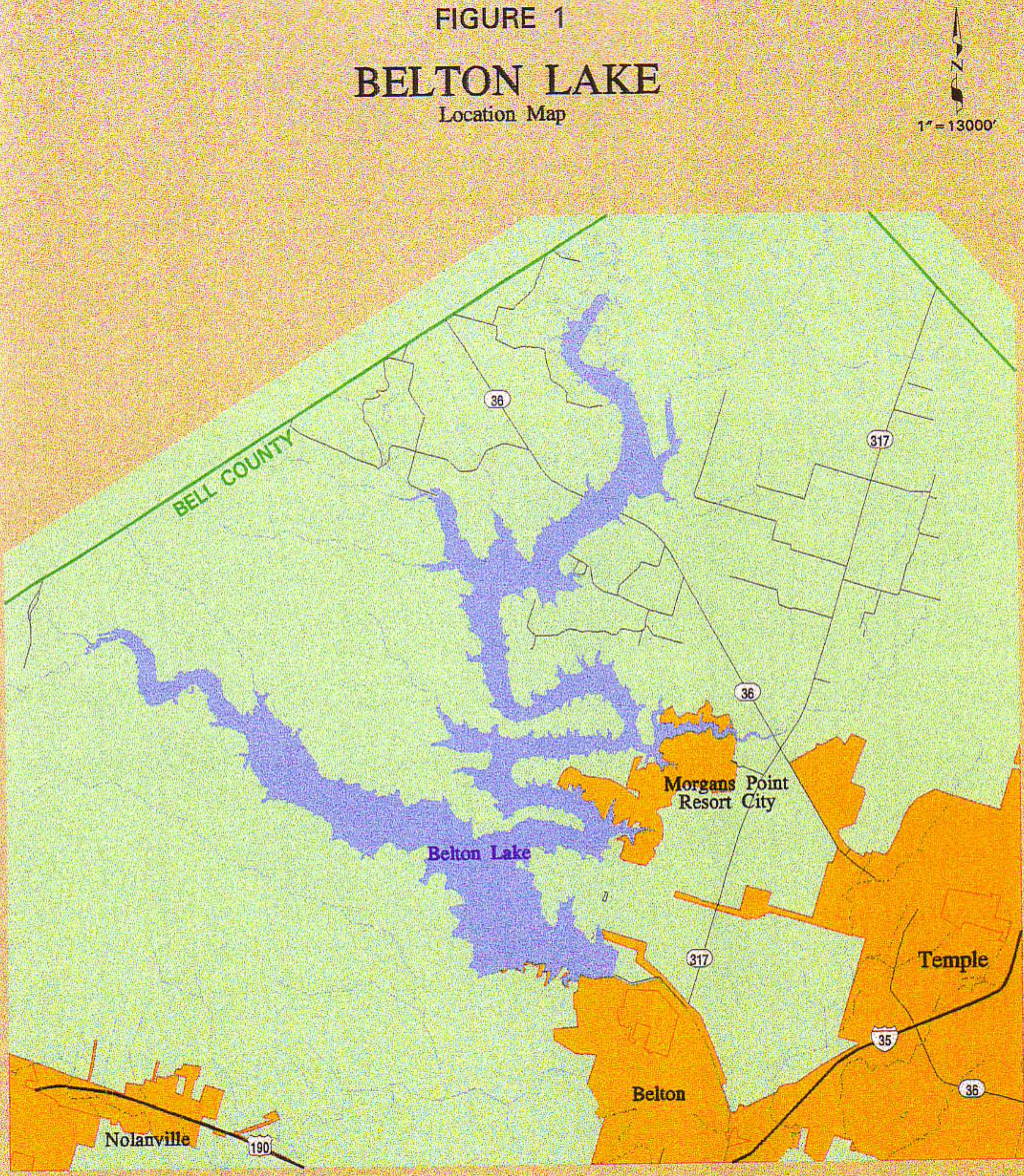
SEPTEMBER 1994 SURVEY

Prepared by: TWDB December 1994

FIGURE 1

BELTON LAKE

Location Map



PREPARED BY: TWDB DECEMBER 1994

FIGURE 2

BELTON LAKE

Location of Survey Data

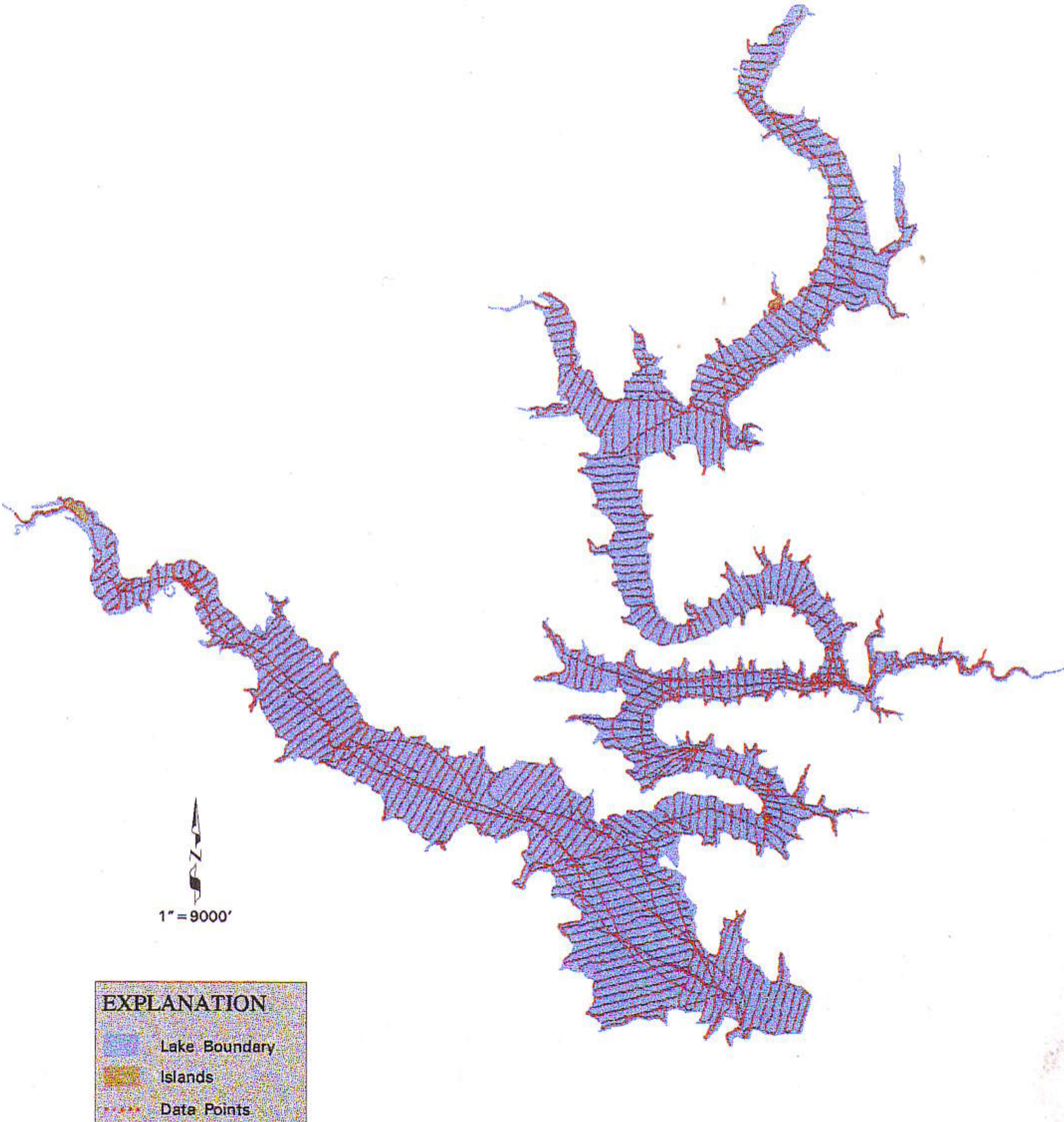


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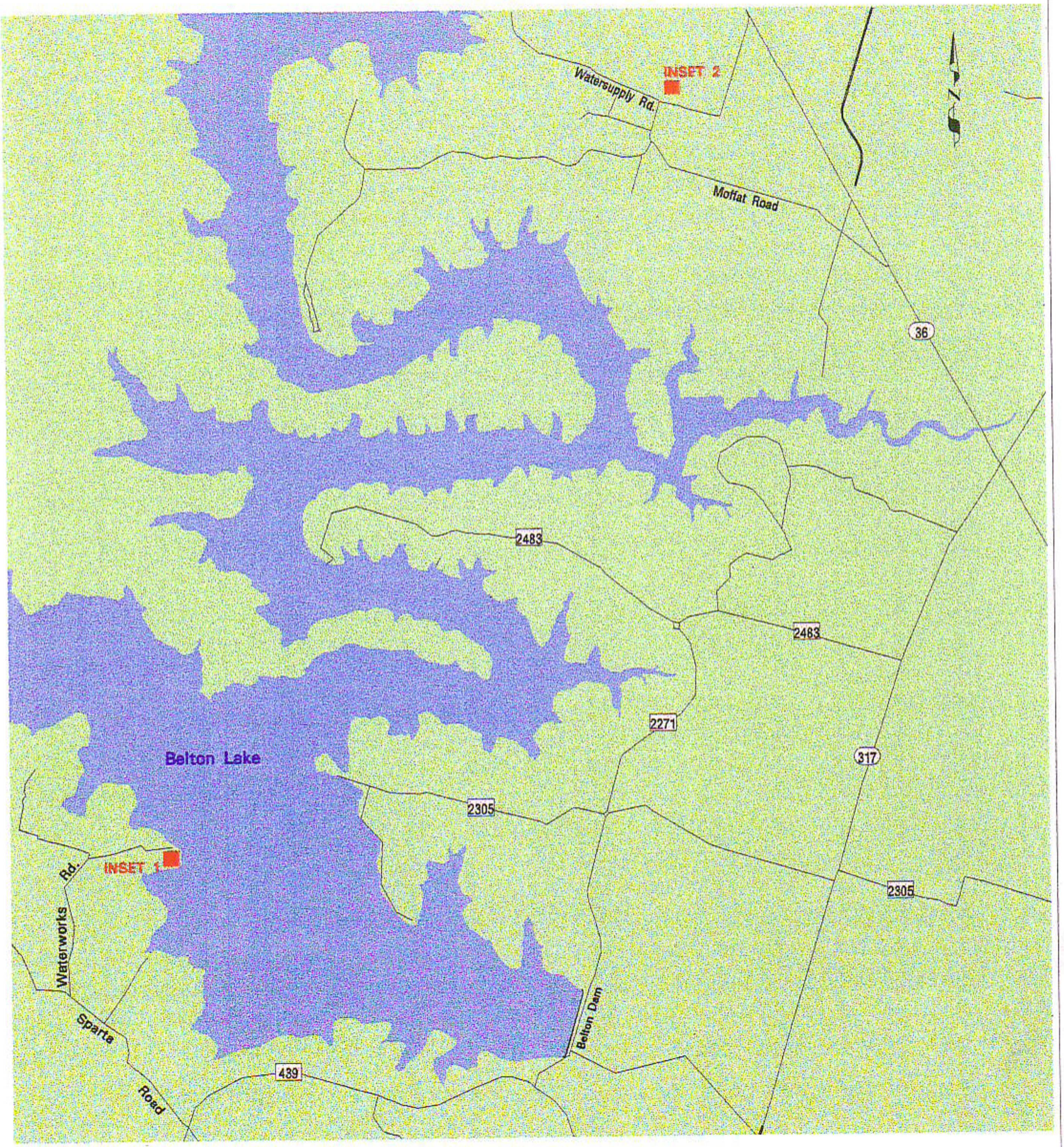
FIGURE 3

Belton Lake

Location of control points
TWDB #015 and TWDB #016

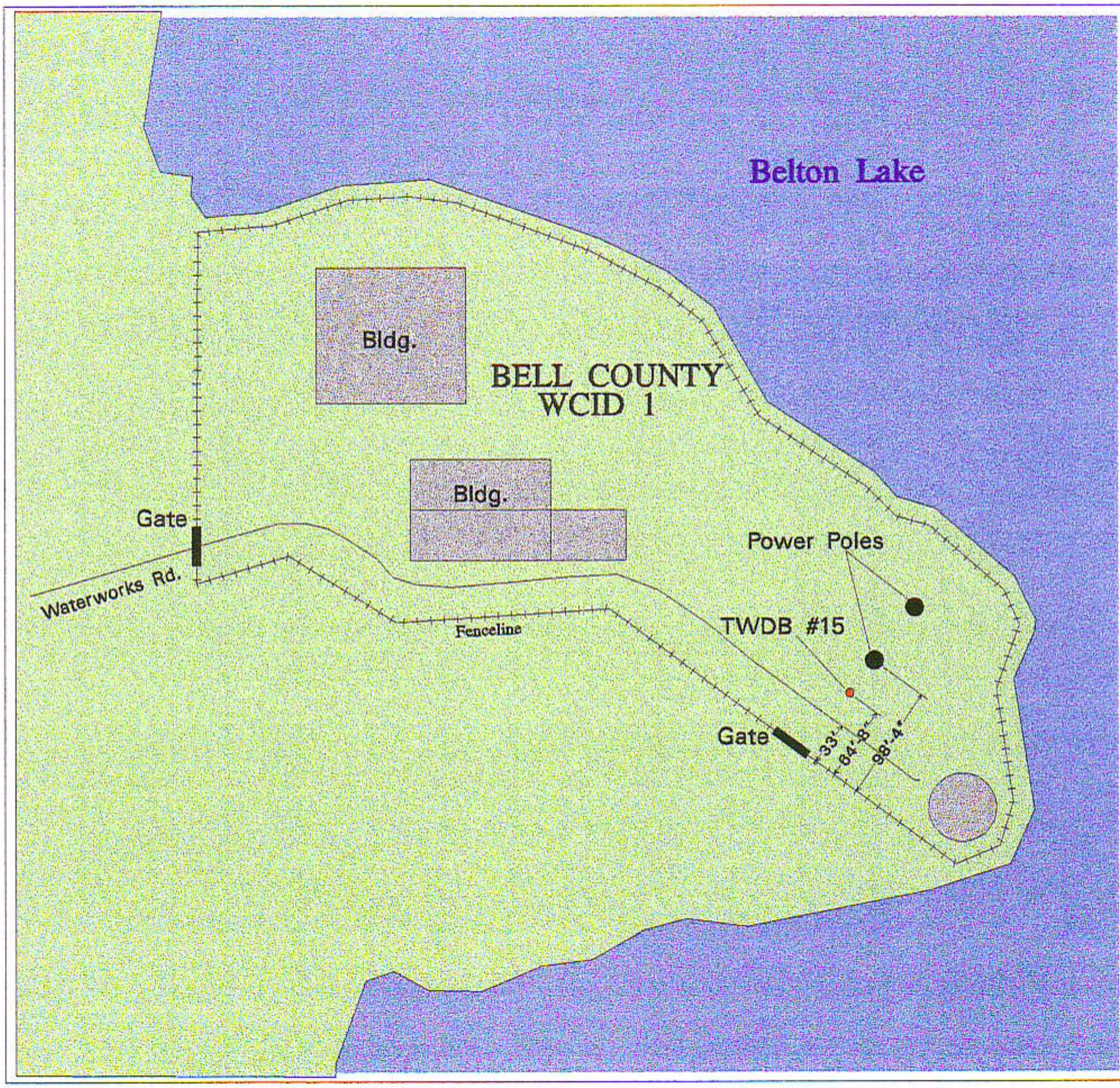


PREPARED BY: TWDB DECEMBER 1994

INSET 1

BELTON LAKE

Location of control point TWDB #015

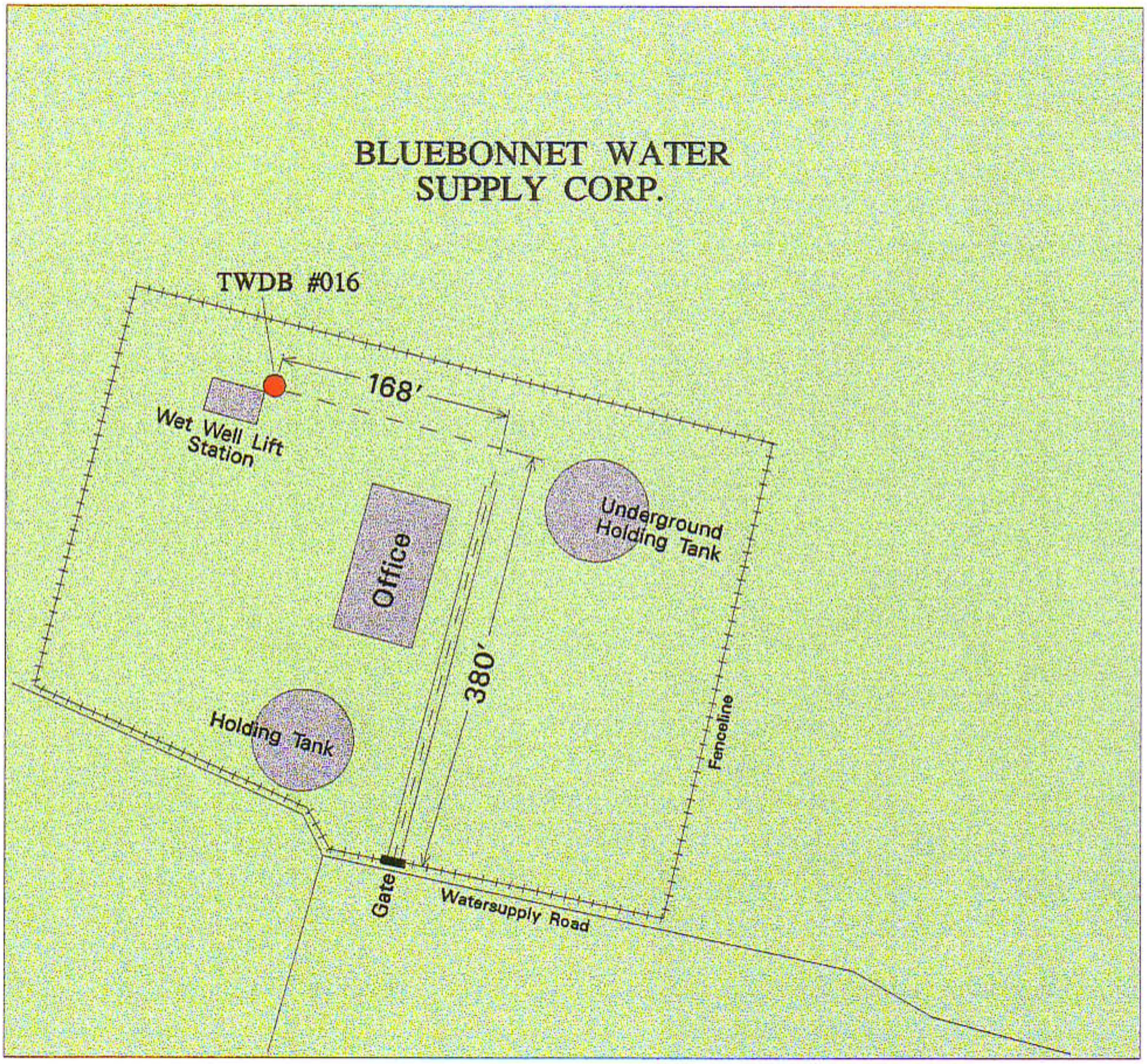


PREPARED BY: TWDB DECEMBER 1994

INSET2

BELTON LAKE

Location of control point TWDB #016

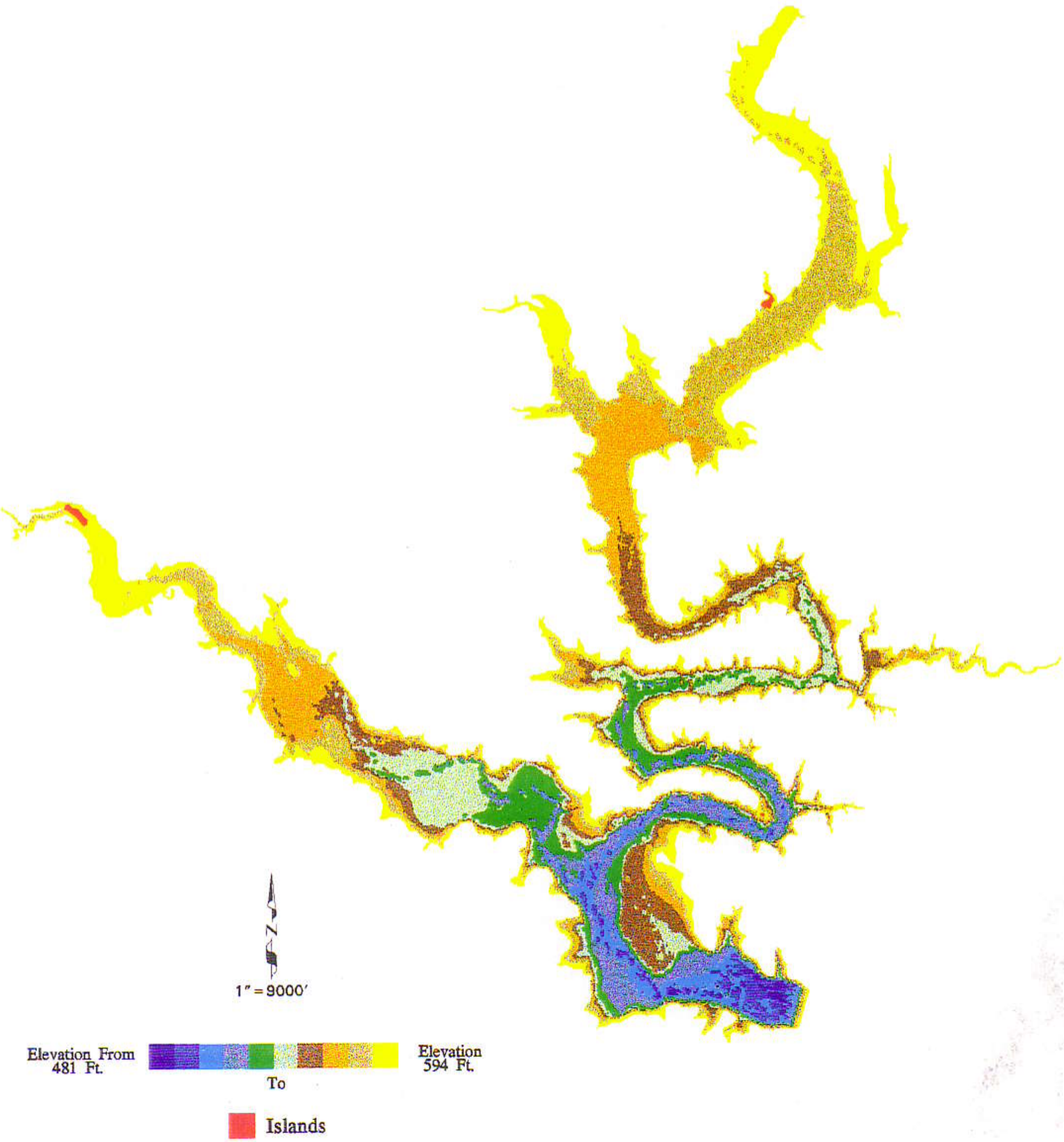


PREPARED BY: TWDB DECEMBER 1994

FIGURE 4

BELTON LAKE

Shaded Relief

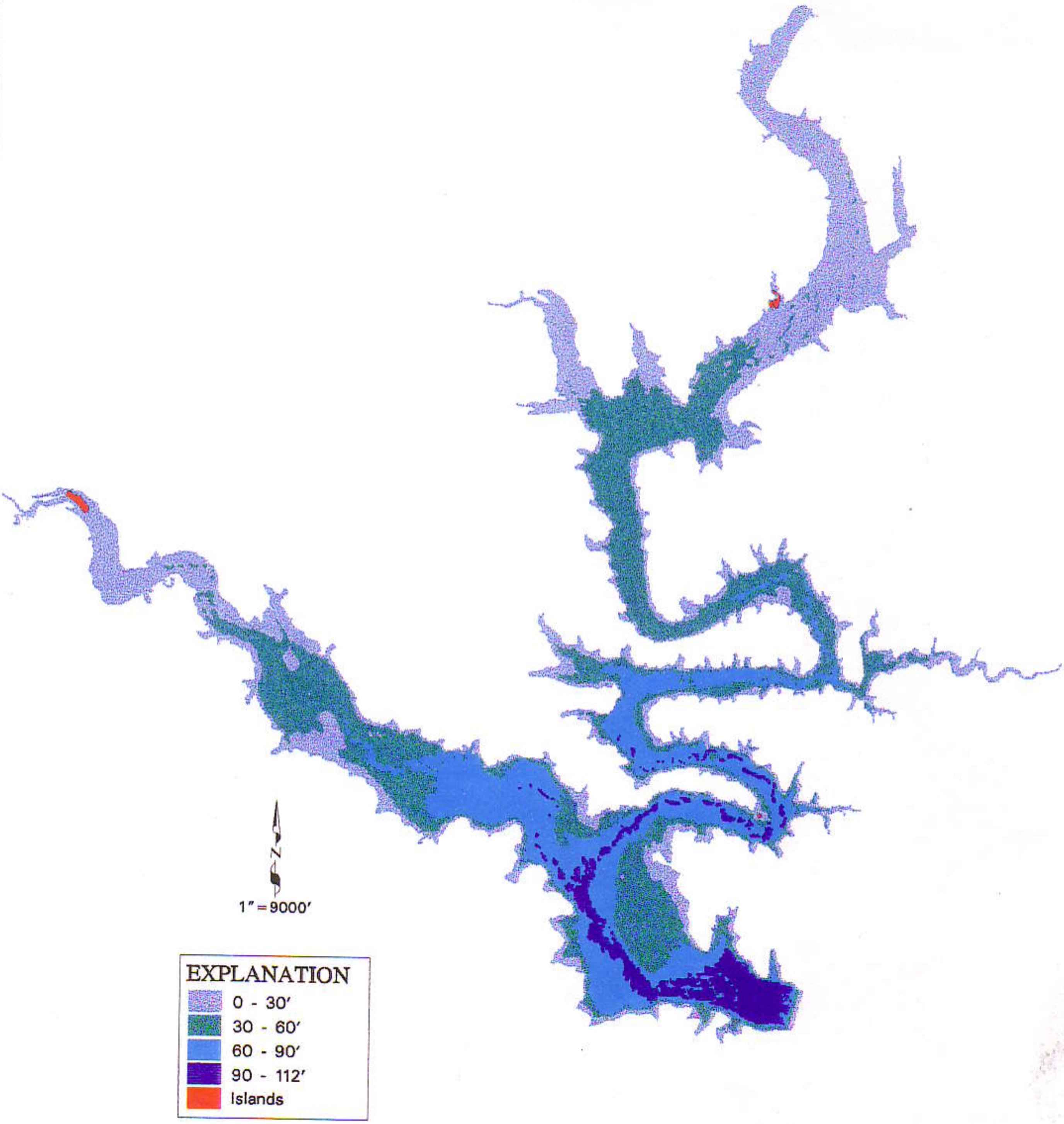


PREPARED BY: TWDB DECEMBER 1994

FIGURE 5

BELTON LAKE

Depth Ranges



PREPARED BY: TWDB DECEMBER 1994