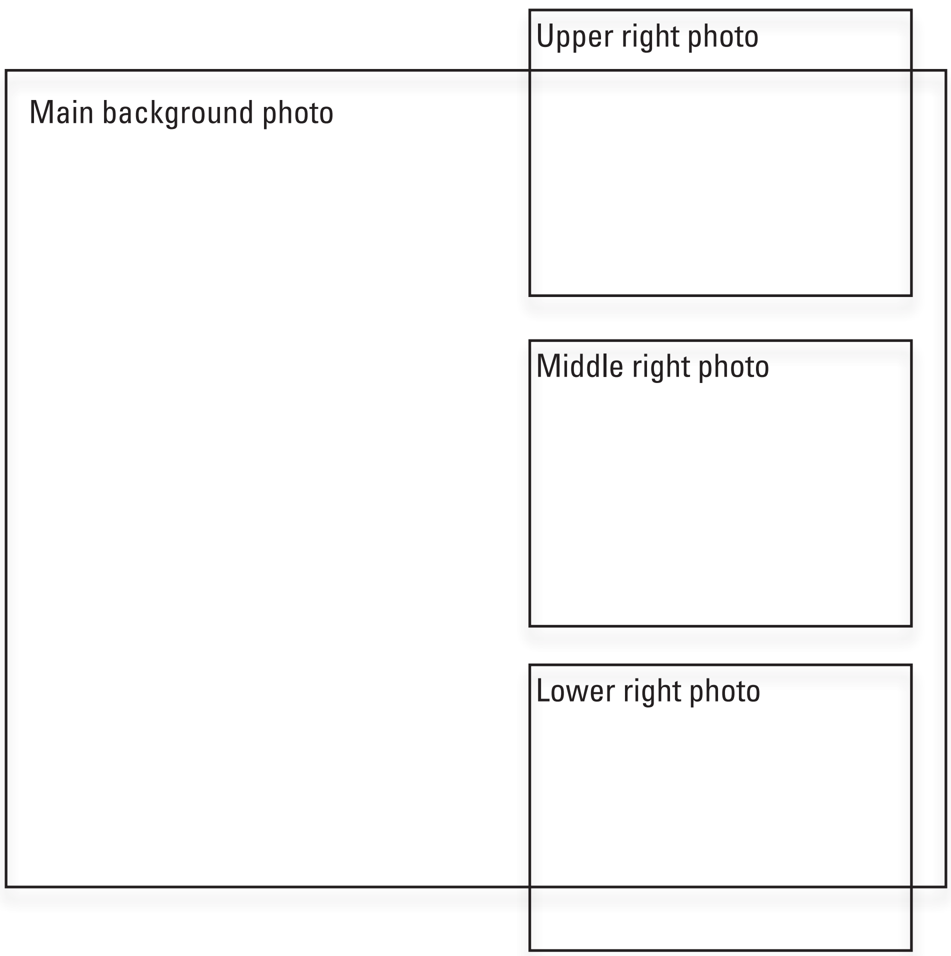
Prepared in cooperation with the Strategic Environmental Research and Development Program

Storage Capacity of the Fena Valley Reservoir, Guam, Mariana Islands, 2014

Scientific Investigations Report 2015–5128

U.S. Department of the Interior
U.S. Geological Survey



Cover. Main Cover Photo: Fena Valley Reservoir with view of intake-screen house and spillway. (Photograph by S.A. Wright, U.S. Geological Survey, February 24, 2014)
Upper right photo: Erosion on steep slopes in the Fena Valley Reservoir Watershed. (Photograph by M.D. Marineau, U.S. Geological Survey, February 22, 2014)
Middle right photo: Imong River upstream from the Fena Valley Reservoir. (Photograph by M.D. Marineau, U.S. Geological Survey , February 23, 2014)
Lower right photo: U.S. Geological Survey hydrologist Mathieu Marineau surveying a section of the Imong River just upstream of the Fena Valley Reservoir. (Photograph by S.A. Wright, U.S. Geological Survey, February 23, 2014)

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Contents

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as
°C = (°F – 32) / 1.8.

Datums

Vertical coordinate information is referenced to the 2004 Vertical Datum of Guam (GUVD04), which is referenced to the Mean Sea Level (MSL) calculated from the National Tidal Datum Epoch (NTDE) of 1983–2001 by Carlson and others (2009).

Previous datums used in historical surveys referenced elevation to the MSL tidal datum or to the mean lower low water (MLLW) tidal datum, although details on the precise elevation of the tidal datums used in the historical surveys is unknown.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) coordinates where the reference frame has been affixed to the stable Mariana tectonic plate [NAD 83(MA11)] (National Geodetic Survey, 2011).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

ADCP	Acoustic Doppler Current Profiler
CTD	Conductivity, temperature, and depth
DEM	Digital Elevation Model
GNSS	Global Navigation Satellite System
GUVD04	Guam Vertical Datum of 2004
MLLW	Mean Lower Low Water
MSL	Mean Sea Level
NTDE	National Tidal Datum Epoch
NAD83(MA11)	North American Datum of 1983 (referenced to the Mariana tectonic plate)
PSS-78	Practical salinity scale
RTK	Real-time kinematic
SERDP	Strategic Environmental Research and Development Program
USGS	U.S. Geological Survey
UHF	Ultra-high frequency

Storage Capacity of the Fena Valley Reservoir, Guam, Mariana Islands, 2014

By Mathieu D. Marineau and Scott A. Wright

Abstract

The Fena Valley Reservoir is in southern Guam and is the primary source of water for the U.S. Naval Base Guam and nearby village residents. Since the construction of the Fena Dam in 1951, sediment has accumulated in the reservoir and reduced its storage capacity. The reservoir was surveyed previously in 1973, 1979, and 1990 to estimate the loss in storage capacity. To determine the current storage capacity, the U.S. Geological Survey, in cooperation with the U.S. Department of Defense Strategic Environmental Research and Development Program, surveyed the bathymetry of the reservoir in February 2014.

The bathymetric survey was accomplished by making depth soundings using a boat-mounted, acoustic Doppler current profiler. Location during bathymetric data collection was determined using a single-base Global Navigation Satellite System-Real Time Kinematic survey. Vertical profiles of conductivity, temperature, and depth were collected periodically. The conductivity, temperature, and depth profiles were used to spatially and temporally adjust the sound-speed calculations used to determine depth from the soundings. Approximately 108 kilometers of transects with a total of about 380,000 depth soundings were surveyed. In addition, approximately 2,100 topographic survey points in shallow, wadable areas near the Imong River Delta were defined by using a Global Navigation Satellite System receiver attached to a fixed-length survey rod. Depth soundings and topographic survey points were compiled and interpolated to generate a digital-elevation model of the reservoir. Data extracted from the digital-elevation model were then tabulated to determine total reservoir capacity and create reservoir stage–surface area and stage–storage capacity tables.

Analyses of the bathymetric data indicate that the reservoir currently has 6,915 acre-feet of storage capacity. The engineering drawings of record show that the total reservoir capacity in 1951 was estimated to be 8,365 acre-feet. Thus, between 1951 and 2014, the total storage capacity decreased by 1,450 acre-feet (a loss of 17 percent of the original total storage capacity). The remaining live-storage capacity, or the volume of storage above the lowest-level reservoir outlet elevation, was calculated to be 5,511 acre-feet in 2014, indicating a decrease of 372 acre-feet (or 6 percent) of the original 5,883 acre-feet of live-storage capacity. The remaining dead-storage capacity, or volume of storage below the lowest-level outlet, was 1,404 acre-feet in 2014, indicating a decrease of 1,078 acre-feet (or 43 percent) of the original 2,482 acre-feet of dead-storage capacity.

Introduction

Fena Valley Reservoir, located in southern Guam, is owned and operated by the U.S. Navy. Construction of the Fena Dam began in 1950 and was completed in 1951. Previous surveys reveal a general decline in the Fena Valley Reservoir storage capacity. The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Defense Strategic Environmental Research and Development Program (SERDP), is investigating the potential effects of climate change on the water resources of Guam. In order to accurately predict surface-water availability by using a watershed model of southern Guam and a water-balance model of the reservoir, up-to-date reservoir capacity information is needed. The need for updated reservoir capacity data and the concern for reservoir sedimentation led to the initiation of this study.

Purpose and Scope

The USGS, in cooperation with the SERDP, conducted a bathymetric survey to determine the present storage capacity of the Fena Valley Reservoir and provide updated reservoir stage–surface-area and stage–capacity curves.

The bathymetric survey was part of a more comprehensive study to investigate the effects of climate change on the water resources of Guam. Some of the other parts of the comprehensive study include downscaling climate projections, developing an updated watershed model for the island, and developing a quantitative assessment of how future changes in streamflow and sediment loads will affect the reservoir.

In this report, the stage-storage and stage-capacity results from the 2014 reservoir capacity survey were compared with those from the 1949 pre-construction survey to provide some general context of the quantity of sediment that has been deposited in the reservoir since construction. A detailed interpretation of sedimentation rates and deposition patterns is not included in this report.

Description of Study Area

The Fena Valley Reservoir is in southern Guam, 8.7 mi southwest of the capitol, Hagåtña, at approximately 13° 21′ N, 144° 42′ E and lies within the Naval Base Guam Ordnance Annex (formerly the Naval Magazine), which is one of many facilities that are a part of Naval Base Guam, a consolidated U.S. Navy installation. At full capacity, the reservoir surface area extends approximately 0.30 square miles (mi^2) and drains a watershed area of about 5.88 mi^2. The reservoir was formed after the construction of the Fena Dam in 1951 and inundation of the Fena River Valley. The earthen dam is 85 feet (ft) tall and 1,050 ft in length. The reservoir currently serves as the primary source of water for Navy Base Guam and the civilian residents living in villages near the base in southern Guam. At the time of construction, the reservoir had an estimated total storage capacity of 8,365 acre-feet (acre-ft; based on digitization of 1949 stage-capacity curve from Frederic R. Harris, Inc., 1949). Live storage, sometimes called usable storage or water-supply storage, is water storage located above the lowest-level outlet, which is 37.00 ft below the spillway crest (Frederic R. Harris, Inc., 1949). The live-storage capacity at the time of construction was estimated to be 5,883 acre-ft. The 2,482 acre-ft of 1949 storage volume below the lowest-level outlet is considered dead storage and is reserved for siltation.

Climate in Guam is characterized as warm and humid. Mean temperature is 84 degrees Fahrenheit (°F) and generally ranges from 79 to 89 °F (National Oceanic and Atmospheric Administration, 2014). Average annual precipitation is approximately 100 inches in southern Guam (Shade, 1983). Most of this precipitation falls between July and November; December through June is considered the dry season. Typhoons and tropical storms happen periodically and can deliver substantial amounts of precipitation in 24- to 48-hour periods.

The geology in the Fena Valley Watershed consists mostly of rocks in the Umatac Formation (primarily weathered rock of volcanic origin) and an older limestone formation in the higher elevations (Tracey and others, 1964). The surficial geology in the western-most part of the watershed appears to have high permeability (evidenced by the lack of any large surface-water features). Precipitation in this region seeps into the soil and underlying rock until it reaches the Umatac Formation, which has low permeability (Ward and others, 1965). The precipitation then resurfaces through springs that are found in the area of Fena Valley Reservoir. Although there are a few roads and facilities in the watershed, it remains largely undeveloped and covered with tall grasses and broad-leaf forests. The volcanic soils are highly erodible when denuded of vegetation (Kennedy Engineers Inc., 1973). Previous studies noted that wildfires (Shade, 1983; Nakama 1992) and fires started by poachers (Kennedy Engineers Inc., 1973) are common during the dry season and indicated that they are the primary underlying cause of erosion. During the survey, no direct evidence of wildfires was observed; however, several areas of recent soil erosion, in the form of translational earth slides, were noted on the steep slopes. The steep slopes are particularly vulnerable to this type of erosion (Schumm and Harvey, 2008), which could be triggered by saturated soil conditions following intense precipitation (Highland and Bobrowsky, 2008).

Three rivers drain into the reservoir from the south and west: the Imong, Almagosa, and Maulap Rivers (fig. 1). Streamflow discharge on all three of these rivers is monitored by USGS streamgages (station 16847000, Imong River near Agat; station 16848100, Almagosa River near Agat Guam; station 16848500, Maulup River near Agat Guam; fig. 1). The watershed draining to the reservoir does not extend far to the east, and there are no major tributary rivers on the east side. Water exiting the reservoir over the spillway enters the Maagas River and eventually drains east to the Pacific Ocean.

Previous Studies and Vertical Datum

The Fena Valley Reservoir was surveyed previously in 1973, 1979, and 1990 (Kennedy Engineers Inc., 1973; Curtis, 1984; Nakama, 1992, respectively) to determine the remaining storage capacity and estimate sedimentation rates. Previous surveys show a general but unsteady decline in the Fena Valley Reservoir storage capacity since completion of the dam in 1951.

The current official vertical datum is the Guam Vertical Datum 2004 (GUVD04); however, the dam construction predates this datum by several decades. Previous studies and the pre-construction engineering drawings of record used a variety of datums or did not indicate a datum. For example, the engineering drawings of record note that elevations were “corrected” to Mean Lower Low Water (MLLW) and designated MLLW as the elevation datum on one sheet; the vertical datum was not indicated on other sheets (Frederic R. Harris, Inc., 1949). Later studies either did not indicate a datum (Kennedy Engineers Inc., 1973) or used Mean Sea Level (MSL; Curtis, 1984; Nakama, 1992). In all cases, the same elevation of the spillway (111.35 ft) was reported but without referencing this elevation to a consistent datum. The original elevation measurement of the spillway crest was likely an error caused by using an unofficial MLLW datum, and that error has propagated through subsequent studies and local surveys.

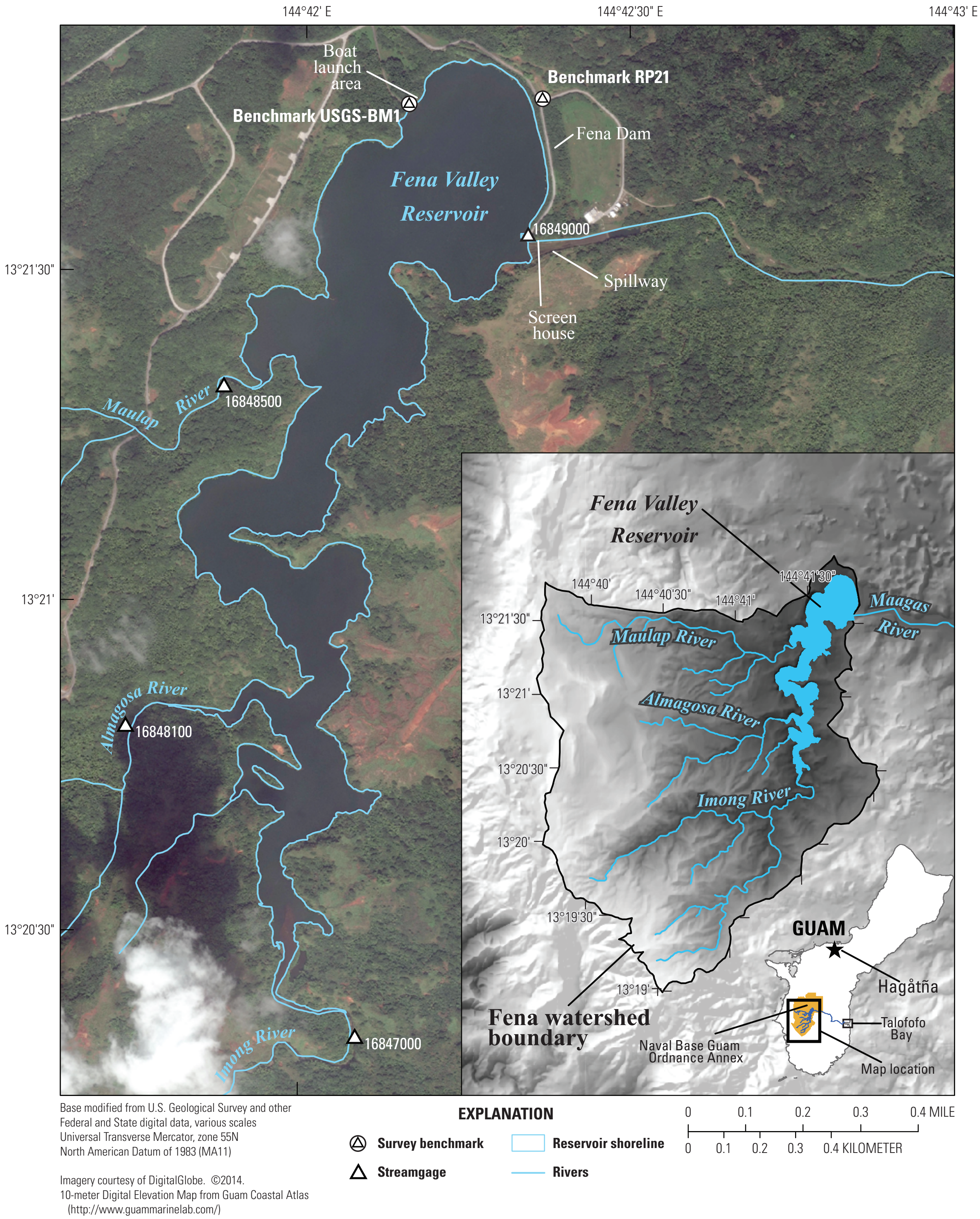

Figure 1. Fena Valley Reservoir and watershed, Guam.

During this study (2014), a control survey using the latest survey techniques was conducted to directly relate the elevation of the Fena Dam spillway crest to GUVD04 vertical datum (Carlson and others, 2009). The results of the spillway elevation differed from that reported in previous studies. Although there are several possible causes of survey error, the original survey also referenced an unofficial tidal datum. Tidal records from a specific 19-year period designated as a National Tidal Datum Epoch (NTDE) are required to compute tidal datums reliably (Gill and Schultz, 2001). Because the first known tidal station on Guam was not established until 1948 (Department of Commerce, 1948), tidal records were not long enough at the time of reservoir construction to compute official tidal datums. Because there are no other known control surveys relating the spillway crest to GUVD04 or any other known benchmark, in this report only the results of the control survey conducted during this study are used. The precise elevation of the spillway, however, does not affect the capacity calculations of this study or previous studies since they all measure reservoir capacity relative to the spillway crest.

Data Collection

The equipment and methods used to collect the topographic and bathymetric data, which were used to calculate the reservoir storage capacity, are described in this section. All fieldwork was conducted during February 22–27, 2014.

Equipment

The following is a list of equipment used during the bathymetric survey and establishment of a temporary benchmark.

- 14-ft McKee Craft fiberglass boat with 4-horsepower engine
- Sontek M9 HydroSurveyor™ acoustic Doppler current profiler (ADCP)
- Field laptop with Sontek HydroSurveyor™ software
- Trimble R7 Global Navigation Satellite System (GNSS) receiver, Ultra-High Frequency (UHF) radio, and Zephyr II antenna mounted to an adjustable-height tripod
- Trimble R10 GNSS receiver used as a rover mounted to the boat or used with a 2-meter fixed-length survey rod
- Trimble TSC3 hand-held controller, used to program the GNSS receivers and record data
- Sontek CastAway™ conductivity, temperature, and depth (CTD) profiler

Horizontal and Vertical Controls

A temporary benchmark was established near the reservoir and used for horizontal and vertical control during this study. This section describes the coordinate systems used in this survey and the methods used to establish the temporary benchmark.

Coordinate systems

The vertical coordinate system used in this study is the Guam Vertical Datum of 2004 (GUVD04). GUVD04 is referenced to the MSL calculated from the NTDE of 1983–2001 (Carlson and others, 2009). The horizontal geographic coordinate system used is the North American Datum of 1983 adjusted by the National Geodetic Survey such that it is referenced to the Mariana tectonic plate; it is abbreviated as NAD83(MA11). NAD83(MA11) is used to define coordinates for Guam and the Northern Mariana Islands (National Geodetic Survey, 2011). The projected coordinate system used in figures in this report is NAD83(MA11) Universal Transverse Mercator zone 55 North.

Temporary Benchmark

The primary benchmark used for horizontal and vertical control at the Fena Dam is benchmark RP21 (fig. 1; Chui Yueng, U.S. Geological Survey, written commun., 2014; fig. 1). However, benchmark RP21 is not readily accessible from the boat launch area and is located below power lines, which can affect GNSS quality and distort measurements (Rydland and Densmore, 2012). In addition, survey-measurement quality information on benchmark RP21 was not well documented. Therefore, a temporary benchmark (designated USGS-BM1) was installed near the boat launch area at the northwestern corner of the reservoir (fig. 1). Horizontal and vertical controls for the bathymetric survey were established by surveying from Guam Department of Land Management (Guam DLM) Benchmark DH3061 (appendix 1; DH3061 is not shown in a figure), using a Level IV (Rydland and Densmore, 2012) single-base global navigation satellite system, real-time kinematics (GNSS-RTK) survey, to temporary benchmark USGS-BM1 (fig. 1). Guam DLM Benchmark DH3061 was selected because of its proximity to the reservoir and because it was surveyed by Carlson and others (2009) during the establishment of GUVD04.

Temporary benchmark USGS-BM1 was installed February 21, 2014, and marked by a USGS brass plate (fig. 2). The asphalt surface of the boat launch parking lot was buried by about 6 inches of soil. To secure the brass plate, a 12-inch diameter hole was dug though the soil to the asphalt and backfilled with quick-setting concrete mix. The brass plate was installed in the concrete (fig. 2). Horizontal and vertical coordinates of temporary benchmark USGS-BM1 and other benchmarks were derived from averaging one or more survey measurements with occupation times typically between 10 and 40 seconds.

The GNSS-RTK base station consisted of a Trimble R7 GNSS receiver with a dual frequency, Zephyr II antenna and UHF transmitting radio mounted on an adjustable height tripod. A laser tribrach was used to center the base station antenna above a benchmark. Each leg of the tripod was braced by sand bags to prevent movement during the survey. The rover consisted of a Trimble R10 Global GNSS receiver mounted to a 2-meter fixed-height survey rod. Data were logged on a Trimble TSC3 hand-held controller using Trimble Access Software (Trimble, 2013).

While the GNSS-RTK base station was set up on Guam DLM Benchmark DH3061 for the survey to temporary benchmark USGS-BM1, three nearby benchmarks (DH3034, DK2736, and DH3040; appendix 1) were surveyed as vertical and horizontal checks. Later, the GNSS-RTK base station was set over temporary benchmark USGS-BM1to perform elevation checks at additional benchmarks and to perform a single-base GNSS-RTK survey of the reservoir. Elevation checks were done for two additional benchmarks (GGN 2053 and GGN 2054; table 1), which are outside of the Naval Base Guam Ordnance Annex near the entrance gate (Thomas Torres, Government of Guam, written commun., 2014). In addition, survey measurements were collected for benchmark RP21 (fig. 1) and the spillway crest (fig. 3).

Horizontal and vertical coordinates for each benchmark and the spillway crest are listed in table 1. Differences between previously published coordinates and the coordinates of survey measurements made during this study are listed in table 2.

Figure 2. Temporary benchmark USGS-BM1, installed February 21, 2014, near the boat launch area of the Fena Valley Reservoir, Guam. (Photographs by M.D. Marineau, February 22, 2014)

Table 1. Survey results for benchmarks used in the February 22, 2014, control survey from Talofofo Bay to Fena Valley Reservoir, Guam.

Benchmark/ survey point	Latitude[1]	Longitude[1]	Ellipsoid height[2] (feet)	Orthometric height[3] (feet)
DH3040	13° 21′ 00.33332″ N	144° 46′ 09.66726″ E	216.47	40.84
DK2736	13° 20′ 32.74334″ N	144° 45′ 44.64012″ E	189.55	14.2
DH3034	13° 20′ 10.72125″ N	144° 45′ 44.64012″ E	184.25	8.8
USGS BM1	13° 21′ 45.11828″ N	144° 42′ 09.96910″ E	289.97	112.69
GGN 2053	13° 23′ 19.11545″ N	144° 41′ 13.24816″ E	576.83	399
GGN 2054	13° 23′ 12.01057″ N	144° 41′ 07.84761″ E	558.63	380.83
RP21	13° 21′ 46.35849″ N	144° 42′ 21.74374″ E	302.63	125.41
Spillway Crest[4]	13° 21′ 32.38333″ N	144° 42′ 20.82923″ E	287.77	110.63
Spillway Crest[5]	13° 21′ 31.86879″ N	144° 42′ 20.94531″ E	288.07	110.93

[1]Symbols and letters °, ′, ″, N, and E refer to degrees, minutes, seconds, north and east, respectively.

[2]Ellipsoid height referenced to North American Datum of 1983 (NAD83) referenced to the Mariana tectonic plate.

[3]Orthometric height referenced to Guam Vertical Datum of 2004 (GUVD04) using GEOID12A (National Geodetic Survey, 2012).

[4]Survey measurement at the northern end of the spillway crest.

[5]Survey measurement at the center of the spillway crest.

Figure 3. Spillway at the Fena Valley Reservoir, Guam. (Photograph by M.D. Marineau, February 21, 2014)

Table 2. Differences between published coordinates and 2014 surveyed coordinates, Fena Valley Reservoir, Guam.

[ft, feet; MSL, mean sea level; n/a, published coordinates were not available for comparison; NGS, National Geodetic Survey. Difference is published minus surveyed coordinates.]

Benchmark/ survey point	Latitude difference[1]	Longitude difference[1]	Orthometric height difference[2] (ft)	Source of published data
DH3040	n/a	n/a	–0.28	NGS datasheet
DK2736	–00° 00′ 0.00039″	00° 00′ 0.00048″	–0.16	NGS datasheet
DH3034	n/a	n/a	–0.11	NGS datasheet
GGN 2053	00° 00′ 0.00886″	00° 00′ 0.01389″	–0.05	Written communication[3]
GGN 2054	00° 00′ 0.00865″	00° 00′ 0.01451″	0.07	Written communication[3]
RP21	n/a	n/a	0.42	Written communication[4]
Spillway crest[5]	n/a	n/a	0.72	Written communication[4]
Spillway crest[6]	n/a	n/a	0.42	Written communication[4]

[1]Symbols and letters: °, ′, and ″, refer to degrees, minutes, seconds, respectively.

[2]Orthometric height referenced to Guam Vertical Datum of 2004 (GUVD04) using GEOID12A (National Geodetic Survey, 2012); NGS datasheets are included in the appendix.

[3]Thomas Torres, Government of Guam, written commun., 2014.

[4]Elevation of RP21, 125.83 ft above MSL; spillway crest elevation, 111.35 ft above MSL (Ron Rickman and Chui Yueng, U.S. Geological Survey, written commun., 2014).

[5]Survey measurement at northern end of Spillway Crest.

[6]Survey measurement at center of Spillway Crest.

A USGS streamgage at the spillway (station 16849000, Fena Dam Spillway near Agat, Guam; fig. 1) monitors reservoir stage and is referenced to the spillway crest. In general, during the 4 days of the bathymetric survey, the reservoir was full. The change in stage was approximately 0.16 ft.

Bathymetric Survey

Bathymetric data were collected using a boat-mounted Sontek M9 HydroSurveyor™ (M9) acoustic Doppler current profiler (ADCP). The ADCP was attached to the side of the 14-ft fiberglass McKee Craft motorized boat at a depth of 1.15 ft (measured from the water surface to the bottom of the ADCP) using an aluminum mount and wooden frame.

The M9 is equipped with nine transducers. One of the transducers is pointed directly below the ADCP, and the other eight are arranged as two sets of four transducers in Janus configurations with each transducer at a 25-degree slant angle. The center transducer (0.5 megahertz [MHz]) is designed to measure depth directly beneath the instrument, and the two sets of transducers in Janus configurations (1 MHz and 3 MHz) are designed to measure three-dimensional velocity profiles. However, the angled transducers also record the depth to the bed such that the ADCP records five depth measurements per ping with the footprint dependent on water depth (larger footprint in deeper water). Internal compass data are used by the HydroSurveyor software (Sontek Inc., 2013) to horizontally locate the depths from the angled transducers with respect to instrument position. In addition to the horizontal position corrections, data from the pitch/roll sensor are used to make geometric corrections. During operation, the center transducer is always in use, whereas only one of the sets of four outer transducers is in use at any given time, depending on water depth and instrument settings. For depths up to 5 meters (m; about 16.4 ft), the 3.0 MHz set of transducers is typically used, and for deeper waters (greater than 5 m), the second set of transducers, operating at 1.0 MHz, is used. The instrument was set to automatically switch from one set of transducers to the other depending on the detected water depth. The maximum depth that the 1.0-MHz transducers are capable of measuring is 40 m (about 130 ft). According to manufacturer specifications, the vertical accuracy of the M9 is 0.02 m (0.07 ft) when using sound-speed corrections (Xylem Inc., 2012a). System checks and compass calibration of the ADCP were performed daily.

Data were recorded on a field laptop using HydroSurveyor software. Location was determined using a single-base GNSS-RTK survey. A Trimble R10 GNSS receiver mounted to the boat was configured to provide a 10 Hz National Marine Electronics Association data stream of vector track and ground speed data and global positioning system fix information data to the HydroSurveyor™ software. The GNSS base station was mounted over benchmark USGS-BM1. The HydroSurveyor™ software uses the coordinates from the R10 GNSS, ADCP heading information, and measured depth to calculate the precise position of each depth sounding.

The approach for conducting the bathymetric survey was first to follow the entire shoreline as closely as possible, given dense vegetation and water depth. Distance to the shoreline was generally between 3 and 9 ft. After the shoreline depth data were collected, the center of the reservoir was surveyed by generally following a crisscross pattern (fig. 4). The real-time display of the boat position along with previously collected data on the field laptop were used to determine where to guide the boat to reduce data gaps. Deltaic deposits were found at the mouth of the Imong River (fig. 5). In these areas, the shallow water prevented use of the boat for surveying. Therefore, the R10 GNSS rover was used with a 2-m (6.56-ft) survey rod (fig. 6) to survey the Imong River and delta. An outline of the reservoir with the location of all depth soundings and topographic survey points is shown in figure 4.

Temperature and Depth Profiles

The density of water is primarily affected by temperature in freshwater reservoirs. Changes in the density above and below a thermocline will affect the speed of sound underwater (referred to as “sound speed”). Sound-speed variation in the water column, if uncorrected, can introduce error in depth measurements collected using acoustically based survey instruments. A 10 °F decrease in temperature (from 65 °F to 55 °F, for example) in freshwater can decrease the sound speed by about 54 ft per second (ft/s), or 1.1 percent, determined on the basis of calculations made using the Chen and Millero (1977) equation for sound speed. Thus, assuming the water column is the same temperature as the surface would cause an overestimate of sound speed leading to a biased-high estimate of depth (resulting in an overestimation of reservoir capacity). Most ADCPs are equipped with built-in temperature sensors that provide only near-surface temperature (Oberg and others, 2005). Vertical profiles of conductivity, temperature, and depth CTD (referred to as “casts”) were collected using a Sontek CastAway™ CTD profiler and were used to calculate the sound speed throughout the water column. Generally, a cast was collected at the start of the survey, during the survey whenever moving to a new location, and at the end of the survey (fig. 4). The CastAway CTD has an internal Global Positioning System (GPS) receiver for measuring the horizontal location of each cast. The CastAway CTD can operate in depths up to 100 m (about 328.1 ft) with an error of ±0.25 percent full scale and temperatures ranging from –5 to 45 °C (about 23 to 113 °F) with an error of ±0.05 °C (about ±0.09 °F) (Yellow Springs Instruments, 2010).

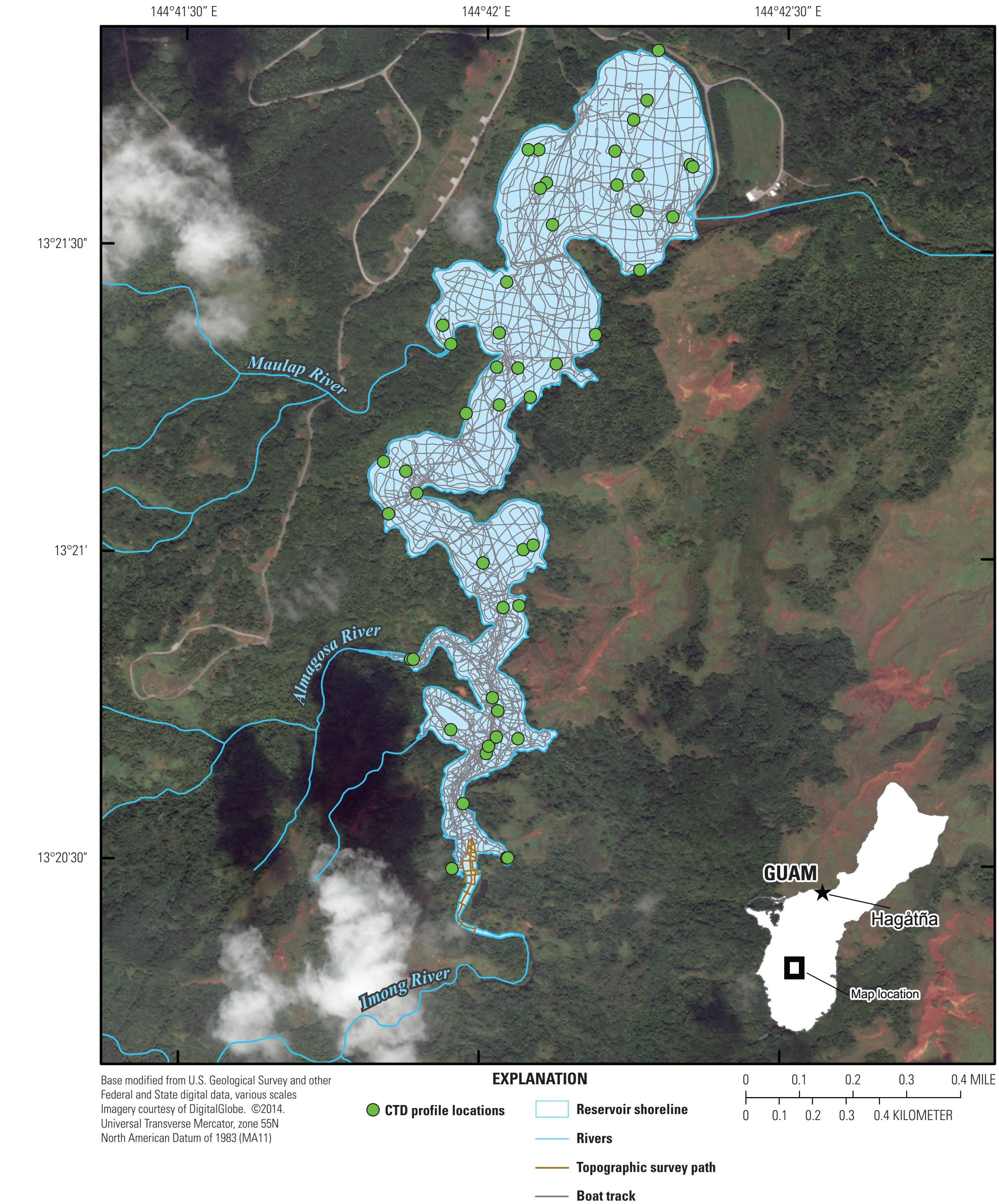

Figure 4. Bathymetric boat-survey track, locations of topographic survey points at Imong River and Imong River Delta, and locations of conductivity, temperature, and depth (CTD) vertical profiles, Fena Valley Reservoir, Guam, 2014.

Figure 5. Sand deposition at Imong River Delta on the southern-most tip of the Fena Valley Reservoir, Guam. (Photograph by M.D. Marineau, February 25, 2014)

Figure 6. Surveying of the Imong River between the Fena Valley Reservoir and the Imong River streamgage (station 16847000), Guam. (Photograph by S.A. Wright, February 25, 2014)

Data Analysis

Raw depth-sounding data were first corrected for changes in sound speed, resulting from potential thermoclines. The sound-speed corrected depth data were then converted to elevation and merged with topographic datasets and the shoreline data. The merged data were interpolated to obtain a 1-meter (3.28-ft) resolution digital elevation model (DEM) of the survey. This DEM was used to compute capacity.

Shallow-Water Survey, Spillway Elevation, and Shoreline Digitization

Additional shallow-water survey measurements were processed in Trimble Business Center software (Trimble, 2014). The coordinates of these points were then merged with bathymetric points. The spillway crest was also surveyed (tables 1 and 2) and found to have an average elevation of 110.8 ft GUVD04.

The elevation of the spillway crest was surveyed by using a fixed-length survey rod with the R10 receiver. The spillway crest was surveyed in two locations, once near the northern wall of the spillway and once in the center of the spillway (tables 1 and 2). Results for these two spillway crest locations differed by about 0.3 ft, and neither corresponded with previously published survey elevations. The differences between the two survey elevations could be associated with multipath signals near the northern wall or could be due to difficulties in maintaining survey rod stability on the spillway crest. For this study, we averaged the two values and reported the surveyed elevation of the spillway crest as 110.8 ft GUVD04.

The shoreline, representing spillway elevation, was digitized from high-resolution satellite imagery of the reservoir (fig. 1), dated February 7, 2014, courtesy of DigitalGlobe Inc. (2014). The imagery was collected when the reservoir was near full capacity, which was based on USGS streamgage measurements recorded at the time. The bathymetric data were overlaid and reviewed to ensure that all points fell within the digitized shoreline. The shoreline was then converted to points at 1-meter (3.28-ft) intervals using ArcGIS™, assigned an elevation of 110.8 ft GUVD04 (elevation the water surface when reservoir is at full capacity), and merged with the bathymetric and topographic data.

Sound-Speed Corrections

The HydroSurveyor™ software integrates multiple measurements made using the CastAway™ CTD with the bathymetric data. Sound speed was calculated by using the Chen and Millero (1977) equation, and beam angle changes resulting from the presence of a thermocline were corrected for by using Snell's Law (Joel Edelman, Sontek Inc., written commun., 2014). The HydroSurveyor software was used to apply sound-speed corrections to each depth sounding. Temperatures in the upper 10 ft of the water column were fairly uniform at about 85 °F. Below 10 ft to around 30 ft, temperatures dropped steadily to about 80 °F, indicating the presence of a thermocline. The average conductivity measured in the reservoir was 211 microsiemens per centimeter (µS/cm), and ranged from 176 to 260 µS/cm. The peak in conductivity occurred right around the thermocline; however, these changes in conductivity were considered low and had very little effect on sound-speed calculations. Average sound speed, calculated from the CTD profiles, was 4,940 ft/s and ranged from 4,925 to 4,947 ft/s. Examples of the water temperature, salinity, density and sound-speed profiles for three locations within the reservoir are shown in figure 7. The salinity in these plots is shown using the practical salinity scale (PSS-78), and the conversion of conductivity to salinity is based on the international equation of state for seawater (United Nations Educational, Scientific, and Cultural Organization, 1981). This conversion was performed internally by the CastAway CTD (Xylem, 2012b).

Bed-Elevation Calculation from Depth Soundings

After sound-speed corrections were applied to the depth soundings, the measurements from the depth soundings were converted to reservoir bed elevations on the basis of the reservoir stage at the time of measurement. Changes in stage can affect the capacity calculations if not properly taken into account. For example, during the time of the survey, the reservoir surface area at the spillway elevation was estimated as 192.6 acres (on the basis of the shoreline digitization), and the maximum observed range in stage was 0.16 ft. Failure to consider this change in stage could introduce error as high as 31 acre-ft in the storage-capacity estimate.

To account for the changes in stage, the corrected depth measurements were exported from the HydroSurveyor™ program to an Excel® file (Microsoft Corp., 2010). The time stamp for each depth sounding was rounded to the nearest 15-minute interval and cross-referenced to the gage-height measurement recorded at the spillway streamgage (Fena Dam Spillway near Agat, Guam, station 16849000; fig. 1). The vertical datum of the streamgage is referenced to the spillway such that a gage height of 0.0 ft corresponds to the spillway crest. The corresponding bed elevation, in ft GUVD04, for each depth sounding was then calculated using equation 1:

$$E = S + 110.8\,ft - D \qquad (1)$$

where

E is bed elevation, in ft GUVD04;

S is gage height recorded at the spillway, in ft; and

D is depth of sounding, in ft.

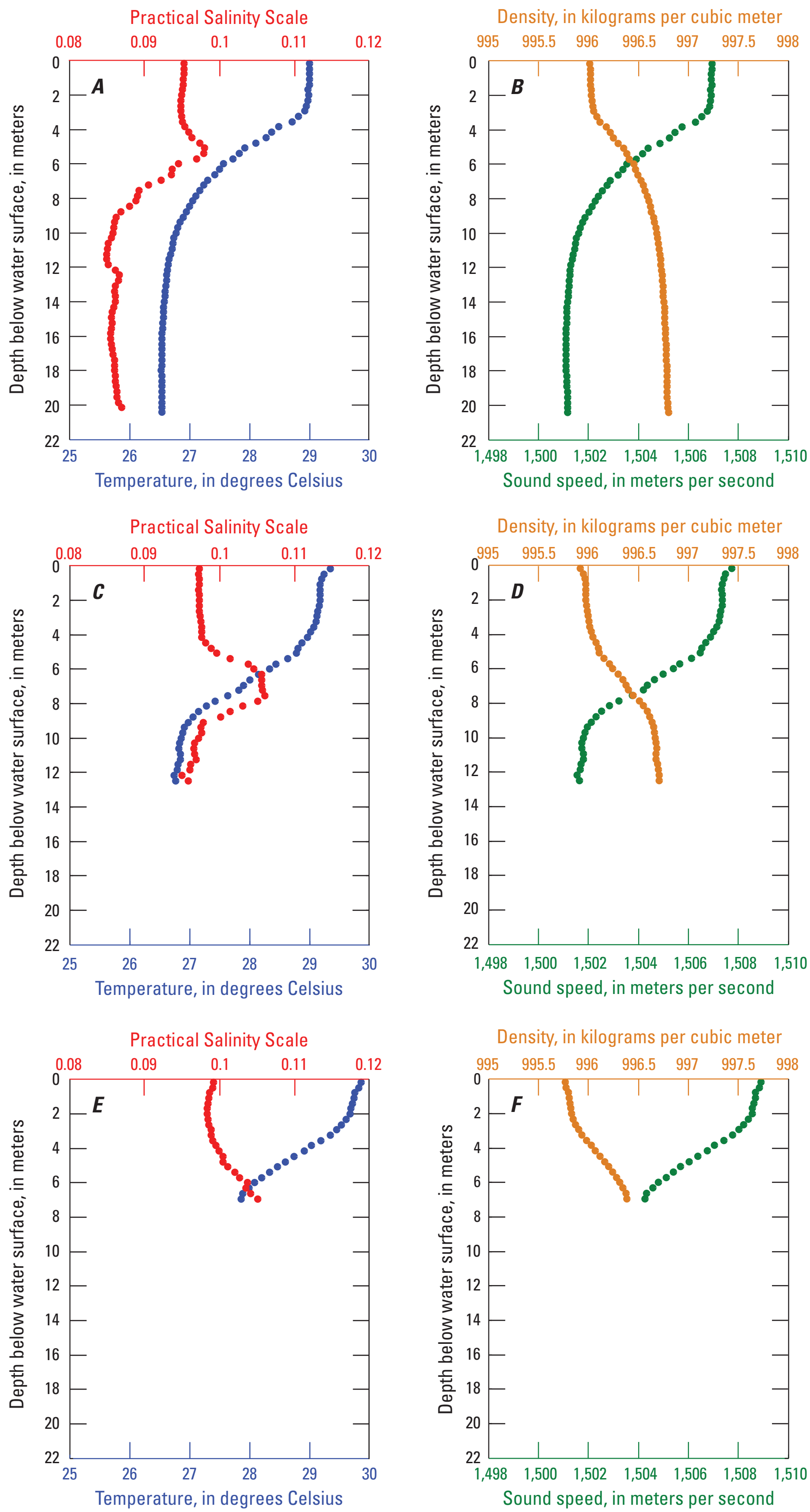

Figure 7. Examples of water temperature, salinity, density, and sound-speed profiles at three locations within the reservoir: *A* and *B*, cast from the downstream part of the reservoir near the dam (depth, 20.4 meters, 66.9 feet); *C* and *D,* cast from the middle part of the reservoir (depth, 12.5 meters, 41.0 feet); and *E* and *F,* cast from the upstream part of the reservoir (depth, 7.0 meters, 23 feet). Salinity is shown using the practical salinity scale (PSS-78). On plots A, C, and E, blue points indicate temperature and red points indicate salinity. On plots B, D, and F, green points indicate velocity and brown points indicate density.

Digital Elevation Model Development

The bed elevation and additional topographic survey points in the Imong River and delta were merged and imported into ArcGIS™ (ESRI Inc., 2013) as a shapefile. Erroneous bed-elevation points, likely caused by sound-wave reflections from the CastAway™ CTD, were removed from the dataset. A digital elevation model (DEM) was created in ArcGIS by using a nearest-neighbor interpolation algorithm. The elevation data from the DEM were then exported and tabulated in MATLAB® (The MathWorks Inc., 2014) to obtain the surface area and cumulative storage volume at 0.1-foot stage intervals. The bathymetric raster dataset was also used to generate contours at 5-foot intervals using an algorithm in ArcGIS. The contours were created only for the figure and were not used to calculate storage capacity. Contours smaller than about 50 ft are not shown.

The transducers in the Sontek M9 ADCP were calibrated by the manufacturer, and no calibration adjustments by the operator were needed. As an indirect check that the ADCP was functioning properly, we compared the maximum depth recorded in each CTD cast (referred to as "CTD-measured depth") to the depth derived from the DEM (referred to as "DEM-derived depth") at that location. Several of the casts collected had high horizontal-positioning error (greater than about 10 ft). This amount of error is acceptable for large-scale adjustments of sound-speed corrections but not for comparisons to DEM-derived depths; therefore, casts with large horizontal error were not used in the comparison. Also, several of the casts were collected in areas with steep bed topography; in those areas if the boat drifted a few meters from the GPS-derived location of the cast while the CastAwayCTD was still underwater, the CTD-measured depth could differ significantly from the DEM-derived depth. Excluding the casts collected in areas with mildly sloped to steep bed topography, the average depth of the remaining casts was 35.08 ft with a range of 3.93–67.06 ft. On average, the CTD-measured depth was 0.40 ft deeper than the DEM-derived depth. Differences in depth could be due to instrumentation error, interpolation between depth soundings, or possibly from the CastAway CTD penetrating the soft bed material in the upper layers of sediment. In general, excluding the casts collected in areas with mildly sloped to steep bed topography, the DEM-derived depths and CTD-measured depths corresponded well. In addition to performing daily system checks on the ADCP, this indirect check against the CTD-measured depths provided additional assurance that the Sontek M9 ADCP was functioning properly.

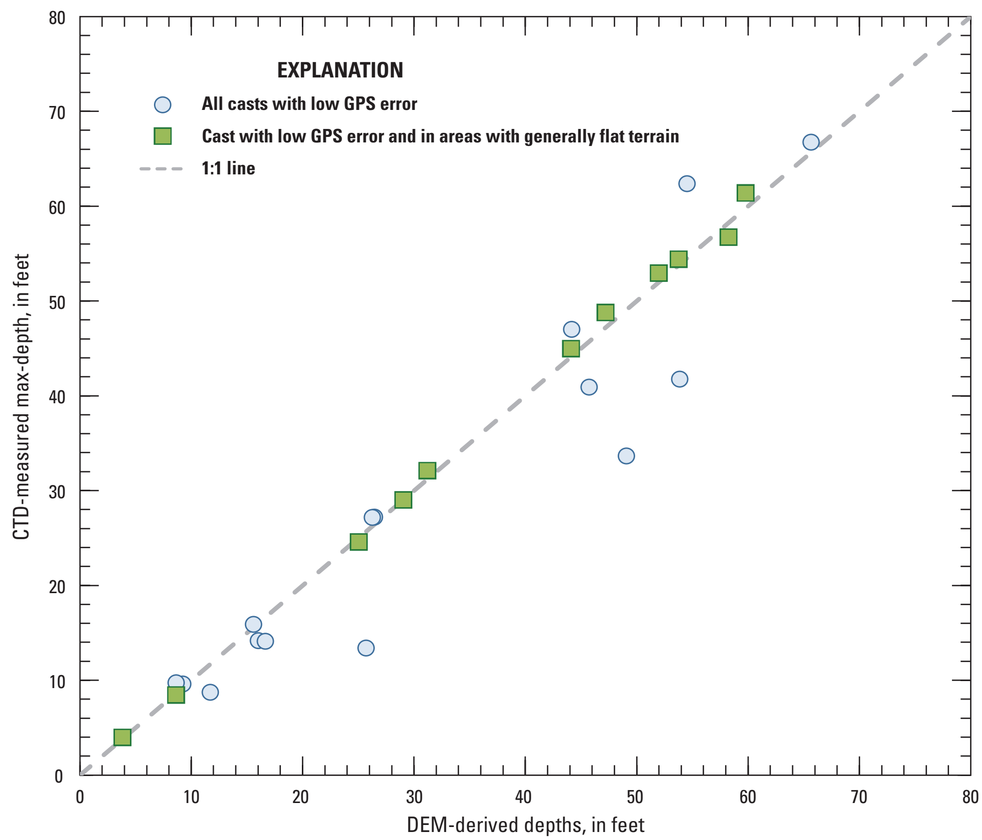

Figure 8. Maximum depths measured using the CastAway Conductivity, Temperature, and Depth profiler in relation to depths derived from the digital elevation model of the Fena Valley Reservoir, Guam, 2014. Casts with Global Positioning System (GPS) error greater than 10 feet were not included in this comparison. Depths from casts collected in areas with generally flat terrain, which would provide a better check against the digital elevation model (DEM)-derived depths, are shown by dark-green markers. (CTD, CastAway Conductivity, Temperature, and Depth).

Results

In this section the results of the 2014 Fena Valley Reservoir capacity analysis are compared to the initial capacity. The 1951 stage-area and stage-capacity curves were digitized from the engineering drawings of record (Frederic R. Harris, Inc., 1949) by using PlotDigitizer software (Huwaldt and Steinhorst, 2012).

Bathymetry

Results of the 2014 bathymetric survey of the reservoir are shown in figure 9. Approximately 380,000 depth soundings and about 2,100 topographic points were used to create the bathymetric map with a point density generally ranging from 0.02 to 0.21 points per ft^2 (average about 1 point per 22 ft^2).

The bathymetric map shows that remnants of the Fena River channel are still fairly well defined in the northern two-thirds of the reservoir. However, significant sediment deposition has occurred in the southern part of the reservoir, particularly just downstream from the Imong and Almagosa Rivers, to the degree that sediment has completely buried the river channels in this area of the reservoir. Coarse sediment (cobbles, sand, and silt) typically settles out quickly near river mouths in a reservoir. In the Fena Valley Reservoir, the Imong River has the most pronounced deltaic deposits. The Almagosa River also contributes a large amount of sediment; however, there was very little noticeable sediment accumulation near the Maulap River mouth. On the basis of this evidence, the Imong River watershed probably contributes the greatest volume of sediment to the reservoir.

In the other parts of the reservoir, if sediment deposition has occurred, it is more uniformly distributed such that some detail of the underlying topography (prior to reservoir inundation) is visible in the bathymetric map. For example, in addition to the visible former Fena River channel, remnants of the retaining levees used during construction of the Fena Dam are also visible in the bathymetric map. These levees are in the downstream-most part of the reservoir, starting diagonally just south of the boat launch area, then following the northern bank of the former Fena River to the screen house.

Reservoir Storage Capacity

The total storage capacity of the Fena Valley Reservoir determined from the 2014 bathymetric survey was 6,915 acre-ft. Rating tables for the surface area and reservoir volume at 0.1-foot stage intervals are provided in tables 3 and 4. The reservoir volume is shown as a stage-capacity curve, along with the 1951 stage-capacity curve, in figure 10.

The total reservoir storage capacity has decreased from 8,365 acre-ft in 1951 to 6,915 acre-ft in 2014 (a loss of 17 percent). The live storage capacity has decreased from 5,883 acre-ft in 1951 to 5,511 acre-ft in 2014 (a loss of 6 percent), and the dead storage capacity has decreased from 2,482 acre-ft in 1951 to 1,404 acre-ft in 2014 (a loss of 43 percent). Seventy-five percent of the capacity loss was in the dead storage. The dead-storage area (defined as the reservoir bed which lies below the lowest-level outlet elevation) extends south from the dam to about the location of the former (that is submerged) confluence of the Almagosa River and the Fena River. On the basis of the historical rates of deposition, a greater portion of future sediment may still end up in the dead storage area; however, sedimentation in the live storage area (or usable storage) is likely to continue, which will affect reservoir management.

At this time we cannot estimate rates of sedimentation because of the uncertainty in the methods used during previous surveys, as well as unknowns regarding the watershed response to infrequent, but major, storms, which could deliver large volumes of sediment. Further analysis is needed to quantify the error associated with the previous surveys and then place those results in the context of the hydrologic history of the watershed.

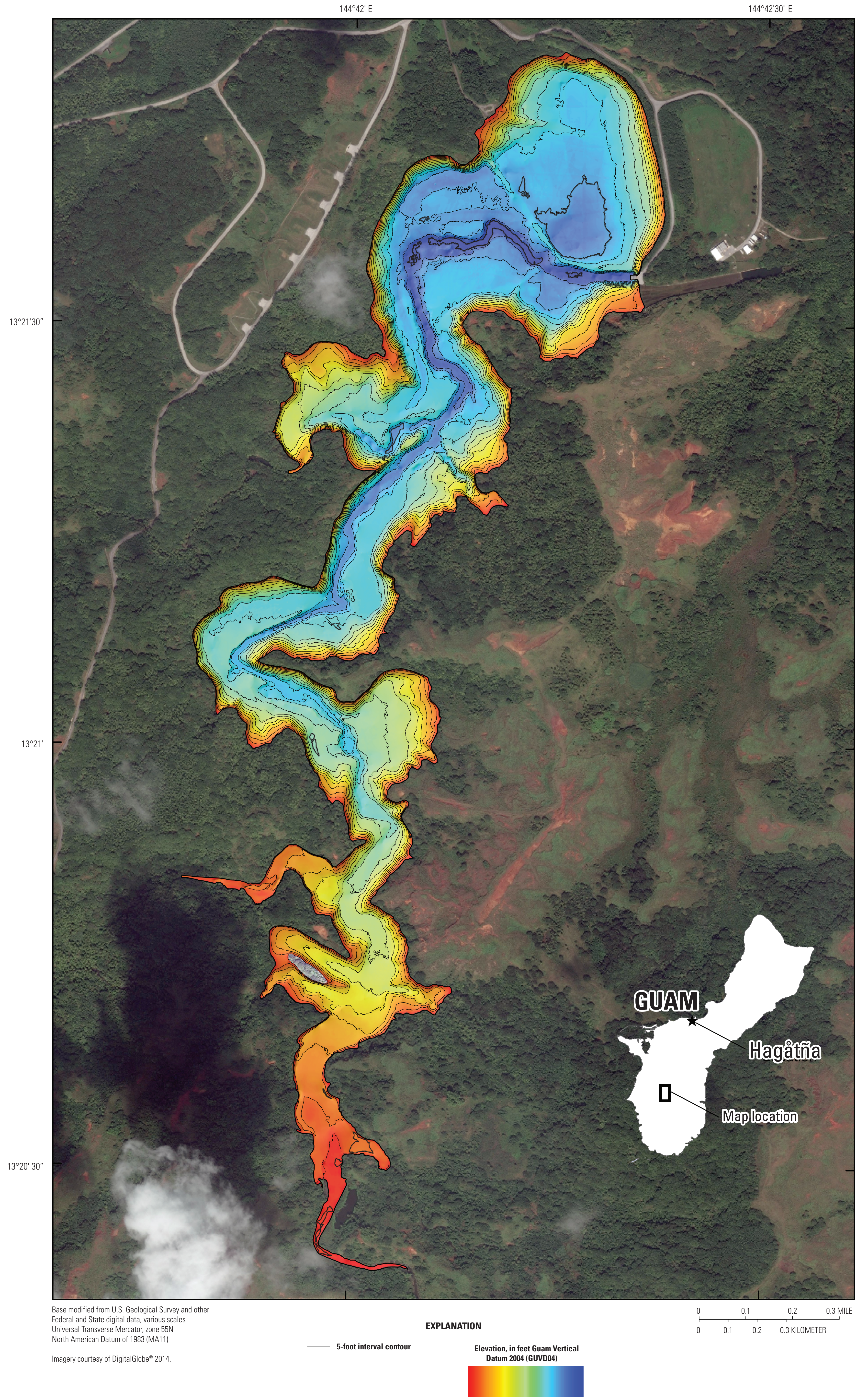

Figure 9. Bathymetry and 5-foot interval contours, based on the February 2014 survey, Fena Valley Reservoir, Guam.

Table 3. Rating table for surface area of the Fena Valley Reservoir, Guam, 2014.

Stage (feet)[1]	Surface area (acres)									
	Intervals									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
42	0	0	0	0	0	0	0	0.1	0.2	0.2
43	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6
44	0.6	0.7	0.7	0.8	0.8	0.8	0.9	1.0	1.0	1.1
45	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.2
46	2.3	2.4	2.5	2.7	2.8	2.9	3.0	3.1	3.2	3.3
47	3.4	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.2
48	4.2	4.3	4.4	4.5	4.6	4.6	4.7	4.8	4.9	5.0
49	5.0	5.1	5.2	5.3	5.4	5.4	5.5	5.6	5.7	5.8
50	5.9	6.0	6.1	6.2	6.4	6.5	6.7	6.9	7.0	7.3
51	7.5	7.7	7.9	8.1	8.4	8.7	8.9	9.2	9.5	9.8
52	10.0	10.3	10.6	11.0	11.3	11.6	12.0	12.4	12.8	13.2
53	13.7	14.1	14.5	15.0	15.4	15.9	16.3	16.8	17.2	17.7
54	18.2	18.6	19.1	19.5	20.0	20.5	21.0	21.5	22.1	22.6
55	23.1	23.7	24.3	24.8	25.4	26.0	26.7	27.2	27.8	28.4
56	28.9	29.5	30.0	30.6	31.2	31.7	32.3	32.8	33.4	33.9
57	34.5	35.1	35.7	36.3	36.9	37.6	38.2	38.8	39.4	40.1
58	40.8	41.5	42.1	42.8	43.4	44.1	44.8	45.4	46.0	46.7
59	47.3	47.9	48.6	49.2	49.8	50.4	50.9	51.5	52.0	52.6
60	53.1	53.5	54.0	54.5	55.0	55.5	55.9	56.4	56.8	57.3
61	57.7	58.1	58.5	59.0	59.4	59.8	60.2	60.6	61.1	61.5
62	62.0	62.4	62.9	63.4	63.8	64.3	64.8	65.3	65.8	66.3
63	66.7	67.2	67.6	68.1	68.5	69.0	69.4	69.9	70.4	70.8
64	71.3	71.7	72.2	72.6	73.1	73.5	74.0	74.4	74.8	75.2
65	75.7	76.1	76.5	77.0	77.4	77.8	78.2	78.6	79.0	79.4
66	79.8	80.2	80.6	81.0	81.4	81.8	82.1	82.5	82.8	83.2
67	83.6	84.0	84.3	84.7	85.1	85.5	85.8	86.2	86.5	86.9
68	87.2	87.6	88.0	88.3	88.7	89.1	89.4	89.7	90.1	90.4
69	90.7	91.0	91.4	91.7	92.0	92.3	92.6	92.9	93.1	93.4
70	93.7	94.0	94.3	94.5	94.8	95.1	95.4	95.6	95.9	96.2
71	96.5	96.8	97.1	97.4	97.7	98.0	98.3	98.6	99.0	99.3
72	99.6	100.0	100.3	100.6	100.9	101.2	101.5	101.8	102.0	102.3
73	102.6	102.8	103.1	103.3	103.6	103.8	104.1	104.3	104.6	104.8
74	105.1	105.4	105.7	106.0	106.2	106.5	106.8	107.1	107.3	107.6
75	107.8	108.1	108.3	108.6	108.8	109.1	109.3	109.6	109.8	110.1
76	110.3	110.6	110.8	111.1	111.3	111.6	111.8	112.1	112.3	112.6
77	112.8	113.1	113.4	113.6	113.9	114.1	114.4	114.6	114.9	115.1

Table 3. Rating table for surface area of the Fena Valley Reservoir, Guam, 2014.—Continued

Stage (feet)[1]	Surface area (acres)									
	Intervals									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
78	115.4	115.6	115.9	116.1	116.4	116.6	116.9	117.2	117.4	117.7
79	117.9	118.2	118.4	118.7	118.9	119.2	119.4	119.7	119.9	120.2
80	120.4	120.6	120.9	121.1	121.3	121.6	121.8	122.0	122.3	122.5
81	122.8	123.0	123.3	123.6	123.8	124.1	124.3	124.6	124.9	125.1
82	125.4	125.7	125.9	126.2	126.4	126.6	126.9	127.1	127.3	127.5
83	127.8	128.0	128.2	128.4	128.6	128.8	129.1	129.3	129.5	129.7
84	130.0	130.2	130.4	130.6	130.8	131.1	131.3	131.5	131.7	131.9
85	132.1	132.3	132.5	132.7	132.9	133.1	133.3	133.5	133.7	134.0
86	134.2	134.4	134.6	134.8	135.0	135.2	135.4	135.7	135.9	136.1
87	136.3	136.5	136.7	136.9	137.1	137.4	137.6	137.8	138.0	138.3
88	138.5	138.7	139.0	139.2	139.4	139.7	139.9	140.1	140.4	140.6
89	140.9	141.1	141.3	141.5	141.8	142.0	142.2	142.4	142.7	142.9
90	143.1	143.3	143.5	143.8	144.0	144.2	144.4	144.6	144.8	145.1
91	145.3	145.5	145.7	145.9	146.1	146.4	146.6	146.8	147.1	147.3
92	147.5	147.7	148.0	148.2	148.4	148.7	148.9	149.1	149.4	149.6
93	149.8	150.1	150.3	150.6	150.8	151.0	151.3	151.5	151.8	152.1
94	152.3	152.6	152.8	153.1	153.3	153.6	153.9	154.1	154.4	154.6
95	154.9	155.2	155.4	155.7	155.9	156.2	156.4	156.7	157.0	157.2
96	157.5	157.8	158.0	158.3	158.6	158.8	159.1	159.4	159.6	159.9
97	160.2	160.4	160.7	161.0	161.2	161.5	161.8	162.0	162.2	162.5
98	162.7	163.0	163.2	163.5	163.7	164.0	164.2	164.4	164.7	164.9
99	165.1	165.3	165.6	165.8	166.0	166.3	166.5	166.7	166.9	167.2
100	167.4	167.7	167.9	168.1	168.3	168.5	168.8	169.0	169.2	169.5
101	169.7	170.0	170.2	170.4	170.7	170.9	171.2	171.4	171.7	171.9
102	172.1	172.3	172.6	172.8	173.0	173.2	173.4	173.7	173.9	174.2
103	174.4	174.6	174.8	175.0	175.2	175.4	175.7	175.9	176.1	176.4
104	176.6	176.8	177.1	177.3	177.5	177.7	178.0	178.2	178.4	178.6
105	178.8	179.1	179.3	179.5	179.7	180.0	180.2	180.4	180.6	180.8
106	181.0	181.3	181.5	181.7	182.0	182.2	182.5	182.7	182.9	183.2
107	183.4	183.6	183.7	184.0	184.2	184.4	184.6	184.8	184.9	185.1
108	185.3	185.5	185.7	185.9	186.0	186.2	186.4	186.6	186.7	186.9
109	187.0	187.2	187.4	187.6	187.7	187.9	188.1	188.3	188.5	188.7
110	189.0	189.4	189.8	190.2	190.6	190.9	191.2	191.5	192.6	

Spillway Crest (110.8 feet GUVD04).

[1]Elevation in feet referenced to Guam Vertical Datum of 2004 (GUVD04).

Table 4. Rating table for storage capacity of the Fena Valley Reservoir, Guam, 2014.

Stage (feet)[1]	Storage capacity (acre-feet)									
	Intervals									
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
42	0	0	0	0	0	0	0	0.1	0.1	0.1
43	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.5	0.5
44	0.6	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.4
45	1.5	1.6	1.8	1.9	2.1	2.2	2.4	2.6	2.8	3.0
46	3.3	3.5	3.8	4.0	4.3	4.6	4.9	5.2	5.5	5.9
47	6.2	6.5	6.9	7.3	7.6	8.0	8.4	8.8	9.2	9.7
48	10.1	10.5	10.9	11.4	11.9	12.3	12.8	13.3	13.8	14.3
49	14.8	15.3	15.8	16.3	16.8	17.4	17.9	18.5	19.1	19.7
50	20.2	20.8	21.5	22.1	22.7	23.4	24.0	24.7	25.4	26.1
51	26.9	27.7	28.5	29.3	30.1	31.0	31.9	32.8	33.7	34.7
52	35.7	36.8	37.8	38.9	40.1	41.2	42.4	43.7	44.9	46.3
53	47.6	49.0	50.5	52.0	53.5	55.1	56.8	58.4	60.2	61.9
54	63.7	65.6	67.5	69.5	71.5	73.5	75.6	77.8	80.0	82.2
55	84.6	86.9	89.4	91.8	94.4	97.0	100	102	105	108
56	111	114	117	120	123	126	129	133	136	139
57	143	146	150	154	157	161	165	169	173	177
58	181	185	189	193	198	202	207	211	216	220
59	225	230	235	240	245	250	255	260	265	270
60	276	281	287	292	297	303	309	314	320	326
61	331	337	343	349	355	361	367	373	379	385
62	391	398	404	410	417	423	430	436	443	449
63	456	463	469	476	483	490	497	504	511	518
64	525	532	540	547	554	562	569	576	584	591
65	599	607	614	622	630	637	645	653	661	669
66	677	685	693	701	709	717	726	734	742	750
67	759	767	776	784	793	801	810	818	827	836
68	844	853	862	871	880	889	898	907	916	925
69	934	943	952	961	970	979	989	998	1,007	1,017
70	1,026	1,035	1,045	1,054	1,064	1,073	1,083	1,092	1,102	1,112
71	1,121	1,131	1,141	1,150	1,160	1,170	1,180	1,190	1,200	1,209
72	1,219	1,229	1,239	1,250	1,260	1,270	1,280	1,290	1,300	1,311
73	1,321	1,331	1,341	1,352	1,362	1,372	1,383	1,393	1,404	1,414
74	1,425	1,435	1,446	1,456	1,467	1,478	1,488	1,499	1,510	1,521
75	1,531	1,542	1,553	1,564	1,575	1,586	1,597	1,608	1,619	1,630
76	1,641	1,652	1,663	1,674	1,685	1,696	1,707	1,718	1,730	1,741
77	1,752	1,764	1,775	1,786	1,798	1,809	1,820	1,832	1,843	1,855

Table 4. Rating table for storage capacity of the Fena Valley Reservoir, Guam, 2014.—Continued

Stage (feet)[1]	Storage capacity (acre-feet)									
	Intervals									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
78	1,866	1,878	1,890	1,901	1,913	1,925	1,936	1,948	1,960	1,971
79	1,983	1,995	2,007	2,019	2,031	2,043	2,055	2,067	2,078	2,091
80	2,103	2,115	2,127	2,139	2,151	2,163	2,175	2,187	2,200	2,212
81	2,224	2,237	2,249	2,261	2,274	2,286	2,298	2,311	2,323	2,336
82	2,348	2,361	2,374	2,386	2,399	2,412	2,424	2,437	2,450	2,462
83	2,475	2,488	2,501	2,514	2,527	2,539	2,552	2,565	2,578	2,591
84	2,604	2,617	2,630	2,643	2,656	2,669	2,683	2,696	2,709	2,722
85	2,735	2,749	2,762	2,775	2,788	2,802	2,815	2,828	2,842	2,855
86	2,869	2,882	2,895	2,909	2,922	2,936	2,949	2,963	2,977	2,990
87	3,004	3,018	3,031	3,045	3,059	3,072	3,086	3,100	3,114	3,128
88	3,141	3,155	3,169	3,183	3,197	3,211	3,225	3,239	3,253	3,267
89	3,281	3,295	3,309	3,324	3,338	3,352	3,366	3,380	3,395	3,409
90	3,423	3,438	3,452	3,466	3,481	3,495	3,510	3,524	3,539	3,553
91	3,568	3,582	3,597	3,611	3,626	3,641	3,655	3,670	3,685	3,699
92	3,714	3,729	3,744	3,758	3,773	3,788	3,803	3,818	3,833	3,848
93	3,863	3,878	3,893	3,908	3,923	3,938	3,953	3,968	3,984	3,999
94	4,014	4,029	4,045	4,060	4,075	4,091	4,106	4,121	4,137	4,152
95	4,168	4,183	4,199	4,214	4,230	4,246	4,261	4,277	4,293	4,308
96	4,324	4,340	4,356	4,371	4,387	4,403	4,419	4,435	4,451	4,467
97	4,483	4,499	4,515	4,531	4,547	4,564	4,580	4,596	4,612	4,628
98	4,645	4,661	4,677	4,694	4,710	4,726	4,743	4,759	4,776	4,792
99	4,809	4,825	4,842	4,858	4,875	4,892	4,908	4,925	4,942	4,958
100	4,975	4,992	5,009	5,025	5,042	5,059	5,076	5,093	5,110	5,127
101	5,144	5,161	5,178	5,195	5,212	5,229	5,246	5,263	5,280	5,298
102	5,315	5,332	5,349	5,367	5,384	5,401	5,419	5,436	5,453	5,471
103	5,488	5,506	5,523	5,541	5,558	5,576	5,593	5,611	5,628	5,646
104	5,664	5,681	5,699	5,717	5,735	5,752	5,770	5,788	5,806	5,824
105	5,842	5,860	5,877	5,895	5,913	5,931	5,949	5,967	5,985	6,004
106	6,022	6,040	6,058	6,076	6,094	6,113	6,131	6,149	6,167	6,186
107	6,204	6,222	6,241	6,259	6,278	6,296	6,314	6,333	6,351	6,370
108	6,388	6,407	6,426	6,444	6,463	6,481	6,500	6,519	6,537	6,556
109	6,575	6,593	6,612	6,631	6,650	6,669	6,687	6,706	6,725	6,744
110	6,763	6,782	6,801	6,820	6,839	6,858	6,877	6,896	6,915	

Spillway Crest (110.78 feet GUVD04).

[1]Elevation in feet referenced to Guam Vertical Datum of 2004 (GUVD04).

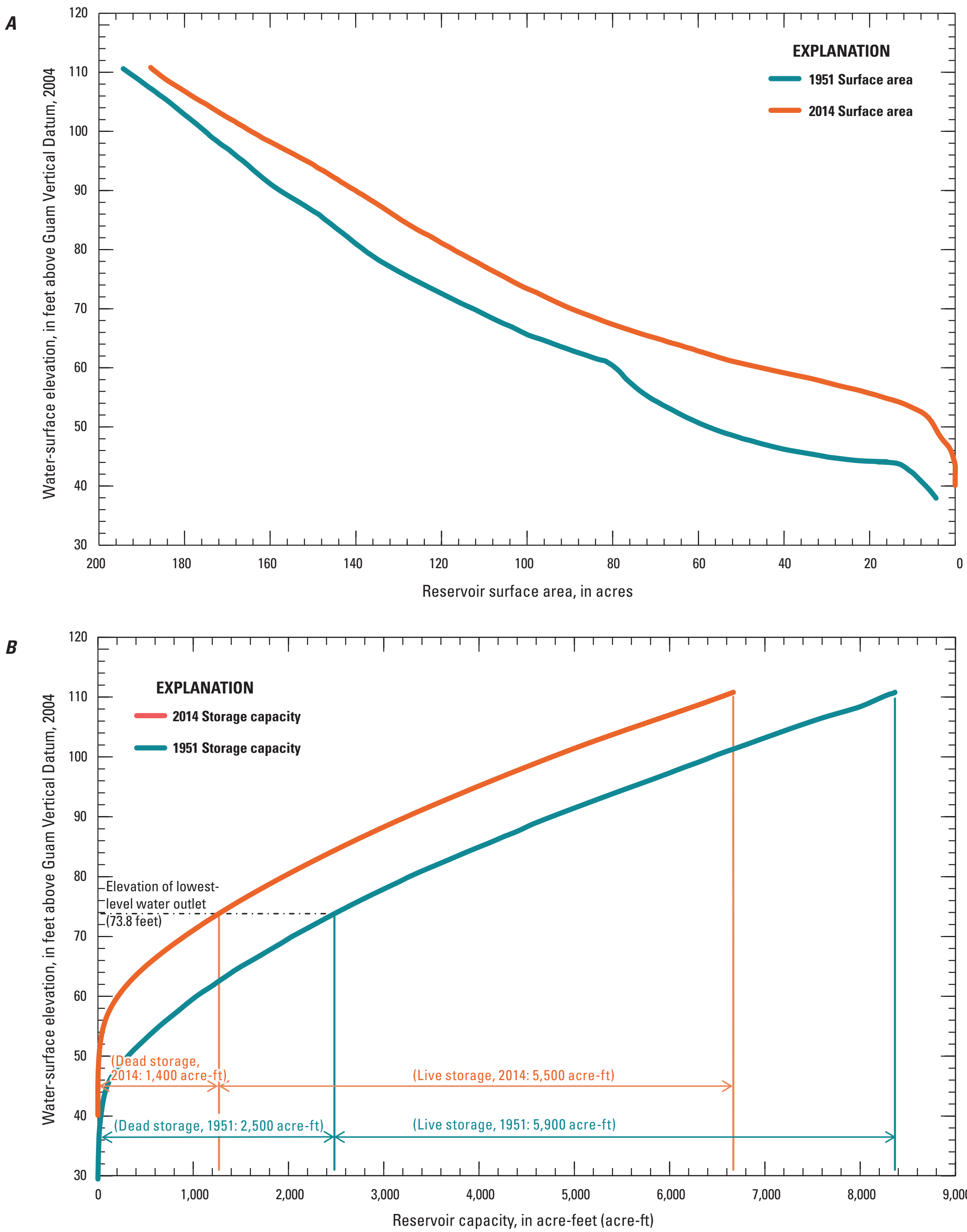

Figure 10. A, stage-surface area curves for 1951 and 2014; and; B, stage-capacity curves with live and dead storage capacity in 1951 and 2014 indicated, Fena Valley Reservoir, Guam.

Summary

Since construction of the Fena Dam in 1951, sediment has been accumulating in the Fena Valley Reservoir. The reservoir was surveyed prior to dam construction, as well as in 1973, 1979, and 1990. In order to accurately predict surface-water availability, up-to-date reservoir capacity information is needed by the U.S. Navy. In response, the U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Defense Strategic Environmental Research and Development Program, surveyed the bathymetry of the reservoir in February 2014 to determine its current storage capacity and to create updated reservoir stage–surface area and stage–capacity curves.

Methods are presented for the collection of data on depth soundings, topographic survey points, and temperature and depth within the water column to correct the depth soundings. Depth soundings and topographic points were then interpolated to create a bathymetric map of the reservoir. During the February 2014 survey, data on approximately 380,000 depth soundings, 2,100 topographic points, and 45 conductivity, temperature, and depth (CTD) profiles were collected. Results from the CTD profiles show that temperature varied slightly, and salinity was relatively constant. The depth soundings were corrected for temperature gradients, merged with topographic survey points in the shallow areas of the Imong River, and spatially interpolated to create a bathymetric map of the reservoir in the form of a digital elevation model (DEM). Elevations from the DEM were tabulated to generate the stage–surface area and stage–capacity tables presented in this report.

A control survey was conducted using Global Navigation Satellite System-Real-Time Kinematic receiver to check the elevations of the spillway and benchmark RP21 (which is used routinely for surveying dam settlement) and to establish a temporary benchmark at the boat launch area. The spillway crest elevation was surveyed at 110.8 feet (ft) Guam Vertical Datum of 2004 (GUVD04), and RP21 was surveyed at 125.41 ft. The survey measurements for the spillway-crest elevation and benchmark RP21 were lower than previously published by 0.42 and 0.57 ft, respectively. Survey measurements were checked against two additional benchmarks (GGN 2053 and GGN 2054) outside the Naval Base Guam Ordnance Annex near the entrance gate. The measurements made during this study were within 0.1 ft of the known elevation of those two benchmarks. We concluded that the original 1948 measurement of the spillway crest which used the Mean Lower Low Water (MLLW) as the datum was in error and that error has propagated through subsequent studies and local surveys. However, this does not affect the result of those previous surveys since they were surveyed relative to the spillway crest.

Results of the analysis of the bathymetric data indicate that the reservoir currently has a total storage capacity of 6,915 acre-feet (acre-ft). The live-storage capacity was calculated as 5,511 acre-ft. Total reservoir capacity in 1951 was estimated to be 8,365 acre-ft, and the live-storage capacity was estimated to be 5,900 acre-ft. Thus, between 1951 and 2014, the total storage capacity decreased by 1,449 acre-ft, and the live-storage capacity decreased by 372 acre-ft (representing losses of 17 and 6 percent of the original capacity, respectively). Between 1951 and 2014, the dead-storage capacity decreased by 1,078 acre-ft, which represents a loss of 43 percent of the original 2,482 acre-ft dead-storage capacity.

Although the overall reservoir capacity is continuing to decline, most of the sediment accumulation has occurred in the dead-storage area of the reservoir. On the basis of the historical rates of deposition, a greater portion of future sediment may still end up in the dead storage area; however, sedimentation in the live storage area (or usable storage) is likely to continue, which will affect reservoir management. Coarse sediment (cobbles, sand, and silt) typically settles out quickly near river mouths in a reservoir. In the Fena Valley Reservoir, the Imong River has the most pronounced deltaic deposits. The Almagosa River also contributes a large amount of sediment; however, there was little noticeable sediment accumulation near the Maulap River mouth. On the basis of this evidence, the Imong River watershed is probably the primary contributor of sediment to the reservoir. Over the lifetime of the reservoir, the average annual decrease in total reservoir capacity was 23.0 acre-feet per year. However, the sediment delivery is likely to happen at an unsteady rate and could be driven by strong tropical storms. At this time, sedimentation rates cannot be estimated because of the uncertainty in previous surveys and unknowns regarding watershed response to infrequent, but major, storms, which could deliver large volumes of sediment. Further analysis is needed to quantify the error associated with the previous surveys and then place those results in the context of the hydrologic history of the watershed.

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Glossary

Conductivity The raw measurement of specific conductance of water which has not been compensated for temperature.

Dead storage The volume of storage that lies below the lower-level water outlet and therefore cannot be drained through normal dam operations. The dead storage is not usable for water-supply purposes; however, it could be useful for the storage of sediment such that sediment deposition in this region does not decrease the live-storage capacity.

Ellipsoid height The height above or below a mathematically defined surface or ellipsoid that provides a representation of the Earth. The height coordinate determined by a Global Navigation Satellite System (GNSS) observation is related to the surface of the ellipsoid and is then converted to an orthometric height using a geoid model.

Live storage The volume of storage above the lower-level water outlet but below the spillway.

Orthometric height The height of a point on the Earth's surface measured as a distance along a plumb line and normal to gravity from that point to a geoid.

Appendix. National Geodetic Survey Datasheets

Benchmark DH3061

```
PROGRAM = datasheet95, VERSION = 8.3
1        National Geodetic Survey,   Retrieval Date = FEBRUARY 19, 2014
 DH3061 ***********************************************************************
 DH3061  DESIGNATION -  SABLAN CASTRO
 DH3061  PID         -  DH3061
 DH3061  STATE/COUNTY-  GU/GUAM
 DH3061  COUNTRY     -  US
 DH3061  USGS QUAD   -  TALOFOFO (1975)
 DH3061
 DH3061                          *CURRENT SURVEY CONTROL
 DH3061  ___________________________________________________________________
 DH3061* NAD 83(MA11) POSITION- 13 20 21.73008(N) 215 13 57.41925(W)   ADJUSTED
 DH3061* NAD 83(MA11) ELLIP HT-    97.358 (meters)        (06/27/12)   ADJUSTED
 DH3061* NAD 83(MA11) EPOCH   -  2010.00
 DH3061* GUVD04  ORTHO HEIGHT -    43.884  (meters)     143.98  (feet) ADJUSTED
 DH3061  ___________________________________________________________________
 DH3061  NAD 83(MA11) X  - -5,070,192.569 (meters)                   COMP
 DH3061  NAD 83(MA11) Y  -  3,580,951.707 (meters)                   COMP
 DH3061  NAD 83(MA11) Z  -  1,461,985.268 (meters)                   COMP
 DH3061  LAPLACE CORR    -         -4.35  (seconds)                  DEFLEC12A
 DH3061  GEOID HEIGHT    -         53.46  (meters)                   GEOID12A
 DH3061  VERT ORDER      -  FIRST     CLASS II
 DH3061
 DH3061  FGDC Geospatial Positioning Accuracy Standards (95% confidence, cm)
 DH3061  Type                                      Horiz  Ellip  Dist(km)
 DH3061  -------------------------------------------------------------------
 DH3061  NETWORK                                    4.08   5.08
 DH3061  -------------------------------------------------------------------
 DH3061  MEDIAN LOCAL ACCURACY AND DIST (014 points)   4.82   5.08     12.81
 DH3061  -------------------------------------------------------------------
 DH3061  NOTE: Click here for information on individual local accuracy
 DH3061  values and other accuracy information.
 DH3061
 DH3061
 DH3061.The horizontal coordinates were established by GPS observations
 DH3061.and adjusted by the National Geodetic Survey in June 2012.
 DH3061
 DH3061.NAD 83(MA11) refers to NAD 83 coordinates where the reference
 DH3061.frame has been affixed to the stable Mariana tectonic plate.
 DH3061
 DH3061.The horizontal coordinates are valid at the epoch date displayed above
 DH3061.which is a decimal equivalence of Year/Month/Day.
 DH3061
 DH3061.The orthometric height was determined by differential leveling and
 DH3061.adjusted by the NATIONAL GEODETIC SURVEY
 DH3061.in May 2005.
 DH3061
```

```
DH3061.The X, Y, and Z were computed from the position and the ellipsoidal ht.
DH3061
DH3061.The Laplace correction was computed from DEFLEC12A derived deflections.
DH3061
DH3061.The ellipsoidal height was determined by GPS observations
DH3061.and is referenced to NAD 83.
DH3061
DH3061. The following values were computed from the NAD 83(MA11) position.
DH3061
DH3061;            North        East     Units Scale Factor Converg.
DH3061;SPC GU     -   182,228.850   101,883.254   MT  1.00000004   +0 00 14.4
DH3061;UTM  55    - 1,475,753.271   258,170.163   MT  1.00032350   -0 30 55.3
DH3061
DH3061!          -  Elev Factor  x  Scale Factor =   Combined Factor
DH3061!SPC GU     -   0.99998469  x   1.00000004  =   0.99998473
DH3061!UTM  55    -   0.99998469  x   1.00032350  =   1.00030818
DH3061
DH3061                     SUPERSEDED SURVEY CONTROL
DH3061
DH3061  NAD 83(1993)-  13 20 21.72936(N)    215 13 57.41964(W) AD(2004.00) A
DH3061  ELLIP H (06/10/05)   97.315  (m)                    GP(2004.00) 3 2
DH3061
DH3061.Superseded values are not recommended for survey control.
DH3061
DH3061.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
DH3061.See file dsdata.txt to determine how the superseded data were derived.
DH3061
DH3061_U.S. NATIONAL GRID SPATIAL ADDRESS: 55PBQ5817075753(NAD 83)
DH3061
DH3061_MARKER: Z = SEE DESCRIPTION
DH3061_SETTING: 7 = SET IN TOP OF CONCRETE MONUMENT
DH3061_MARK LOGO: GUAMLM
DH3061_MAGNETIC: R = STEEL ROD IMBEDDED IN MONUMENT
DH3061_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
DH3061+STABILITY: SURFACE MOTION
DH3061_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
DH3061+SATELLITE: SATELLITE OBSERVATIONS - May 21, 2004
DH3061
DH3061  HISTORY     - Date     Condition        Report By
DH3061  HISTORY     - 20040521 MONUMENTED       GUAMLM
DH3061
DH3061                     STATION DESCRIPTION
DH3061
DH3061'DESCRIBED BY GUAM DEPARTMENT OF LAND MANAGEMENT 2004 (TJT)
DH3061'GENERAL STATION LOCATION- THE STATION IS LOCATED IN THE MUNICIPALITY
DH3061'OF TALOFOFO.
DH3061'
DH3061'TO REACH NARRATIVE- TO REACH THE STATION FROM THE JUNCTION OF ROUTE 4
DH3061'AND ROUTE 17, GO SOUTH ON ROUTE 4 FOR 3.5 MILE, STATION ON THE LEFT
DH3061'SIDE OF ROUTE 4 AND 4A.  THE STATION IS CENTER WITHIN TALOFOFO BAY
DH3061'OVERLOOK.
DH3061'
DH3061'MONUMENT DESCRIPTION AND MEASUREMENTS- THE STATION IS 13.30M SOUTHEAST
DH3061'FROM A CONCRETE POWER POLE, 23.70M SOUTHEAST FROM CENTERLINE OF ROUTE
DH3061'4 AND 5.80M SOUTHWEST FROM THE NORTHEAST CORNER OF A STONE WALL.
DH3061'
```

DH3061’THE STATION IS A NO 4 REBAR PROJECTING 1/4 INCH SET IN CONCRETE
DH3061’INSCRIBED DEL. LM 3-24-60 SABLAN CASTRO.

Benchmark DH3040

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PROGRAM = datasheet95, VERSION = 8.3
1        National Geodetic Survey,   Retrieval Date = FEBRUARY 19, 2014
 DH3040 *********************************************************************
 DH3040  DESIGNATION -  GGN 2669
 DH3040  PID         -  DH3040
 DH3040  STATE/COUNTY-  GU/GUAM
 DH3040  COUNTRY     -  US
 DH3040  USGS QUAD   -  TALOFOFO (1975)
 DH3040
 DH3040                         *CURRENT SURVEY CONTROL
 DH3040  ___________________________________________________________________
 DH3040* NAD 83(1986) POSITION- 13 21 00.     (N) 215 13 51.     (W)   SCALED
 DH3040* GUVD04  ORTHO HEIGHT -    12.365  (meters)       40.57  (feet) ADJUSTED
 DH3040  ___________________________________________________________________
 DH3040  GEOID HEIGHT    -         53.53  (meters)                    GEOID12A
 DH3040  VERT ORDER      -  FIRST     CLASS II
 DH3040
 DH3040.The horizontal coordinates were scaled from a topographic map and have
 DH3040.an estimated accuracy of +/- 6 seconds.
 DH3040.
 DH3040.The orthometric height was determined by differential leveling and
 DH3040.adjusted by the NATIONAL GEODETIC SURVEY
 DH3040.in May 2005.
 DH3040
 DH3040;                     North         East     Units  Estimated Accuracy
 DH3040;SPC GU       -   183,410.       102,080.      MT  (+/- 180 meters Scaled)
 DH3040
 DH3040                          SUPERSEDED SURVEY CONTROL
 DH3040
 DH3040.No superseded survey control is available for this station.
 DH3040
 DH3040_U.S. NATIONAL GRID SPATIAL ADDRESS: 55PBQ583769(NAD 83)
 DH3040
 DH3040_MARKER: DD = SURVEY DISK
 DH3040_SETTING: 7 = SET IN TOP OF CONCRETE MONUMENT
 DH3040_STAMPING: 2669
 DH3040_MARK LOGO: GUAMLM
 DH3040_MAGNETIC: N = NO MAGNETIC MATERIAL
 DH3040_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
 DH3040+STABILITY: SURFACE MOTION
 DH3040_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
 DH3040+SATELLITE: SATELLITE OBSERVATIONS - May 04, 2004
 DH3040
 DH3040  HISTORY     - Date     Condition        Report By
 DH3040  HISTORY     - 20040504 MONUMENTED       GUAMLM
 DH3040
 DH3040                          STATION DESCRIPTION
 DH3040
 DH3040’DESCRIBED BY GUAM DEPARTMENT OF LAND MANAGEMENT 2004 (TJT)
 DH3040’GENERAL STATION LOCATION- THE STATION IS LOCATED IN SUBURBAN OF IPAN,
```

DH3040'THE MUNICIPALITY OF TALOFOFO.
DH3040'
DH3040'TO REACH NARRATIVE- TO REACH THE STATION FROM JUNCTION OF ROUTE 4 AND
DH3040'ROUTE 17, GO SOUTH ON ROUTE 4 FOR 2.5 MILES, TO THE STATION ON THE
DH3040'EAST SIDE OF ROUTE 4 AND ACROSS PAULINO HEIGHTS ROAD. THE MARK IS
DH3040'SOUTH OF BUS SHELTER (YT-95).
DH3040'
DH3040'MONUMENT DESCRIPTION AND MEASUREMENTS- THE STATION IS 8.10M EAST OF
DH3040'CENTERLINE OF ROUTE 4, 12.10M SOUTH OF A CONCRETE POWER POLE (PU-23-7)
DH3040'AND 8.20M NORTH OF A TELEPHONE BOX.
DH3040'
DH3040'THE MARK IS A STANDARD 1993 GUAM GEODETIC NETWORK DISK
DH3040'STAMPED--2669--, SET IN A CONCRETE POST.

*** retrieval complete.
Elapsed Time = 00:00:03

Benchmark DK2736

PROGRAM = datasheet95, VERSION = 8.4
1 National Geodetic Survey, Retrieval Date = MAY 14, 2014
DK2736 ***
DK2736 DESIGNATION - NUTZ
DK2736 PID - DK2736
DK2736 STATE/COUNTY- GU/GUAM
DK2736 COUNTRY - US
DK2736 USGS QUAD - TALOFOFO (1975)
DK2736
DK2736 *CURRENT SURVEY CONTROL
DK2736 ____
DK2736* NAD 83(MA11) POSITION- 13 20 32.74295(N) 215 13 43.41794(W) ADJUSTED
DK2736* NAD 83(MA11) ELLIP HT- 57.710 (meters) (06/27/12) ADJUSTED
DK2736* NAD 83(MA11) EPOCH - 2010.00
DK2736* GUVD04 ORTHO HEIGHT - 4.28 (meters) 14.0 (feet) LEVELING
DK2736 ____
DK2736 GEOID HEIGHT - 53.44 (meters) GEOID12A
DK2736 NAD 83(MA11) X - -5,070,340.329 (meters) COMP
DK2736 NAD 83(MA11) Y - 3,580,540.231 (meters) COMP
DK2736 NAD 83(MA11) Z - 1,462,305.433 (meters) COMP
DK2736 LAPLACE CORR - -4.41 (seconds) DEFLEC12A
DK2736 VERT ORDER - THIRD ?
DK2736
DK2736 FGDC Geospatial Positioning Accuracy Standards (95% confidence, cm)
DK2736 Type Horiz Ellip Dist(km)
DK2736 ---
DK2736 NETWORK 1.28 1.45
DK2736 ---
DK2736 MEDIAN LOCAL ACCURACY AND DIST (004 points) 1.25 1.51 5.39
DK2736 ---
DK2736 NOTE: Click here for information on individual local accuracy
DK2736 values and other accuracy information.
DK2736
DK2736
DK2736.The horizontal coordinates were established by GPS observations
DK2736.and adjusted by the National Geodetic Survey in June 2012.

```
DK2736
DK2736.NAD 83(MA11) refers to NAD 83 coordinates where the reference
DK2736.frame has been affixed to the stable Mariana tectonic plate.
DK2736
DK2736.The horizontal coordinates are valid at the epoch date displayed above
DK2736.which is a decimal equivalence of Year/Month/Day.
DK2736
DK2736.The orthometric height was determined by differential leveling.
DK2736.The vertical network tie was performed by a horz. field party for horz.
DK2736.obs reductions. Reset procedures were used to establish the elevation.
DK2736
DK2736.The X, Y, and Z were computed from the position and the ellipsoidal ht.
DK2736
DK2736.The Laplace correction was computed from DEFLEC12A derived deflections.
DK2736
DK2736.The ellipsoidal height was determined by GPS observations
DK2736.and is referenced to NAD 83.
DK2736
DK2736. The following values were computed from the NAD 83(MA11) position.
DK2736
DK2736;              North        East      Units Scale Factor Converg.
DK2736;SPC GU    -   182,567.325   102,304.569   MT  1.00000007   +0 00 17.7
DK2736;UTM  55   - 1,476,088.020   258,594.666   MT  1.00032096   -0 30 52.5
DK2736
DK2736!          -  Elev Factor  x  Scale Factor =   Combined Factor
DK2736!SPC GU    -   0.99999092  x   1.00000007  =   0.99999099
DK2736!UTM  55   -   0.99999092  x   1.00032096  =   1.00031188
DK2736
DK2736|---------------------------------------------------------------------|
DK2736| PID    Reference Object                  Distance      Geod. Az  |
DK2736|                                                      dddmmss.s |
DK2736| DK2735 BIRU                              35.002 METERS 15701     |
DK2736| DH2964 CLQT                              184.595 METERS 16031     |
DK2736|---------------------------------------------------------------------|
DK2736
DK2736                    SUPERSEDED SURVEY CONTROL
DK2736
DK2736  NAD 83(1993)-  13 20 32.74344(N)    215 13 43.41842(W) AD(2004.00) 1
DK2736  ELLIP H (10/11/07)   57.708  (m)                 GP(2004.00) 4 2
DK2736
DK2736.Superseded values are not recommended for survey control.
DK2736
DK2736.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
DK2736.See file dsdata.txt to determine how the superseded data were derived.
DK2736
DK2736_U.S. NATIONAL GRID SPATIAL ADDRESS: 55PBQ5859476088(NAD 83)
DK2736
DK2736_MARKER: DD = SURVEY DISK
DK2736_SETTING: 0 = UNSPECIFIED SETTING
DK2736_STAMPING: NUTZ 2007
DK2736_MARK LOGO: USACE
DK2736_MAGNETIC: N = NO MAGNETIC MATERIAL
DK2736_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
DK2736+STABILITY: SURFACE MOTION
DK2736_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
DK2736+SATELLITE: SATELLITE OBSERVATIONS - July 20, 2007
```

DK2736
DK2736 HISTORY - Date Condition Report By
DK2736 HISTORY - 20070720 MONUMENTED USACE
DK2736
DK2736 STATION DESCRIPTION
DK2736
DK2736'DESCRIBED BY US ARMY CORPS OF ENGINEERS 2007
DK2736'STATION LOCATION - THE STATION IS LOCATED ALONG THE OCEAN-SIDE OF
DK2736'ROUTE 4 IN THE MUNICIPALITY OF TALOFOFO, GUAM JUST NORTH OF TALOFOFO
DK2736'BAY AT ASQUIROGA BAY.
DK2736'
DK2736'OWNERSHIP - GUAM DEPARTMENT OF PUBLIC WORKS TO REACH THE STATION
DK2736'FROM THE INTERSECTION OF ROUTE 4 AND ROUTE 4A, TRAVEL NORTH ALONG
DK2736'ROUTE 4 FOR 0.5 MI (0.8 KM) TOWARDS ASQUIROGA BAY (AWAY FROM TALOFOFO
DK2736'BAY). THE BENCH MARK IS LOCATED ON THE OCEAN-SIDE OF ROUTE 4 AND ITS
DK2736'ASSOCIATED GUARDRAIL. THE BENCH MARK SITS FLUSH IN A CONCRETE SLURRY
DK2736'ADJACENT TO A U.S. ARMY CORPS OF ENGINEERS HURRICANE SHORE PROTECTION
DK2736'PROJECT. AN OLD PILLBOX SITS ON THE NORTH SIDE OF ASQUIROGA BAY, AND
DK2736'THE BAY IS A POPULAR SWIMMING/SNORKELING LOCATION.
DK2736'
DK2736'THE STATION IS AS FOLLOWS - 95 FT (29.0 M) AT AN ANGLE OF 340 FROM
DK2736'CONCRETE POWER POLE DC-YP 45-600 84-11. - 40 FT (12.2 M) 4 INCHES (10
DK2736'CM) AT AN ANGLE OF 263.5 FROM THE CENTERLINE OF ROUTE 4. - 50 FT (15.2
DK2736'M) AT AN ANGLE OF 150 FROM CONCRETE POWER POLE DC-YP 45-600 84-13. - 9
DK2736'FT (2.7 M) 6 INCHES (15 CM) AT AN ANGLE OF 263.5 FROM THE GUARDRAIL. -
DK2736'19 FT (5.8 M) 6 INCHES (15 CM) ALONG THE GUARDRAIL IF I START
DK2736'MEASURING FROM THE NORTH END OF IT.
DK2736'
DK2736'DESCRIBED BY JUSTIN PUMMELL, U.S. ARMY CORPS OF ENGINEERS, HONOLULU
DK2736'DISTRICT PHONE (808) 438-7038 E-MAIL JUSTIN.D.PUMMELL USACE.ARMY.MIL

*** retrieval complete.
Elapsed Time = 00:00:04

Benchmark DH3034

PROGRAM = datasheet95, VERSION = 8.3
1 National Geodetic Survey, Retrieval Date = FEBRUARY 22, 2014
DH3034 ***
DH3034 DESIGNATION - GGN 2555
DH3034 PID - DH3034
DH3034 STATE/COUNTY- GU/GUAM
DH3034 COUNTRY - US
DH3034 USGS QUAD - TALOFOFO (1975)
DH3034
DH3034 *CURRENT SURVEY CONTROL
DH3034 ____
DH3034* NAD 83(1986) POSITION- 13 20 10. (N) 215 14 16. (W) SCALED
DH3034* GUVD04 ORTHO HEIGHT - 2.648 (meters) 8.69 (feet) ADJUSTED
DH3034 ____
DH3034 GEOID HEIGHT - 53.48 (meters) GEOID12A
DH3034 VERT ORDER - FIRST CLASS II
DH3034
DH3034.The horizontal coordinates were scaled from a topographic map and have
DH3034.an estimated accuracy of +/- 6 seconds.

DH3034.
DH3034.The orthometric height was determined by differential leveling and
DH3034.adjusted by the NATIONAL GEODETIC SURVEY
DH3034.in May 2005.
DH3034
DH3034; North East Units Estimated Accuracy
DH3034;SPC GU - 181,870. 101,320. MT (+/- 180 meters Scaled)
DH3034
DH3034 SUPERSEDED SURVEY CONTROL
DH3034
DH3034.No superseded survey control is available for this station.
DH3034
DH3034_U.S. NATIONAL GRID SPATIAL ADDRESS: 55PBQ576753(NAD 83)
DH3034
DH3034_MARKER: DD = SURVEY DISK
DH3034_SETTING: 7 = SET IN TOP OF CONCRETE MONUMENT
DH3034_STAMPING: 2555
DH3034_MARK LOGO: GUAMLM
DH3034_MAGNETIC: N = NO MAGNETIC MATERIAL
DH3034_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
DH3034+STABILITY: SURFACE MOTION
DH3034_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
DH3034+SATELLITE: SATELLITE OBSERVATIONS - May 04, 2004
DH3034
DH3034 HISTORY - Date Condition Report By
DH3034 HISTORY - 20040504 MONUMENTED GUAMLM
DH3034
DH3034 STATION DESCRIPTION
DH3034
DH3034'DESCRIBED BY GUAM DEPARTMENT OF LAND MANAGEMENT 2004 (TJT)
DH3034'GENERAL STATION LOCATION- THE STATION IS LOCATED IN THE MUNICIPALITY
DH3034'OF TALOFOFO.
DH3034'
DH3034'TO REACH NARRATIVE- TO REACH THE STATION FROM JUNCTION OF ROUTE 4 AND
DH3034'ROUTE 14, GO SOUTH ON ROUTE 4 FOR 0.5 MILES, TO THE STATION ON THE
DH3034'NORTHWEST CORNER PAULINO HEIGHTS ROAD AND SOUTHWEST OF TALOFOFO SURF
DH3034'BEACH PARK. THE STATION IS A CONCRETE MONUMENT FLUSH WITH SURFACE.
DH3034'
DH3034'MONUMENT DESCRIPTION AND MEASUREMENTS- THE STATION IS 6.60M SOUTHWEST
DH3034'OF CENTERLINE OF ROUTE 4, 18.60M NORTHWEST OF A CONCRETE POWER POLE
DH3034'AND 8.70M NORTHWEST OF CENTERLINE OF (AC) PAULINO HEIGHTS.
DH3034'
DH3034'THE MARK IS A STANDARD 1993 GUAM GEODETIC NETWORK DISK
DH3034'STAMPED--2555--, SET IN A CONCRETE POST.

*** retrieval complete.
Elapsed Time = 00:00:08

Prepared by the Sacramento Publishing Service Center.

For more information concerning this report, contact:

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California Water Science Center
6000 J Street, Placer Hall
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or visit our Web site at:
http://ca.water.usgs.gov

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