VOLUMETRIC SURVEY
OF
LAKE MEREDITH

Prepared for:

CANADIAN RIVER MUNICIPAL WATER AUTHORITY

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LAKE MEREDITH
HYDROGRAPHIC SURVEY REPORT

INTRODUCTION

Staff of the Hydrographic Survey Unit of the Texas Water Development Board (TWDB) conducted a hydrographic survey on Lake Meredith in June, 1995. 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. The survey was performed at a lake water surface elevation about 41 feet below the top of the conservation pool because this elevation represented the historic normal near-maximum operating level of the lake. Contour lines from the latest U.S. Geological Survey topographic maps were added to the field survey data to allow for calculation of volumes and surface areas of the lake below the top of the conservation pool. 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. Based on a 1980 sediment resurvey, the U. S. Bureau of Reclamation (BUREC) calculated the surface area of Lake Meredith at the normal pool elevation of 2,936.5 feet to be 16,513 acres with a corresponding capacity of 839,200 acre-feet.

HISTORY AND GENERAL INFORMATION OF THE RESERVOIR

Sanford Dam is located on the Canadian River in Hutchinson County, about ten miles northwest of Borger, Tx. Waters impounded by Sanford Dam form Lake Meredith which extends from Hutchinson County into Moore and Potter Counties. The facility was originally built and financed by the BUREC and is now owned by the Canadian River

Municipal Water Authority. Inflows to the lake originate over a 20,220 square mile drainage area of which 4,172 is probably non-contributing. The lake, at the conservation capacity pool elevation of 2936.5 feet, is approximately nineteen miles long with an average width of 1.5 miles.

Federal authorization for Lake Meredith and Sanford Dam was granted under Public Law No. 898 on December 29, 1950. State authorization was granted by the Board of Water Engineers on April 11, 1956 under Permit No. 1815. It authorized the Canadian River Municipal Water Authority to divert the storm, flood and unappropriated waters of the Canadian River not to exceed 100,000 acre-feet of water per annum for municipal use and not to exceed 51,200 acre-feet of water per annum for industrial use. Certificate of Adjudication #3782 was issued May 30, 1985. It basically stated that the Canadian River Municipal Water Authority was authorized to impound 1,407,572 acre-feet of water on the Canadian River known as Lake Meredith and impound therein not to exceed 500,000 acre-feet of water in conservation storage and 404,000 acre-feet of water for silt and dead storage. It also stated in the special conditions that this project was to comply with the Canadian River Compact which provides for the division of water of the Canadian River among New Mexico, Oklahoma and Texas.

Construction of the project started March 11, 1962. Deliberate impoundment of water began January 28, 1965 and the project was completed August 21 of the same year. The BUREC engineered the project and H. B. Zachry Company was general contractor. Estimated cost of the project was $18,587,000.

Sanford Dam is a rolled earthfill structure with a length of 6,410 feet, rising 200 feet above the natural streambed to an elevation of 3,011.0 feet. Located near the left end of the dam, the service spillway is an uncontrolled drop inlet concrete structure that discharges into a 22-foot-diameter conduit. The conduit is designed to discharge 19,300 cubic feet per second (cfs) at the maximum design flood stage of 3,004.9 feet. The flood-control outlet works are composed of three 12- by 15-foot gates that open into three 15.5-foot concrete conduits. These outlet works are located to the left of the service spillway, near the left end of the dam.

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 and Methodology

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.

The GPS equipment, survey vessel, and depth sounder combine together to provide an efficient hydrographic survey system. As the boat travels across the lake surface, the depth sounder gathers approximately ten readings of the lake bottom each second. The depth readings are stored on the survey vessel's on-board computer along with the corrected positional data generated by the boat's GPS receiver. The daily data files collected are downloaded from the computer and brought to the office for editing after the survey is completed. During editing, bad data is removed or corrected, multiple data points are averaged together to get one data point per second, and average depths are converted to elevation readings based on the daily recorded lake elevation on the day the survey was performed. Accurate estimates of the lake volume can be quickly determined by building a 3-D model of the reservoir from the collected data. 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 four USGS quad sheets. The names of the quad sheets are as follows: McDowell Creek, TX 1970; Alibates Ranch, TX 1970; Evans Canyon, TX 1970; and Sanford, TX 1970. The graphic boundary file created was then transformed into the proper datum, 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.

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 446 survey lines to be placed along the length of the lake. Survey setup files were created using Coastal Oceangraphics, Inc. Hypack 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 Lake Meredith was to establish a horizontal reference control point. Figure 3 shows the location of the control point established. This location was chosen due to the close proximity to the reservoir and the security of the area. An additional temporary control point was established during the survey do to the length of the lake. No permanent marker was set for this point located on the dam. The data and location for this site are contained in the raw data files.

Prior to the field survey, TWDB staff had researched locations of known first-order benchmarks and requested Canadian River Municipal Water Authority staff to physically locate the associated monuments. Of the monuments found, the one chosen to provide horizontal control for the survey was a U. S. Geological Survey first-order monument named CANADIAN located approximately three miles southeast of Stinnett, Tx.. The coordinates for the monument are published as Latitude 35° 46' 43.97587"N and Longitude 101° 25' 40.36620"W.

On May 31, 1995, TWDB staff performed a static GPS survey to determine the WGS'84 coordinates for the horizontal reference control point. The control point used for the shore station was a BUREC property corner surveyor's cap identification #271 set in concrete located about mid-lake. The GPS receivers were set up over this point and the U. S. Geological Survey first-order monument named CANADIAN. Satellite data were gathered for approximately one hour, with up to six satellites visible at the same time to the receivers.

Once data collection ended, the data were retrieved and processed from both receivers, using Trimble Trimvec software, to determine the coordinates for the control point. The WGS' 84 coordinates for BUREC #271 were determined to be North latitude 35° 38' 38.46776" and West longitude 101° 37' 55.81259".

Using the newly determined coordinates, a shore station was set up at BUREC #271 to provide 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. Satellite data received during the survey could then be corrected and broadcast to the GPS receiver on the moving boat during the survey for differential correction.

SURVEY PROCEDURES

The following procedures were followed during the hydrographic survey of Lake Meredith 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 Lake Meredith 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 Lake Meredith, the speed of sound in the water column varied daily between 4833 and 4868 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 $\pm$0.2 feet, plus an estimated error of $\pm$0.3 feet due to the plane of the boat for a total accuracy of $\pm$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 were collected on Lake Meredith during the period of June 1-7, 1995. The lake was about 41 ft. below conservation pool storage capacity during the survey. Approximately 62,660 data points were collected over the 159.4 miles traveled along the pre-planned survey lines and the random data-collection lines. The points collected were stored digitally on the boat's computer in 190 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 $\pm$ 3 meters to the point poled. Figure 2 shows the actual location of the data collection points.

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 future processing.

Data Processing

The 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. To process the data, the EDIT routine in the Hypack Program was run on each raw data file. Data points such as depth spikes or data with missing depth or positional information were deleted from the file. The depth information collected every 0.1 seconds was averaged to get one reading for each second of data collection. A correction for the lake elevation at the time of data collection was also applied to each file during the EDIT routine. During the survey, the water surface ranged daily from 2893.05 to 2895.71 feet. After all changes had been made to the raw data file, the edited file was saved with a different extension. After all the files were edited, the edited files were combined into a single data file, representative of the lake, to be used with the GIS software 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 System 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 previously digitized was also imported.

The boundary and MASS points files were graphically edited using the Arc/Edit module. The MASS points file was converted into a point coverage and plotted along with the boundary file. If data points were collected outside the boundary file, the boundary was modified to include the data points. Also, 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 16,411 acres for Lake Meredith. 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 topographic map 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. Information for the entire reservoir area can be determined from the triangulated irregular network created 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. Additional contour lines from U.S.G.S. topographical maps were added to the model to allow for interpolation and contouring of the entire lake surface. These lines were added to provide data in between the top of the conservation pool and the elevation of the lake during the survey. The TIN product then 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

Lake Meredith is basically a submerged canyon formed by the Canadian River with the following major contributing creeks: Bugbee, Turkey, Blue, Plum, Short and Alibates. The shore around the lake consisted of sedimentary rocks composed of sandstone and red iron-rich clays with very little protective vegetation. While surveying the lake, the field crew observed steep-walled canyons along each of the creeks and many protected coves along the main body of the lake. Lake grasses were found periodically in the shallow areas of the lake near the shoreline, but most of the lake was free of any vegetation. Small trees and stumps were encountered in many of the coves in the upper reaches of the reservoir, making it difficult to maneuver the boat. The crew was able to collect data in the main reservoir from the dam to immediately upstream of the confluence of Evans Canyon (on the west side) and Turkey Creek (on the East side). Almost everyday, the survey was interrupted for varying periods due to high winds, hail, rain and severe electrical storms in the area.

Results from the 1995 survey indicate Lake Meredith now encompasses around 16,411 surface acres and contains a volume of 817,970 acre-feet at the normal pool elevation of 2936.5 feet. The shoreline at this elevation was calculated to be 124.56 miles. The lowest elevation encountered was around elevation 2818 feet, or 118.5 feet of depth and was found near the dam.

The storage volume calculated by the 1995 survey is approximately 2.5 percent less than the 1980 sediment re-survey information for the lake. The lowest gated outlet invert elevation is at elevation 2850.0 feet. The dead storage volume at this elevation corresponds to 38,414 acre-ft. Therefore, the conservation storage capacity for the lake is calculated to be 779,560 acre-feet.

SUMMARY

Sanford Dam and Lake Meredith were authorized by the Federal Government under Public Law No. 898 and by the State Permit No. 1815. Construction commenced March 11, 1962. Deliberate impoundment began January 28, 1965. Initial storage calculations estimated the volume of the lake at the conservation pool elevation of 2936.5 to be 864,400 acre-feet with surface area of 16,504 acres. In May 1980, the BUREC performed a sediment resurvey and the storage volume at the top of conservation pool was revised to 839,200 acre-feet with a surface area of 16,513.

During the period June 1-7, 1995, a hydrographic survey of Lake Meredith was performed by the Texas Water Development Board's Hydrographic Survey Program. The water elevation of the lake during this period ranged from 2893.05 - 2895.71 ft., or about 41 ft below the normal pool elevation. Technological advances such as differential global positioning system and geographical information system technology were used to build a model of the reservoir's bathemetry. Contour lines from U.S. Geological Survey 7.5 minute maps supplemented the hydrographic survey data to allow for area-volume calaculations throughout the entire depth range of the conservation storage pool of the reservoir. With these advances an accurate survey could be performed quickly, collect significantly more data of the bathemetry of Lake Meredith, and the collected information processed much quicker than previous survey methods. Results from the survey indicate that the lake's capacity at the normal pool elevation of 2396.5 feet was 817,970 acre-feet. The estimated reduction in storage capacity, if compared to the volume in 1980 was 21,230 acre-feet, or 2.5 percent. This equates to an estimated loss of 1415.33 acre-feet per year during the 15 years between the TWDB's survey and the 1980 sediment re-survey. The annual deposition rate of sediment in the conservation pool can be estimated at 0.088 acre-ft per square mile of contributing drainage area.

It is difficult to compare the original design information, the survey performed by the BUREC, and the survey performed by the TWDB because little is know about the procedures and data used in the previous surveys. However, the TWDB considers the 1995 survey to be a significant improvement over previous survey procedures and recommends that the same methodology be used in five to ten years or after major flood events to monitor changes to the lake's storage capacity. The second survey will remove any noticeable errors between the previous surveys and the 1995 survey and will facilitate accurate calculations of sedimentation rates and storage losses presently occurring in Lake Meredith. Repeating the survey when the lake is at a higher elevation will also provide more accurate estimates of the upper 41 ft. of the reservoir that were not physically surveyed during this survey.

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')