Introduction

Lake Manatee is located in central Manatee County, Florida (fig. 1), and is the principal drinking-water source for Manatee and Sarasota Counties (Stanley and others, 2003). The drainage basin of Lake Manatee encompasses approximately 120 square miles, and the reservoir covers a surface area of about 1,450 acres at an elevation of 38.8 feet above the North American Vertical Datum of 1988 (NAVD 88) or 39.7 feet above the National Geodetic Vertical Datum of 1929 (NGVD 29). The full pool water-surface elevation is 39.1 feet above NAVD 88 (40.0 feet above NGVD 29), and the estimated minimum usable elevation is 25.1 feet above NAVD 88 (26.0 feet above NGVD 29). The minimum usable elevation is based on the elevation of water intake structures.

Manatee County has used the stage/volume relation developed from the original survey in the 1960s to estimate the volume of water available for consumption. Concerns about potential changes in storage capacity of the Lake Manatee reservoir, coupled with a recent drought, led to this bathymetry mapping effort.

Methods

Bathymetric data were collected during July 13-17, and on July 28, 2009, using a boat-mounted global positioning system (GPS), an echo sounder, and commercially available hydrographic software. The GPS data were post-processed to apply differential corrections, which resulted in a stated horizontal accuracy of approximately 3.28 feet (NovAtel, Inc., 2008).

The echo sounder emits pulses of sound that are reflected by sediments on the bottom of the lake and detected by the receiver. The two-way traveltime of sound pulses is directly affected by the speed of sound in water, which is affected by temperature and salinity. Shallow depths and low salinity typically encountered in freshwater lakes are not major factors affecting sound speed (U.S. Army Corps of Engineers, 2002). For Lake Manatee, effects of water temperature and salinity were expected to be minimal. A bar check of the echo sounder, where depth is measured to a metal plate suspended in the water at a known depth, was performed daily to calibrate the depth readings based on the speed of sound (Wilson and Richards, 2006). No depth adjustments were needed for this survey based on the bar checks.

The use of hydrographic software (HYPACK, Inc., 2007) allowed pre-planned transect lines to be developed and followed during the survey. These transect lines were spaced approximately 130 feet apart. The individual data points measured along these transect lines are very close together and appear as lines in figure 2. Some of these "lines" appear lighter than others because the density of the data collected along those transects was low, which was likely due to filtering of shallow-water points or other equipment limitations. Boat speed during data acquisition was maintained between 3 and 4 knots along all transects. Data points collected in areas of the reservoir shallower than 5 feet were periodically verified by hand using a fiberglass rod marked in 0.1-foot increments. Areas that were inaccessible by boat were not measured.

All data were imported into a geographic information system to produce a triangulated irregular network (TIN) model of the reservoir bottom, which was then used to calculate reservoir capacity. Bathymetric contours were derived from a separately interpolated surface that was created using ordinary kriging, a common geostatistical modeling technique. These contours were smoother than those that were extracted from the TIN model. The smoothed contours were then checked against the original data and cartographically edited where necessary. The shoreline was digitized using aerial orthophotography taken on February 10, 2006, at a reservoir level of 38.9 feet above NAVD 88 (39.8 feet above NGVD 29).

Quality-assurance transect lines were created at an oblique angle to the main transects and were spaced approximately 650 feet apart (Wilson and Richards, 2006). The quality-assurance data points were used to check the accuracy of the TIN created from the main dataset as well as the final map contour lines. All quality-assurance points were used to compute a difference in elevation from the interpolated TIN surface for that portion of the computation, but only those points occurring within 1 foot of a contour line were used to compute the accuracy of the map contours.

Results

Results of the bathymetric survey indicate that at the full pool elevation of 39.1 feet above NAVD 88 (40.0 feet above NGVD 29), the reservoir holds 5,911 million gallons of freshwater (table 1). At the estimated minimum usable elevation of 25.1 feet above NAVD 88 (26.0 feet above NGVD 29), the reservoir holds 1,036 million gallons. The usable volume at full pool is 4,875 million gallons and is calculated by subtracting the volume associated with the minimum usable reservoir level (1,036 million gallons) from the full pool volume (5,911 million gallons). Full pool and minimum usable volumes based on the original equation are 7,205 and 1,591 million gallons, respectively. Reservoir storage capacity at full pool as determined by the current survey is 18 percent less than the original survey (fig. 3 and table 1). If the differences in storage were all due to sediment accumulation, this would equate to an accumulation rate of 0.08 foot per year over the last 42 years.

Reservoir water-surface elevation ranged from 37.5 to 37.6 feet above NAVD 88 (38.4 to 38.5 feet above NGVD 29) during data collection when the average depth of water was 11.3 feet. Reservoir depth generally increases from east to west toward the dam where the lowest point of the reservoir bottom is 11.2 feet below NAVD 88 (10.3 feet below NGVD 29) (see enlarged area of fig. 1). The lowest points are in a linear, trench-like feature near the southwest shore. The old stream channel of the Manatee River is well defined throughout the reservoir except at the upper end near Verna Bethany Road. The reservoir bottom is relatively flat near the middle, and gradually slopes upward toward the edges.

The bathymetric data were used to create stage-volume relations that can be used to predict reservoir volume based on water-surface elevation using either elevation in feet above NAVD 88 or NGVD 29 as input:

$$y = -0.3275x_{88}^3 + 43.368x_{88}^2 - 1,406.4x_{88} + 14,200 \; (R^2 = 0.99998, n = 128) \quad (1)$$

$$y = -0.3275x_{29}^3 + 44.299x_{29}^2 - 1,489.5x_{29} + 15,573 \; (R^2 = 0.99998, n = 128) \quad (2)$$

where y is lake volume in million gallons, x_{88} is water-surface elevation in feet above NAVD 88, x_{29} is water-surface elevation in feet above NGVD 29, R^2 is the coefficient of determination, and n is the number of observations used to define the curve to which each equation was fit. The average difference in calculated volume between these equations is 0.05 percent and is considered to be negligible. Calculated volumes using these equations are presented for selected reservoir elevations in table 1.

Discussion of Accuracy

During data collection, a latency offset was introduced for which a correction was not possible because of the method of GPS post-processing. Latency is a problem associated with moving survey vessels and is caused by the lag in time between the capture of the GPS signal and computation of the horizontal coordinates. While depth and horizontal coordinates are measured simultaneously by the echo sounder and GPS, respectively, the GPS hardware requires additional processing time to calculate horizontal coordinates from the GPS signal, which causes a delay in the arrival time of the horizontal coordinates to the data recorder. The distance traveled by the survey vessel during this time affects the magnitude of the observed latency offset. At slow speeds (less than 5 knots), the offsets caused by latency are relatively small (less than 10 feet for this survey) though distances of up to 60 feet have been observed at faster speeds (U.S. Army Corps of Engineers, 2002).

While the latency offset introduced during data collection introduced directional bias reducing the overall horizontal and vertical accuracy of the map, the net effect on the computations of reservoir storage capacity is expected to be negligible. Latency affects the position of the depth measurements, not the depth measurements themselves, and since all of the depth measurements along each transect were affected uniformly, the resulting areas computed from these transects are the same regardless of the absolute position of each transect. Therefore volume, as a derivative of these areas, should also be unaffected by the latency offset.

The accuracy of the TIN and map contours was calculated using the quality-assurance dataset and is expressed in terms of the root mean square error (RMSE) (Wilson and Richards, 2006). The computed RMSE of the TIN was 2.08 feet (4.08 feet at the 95-percent confidence interval) using 11,430 quality-assurance data points, meaning that 95 percent of all points on the TIN are within 4.08 feet of the true elevation. The computed RMSE of the bathymetric contours was 3.80 feet (7.45 feet at the 95-percent confidence interval) using 302 quality-assurance data points.

The difference in computed storage capacity between the current and original surveys is attributed to a combination of both sedimentation and differences in accuracy between the current survey and the original survey. Although the reservoir may have lost storage capacity between 1967 and 2009 because of sedimentation, the loss was probably not as high as computed for two reasons. First, the low topographic relief of the Lake Manatee basin does not warrant the production of large quantities of sediment. Sedimentation rates of reservoirs in the United States with capacities similar to Lake Manatee were found to range from 0.4 to 0.8 percent depletion per year (Dendy and others, 1973), but few estimates of reservoir sedimentation are available for Florida (Ackerman and others, 2009). The highest sedimentation rates for Lake Okeechobee were between 0.09 and 0.12 gram per square centimeter (Brezonik and Engstrom, 1998), or less than 0.002 foot per year, which is substantially less than the rate computed for Lake Manatee. Second, the recently created bathymetric map of the reservoir still clearly identifies the location of the old river channel, suggesting that the reservoir probably has not experienced a substantial amount of sedimentation. A sediment transport study may help quantify the degree to which the reservoir has actually filled in since 1967.

Difference in accuracy between the current and original surveys is probably the main cause of the apparent loss in storage capacity. However, it is impossible to determine the accuracy of the original survey because the data are no longer available, although the older survey is likely less accurate because of lower resolution and improvements in technology. The current survey provides detailed documentation to assess changes in storage in the future.

Summary

The U.S. Geological Survey, in cooperation with Manatee County, conducted a bathymetric survey of Lake Manatee from July 13 to July 28, 2009. Lake Manatee is a manmade reservoir that was created in 1967 when a dam was built on the Manatee River just east of the town of Rye, Florida. The survey was conducted to provide Manatee County Utilities Department personnel with an updated equation to use in calculating the capacity of the reservoir at different water-surface elevations. Bathymetric data were collected using a boat-mounted global positioning system, an echo sounder, and commercially available hydrographic software. The data were post-processed to apply differential corrections and exported into a geographic information system for mapping and calculation of volume. At a water-surface elevation of 39.1 feet above NAVD 88 (40.0 feet above NGVD 29), reservoir storage capacity for the current survey was 18.0 percent less than the original survey, which was completed around the time the dam was built in the late 1960s. The apparent loss of storage is attributed to both sedimentation of the lake and assumed differences in accuracy between the current and the original surveys.

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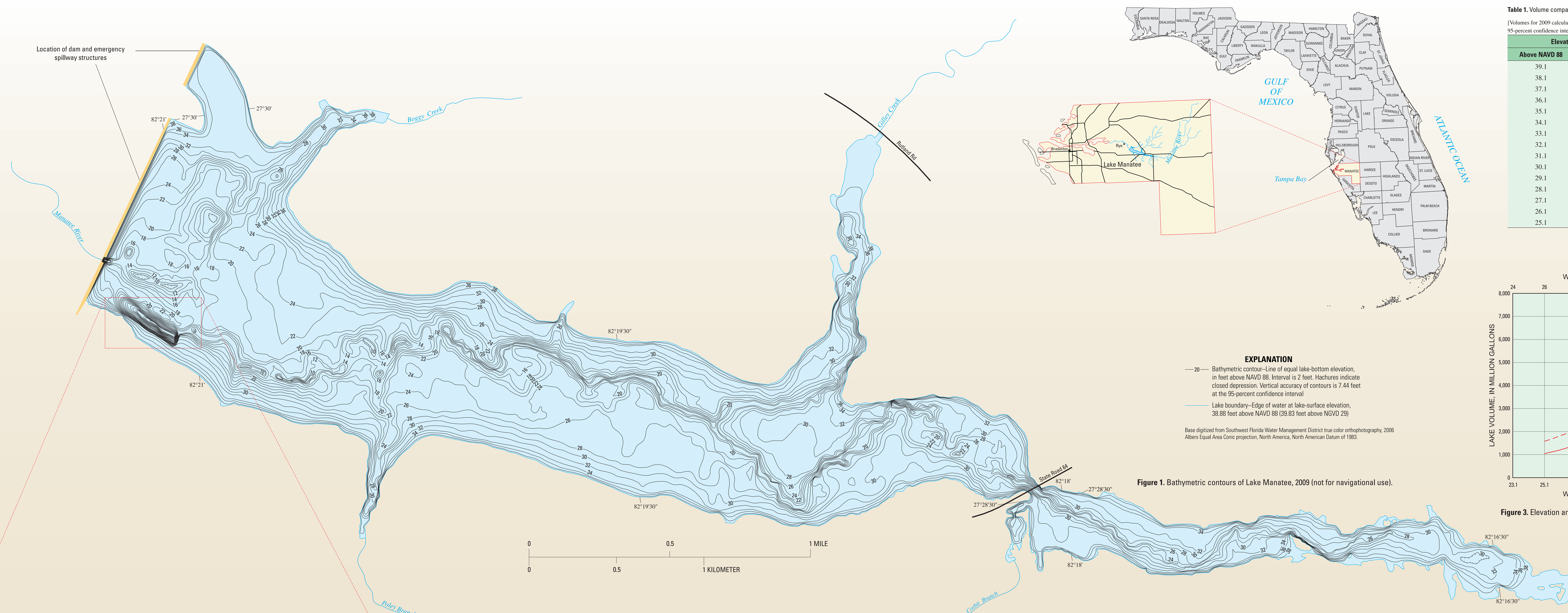
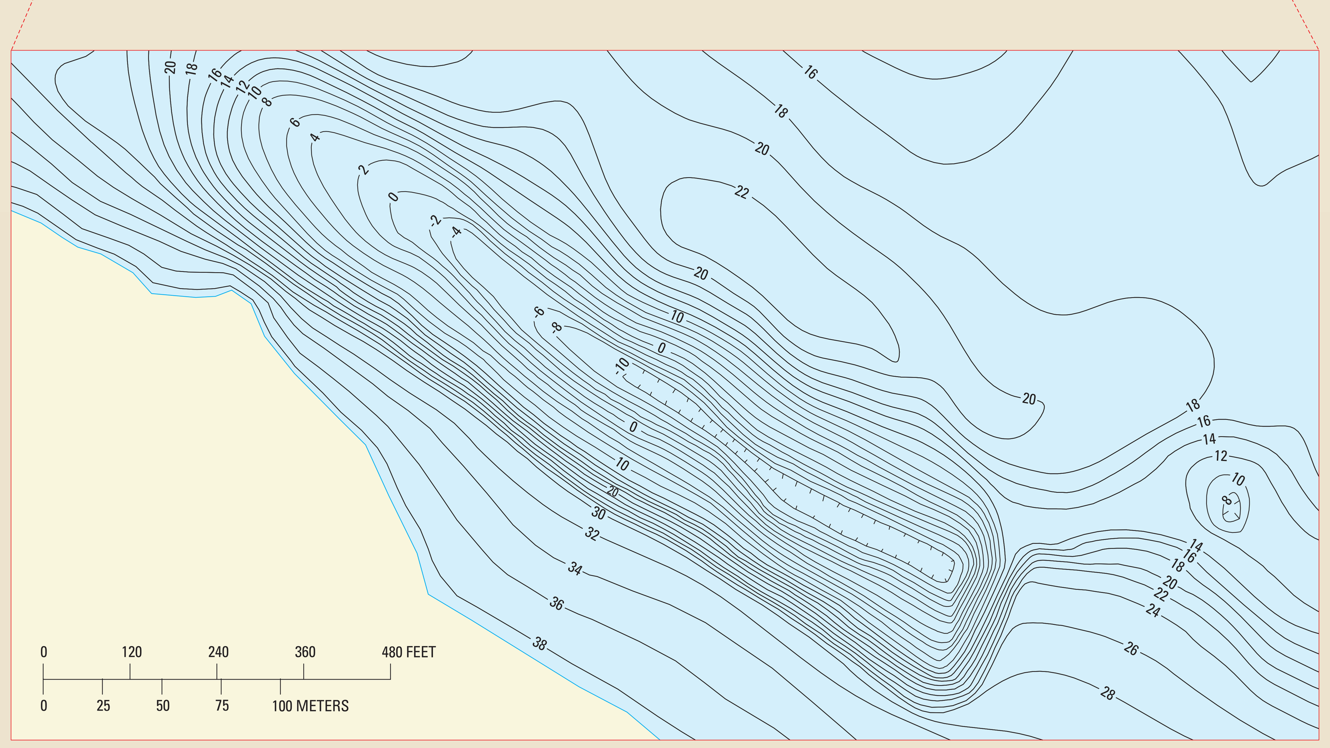
Table 1. Volume comparison for selected elevations of Lake Manatee, Manatee County, Florida.

[Volumes for 2009 calculated using equation derived from surface with tested vertical accuracy of 4.08 feet at the 95-percent confidence interval]

Elevation, in feet		Volume, in million gallons	
Above NAVD 88	Above NGVD 29	1967	2009
39.1	40.0	7,205	5,934
38.1	39.0	6,609	5,457
37.1	38.0	6,046	4,991
36.1	37.0	5,516	4,539
35.1	36.0	5,017	4,103
34.1	35.0	4,549	3,685
33.1	34.0	4,111	3,286
32.1	33.0	3,702	2,909
31.1	32.0	3,322	2,556
30.1	31.0	2,969	2,228
29.1	30.0	2,643	1,928
28.1	29.0	2,343	1,657
27.1	28.0	2,068	1,418
26.1	27.0	1,818	1,213
25.1	26.0	1,591	1,043





EXPLANATION

—20— Bathymetric contour--Line of equal lake-bottom elevation, in feet above NAVD 88. Interval is 2 feet. Hachures indicate closed depression. Vertical accuracy of contours is 7.44 feet at the 95-percent confidence interval

Lake boundary--Edge of water at lake-surface elevation, 38.88 feet above NAVD 88 (39.83 feet above NGVD 29)

Base digitized from Southwest Florida Water Management District true color orthophotography, 2006
Albers Equal Area Conic projection, North America, North American Datum of 1983.

Figure 1. Bathymetric contours of Lake Manatee, 2009 (not for navigational use).

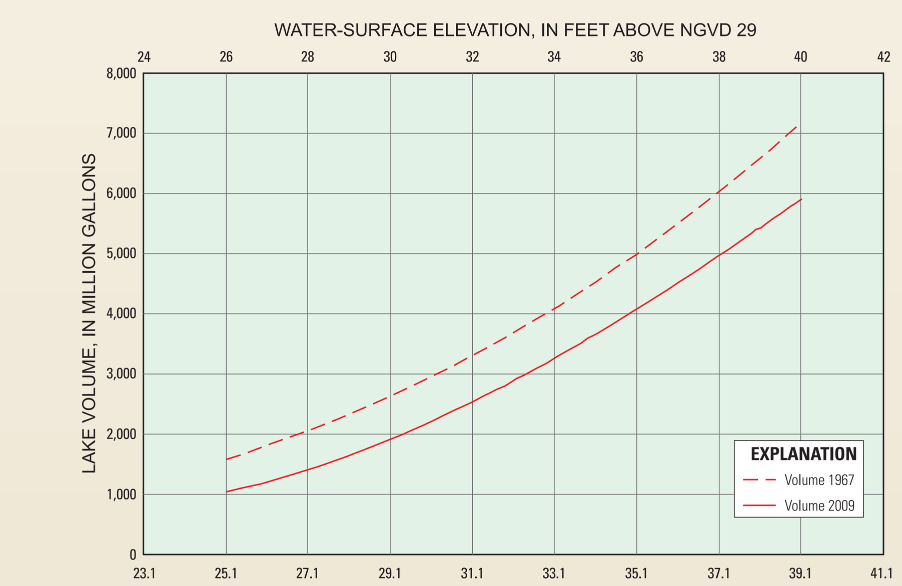
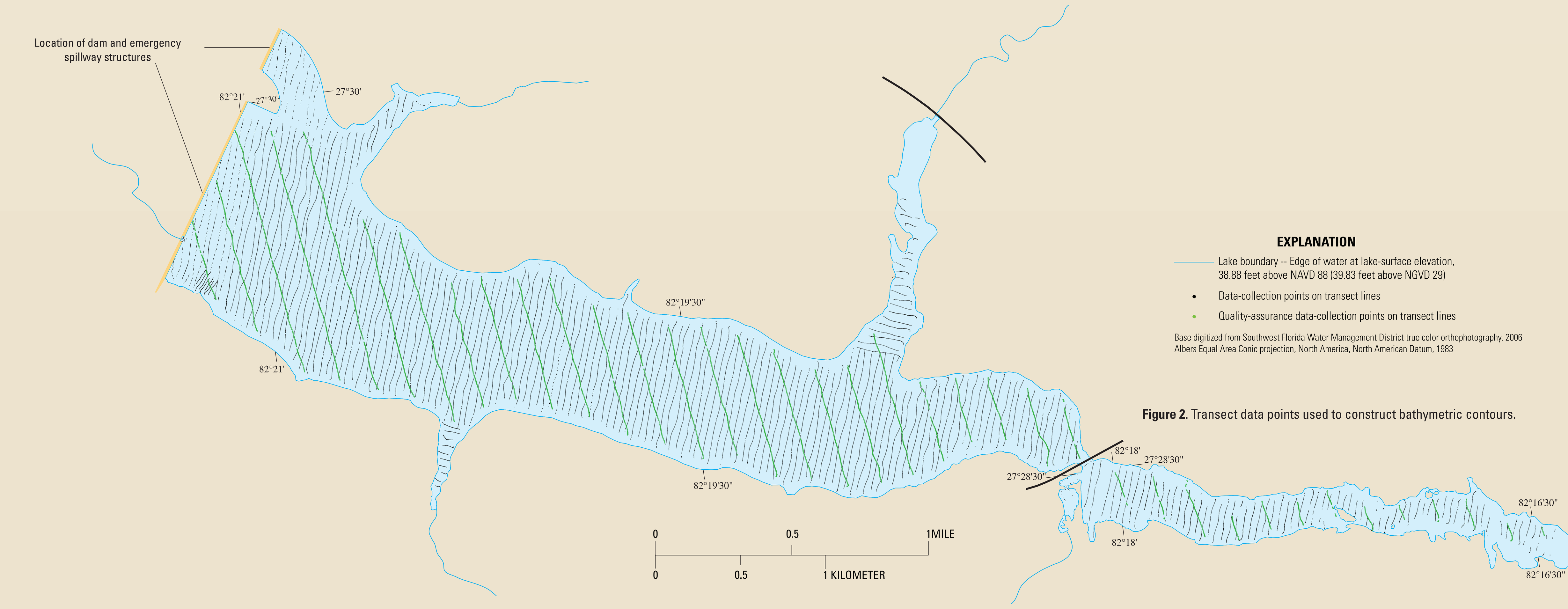


Figure 3. Elevation and volume curve comparison for Lake Manatee, Manatee County, Florida.



EXPLANATION

Lake boundary -- Edge of water at lake-surface elevation, 38.88 feet above NAVD 88 (39.83 feet above NGVD 29)

• Data-collection points on transect lines

• Quality-assurance data-collection points on transect lines

Base digitized from Southwest Florida Water Management District true color orthophotography, 2006
Albers Equal Area Conic projection, North America, North American Datum, 1983

Figure 2. Transect data points used to construct bathymetric contours.

Bathymetry of Lake Manatee, Manatee County, Florida, 2009

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