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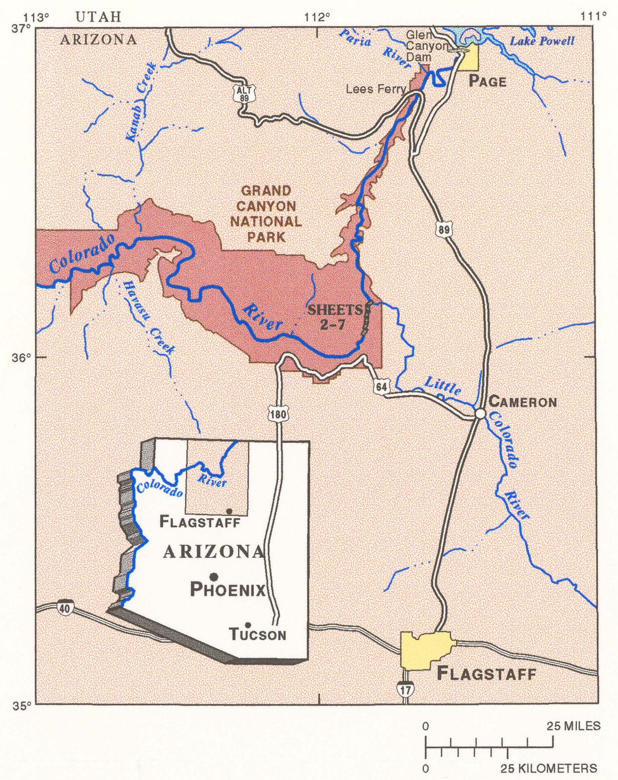
Topography and Bathymetry of the Colorado River, Grand Canyon National Park,
Little Colorado River Confluence to Tanner Rapids—SHEET 1
Julia B. Graf, Samuel M.D. Jansen, Gregory G. Fisk, and Jonathan E. Marlow



INTRODUCTION

In the early 1980's, agencies charged with management of the Colorado River in Grand Canyon National Park (GCNP), whitewater rafters, and anglers became concerned that operations of Glen Canyon Dam were producing streamflows that were eroding sandbars that are critical to the riparian system in the park. Since 1982, the Bureau of Reclamation (BOR) has coordinated a comprehensive program of investigations—the Glen Canyon Environmental Studies (GCES)—to determine the effects of releases from Glen Canyon Dam on the riparian and aquatic resources in the park.

As a part of the GCES, the U.S. Geological Survey (USGS) began in 1991 to develop a suite of multidimensional models of flow, sediment transport, and bed evolution required for prediction of the response of sandbars to discharges in the river produced by dam releases. Accurate characterization of channel geometry to the highest elevation of proposed flows is required for the creation of those models. Topographic information from published USGS maps did not have the detail required for the models under development and did not show channel morphology below the water surface.

In 1989, an interagency group selected 13 reaches of 5 to 31 km in length along the river corridor for detailed topographic mapping and development of a geographic data base. As a part of that effort, a control network was established for those reaches, and topographic information above a low-discharge (about 142 m^3/s) river stage was developed photogrammetrically. The data base was developed by the BOR using ARC/INFO Geographic Information System (GIS) software (Environmental Systems Research Institute, Inc., 1991)[1], and the data are maintained by the BOR as ARC/INFO coverages. Werth and others (1993) list the reaches and describe the development of the control network, the topographic information, and the GIS data base. The topographic data were developed from aerial photographs taken in June and July 1990 and 1991 (Werth and others, 1993). The GCES have generated 1:2400-scale topographic base maps with a contour interval that varies but is as small as 0.5 m in areas of relatively low relief. Data in the GCES GIS data base and map products are referenced to the Arizona State Plane Coordinate System, in meters, using a Transverse Mercator projection (Werth and others, 1993).

[1] The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

In 1991, the USGS began collection of bathymetric data for the reaches in the GIS data base to extend topographic information to the channel bottom to define the channel morphology for model development. Reach 5, which is about 19 km long and extends from river mile 60 to river mile 72[2] (see index map below), was selected as the reach in which to begin model development because the Little Colorado River, which joins the Colorado River at about river mile 61, is the largest source of sand to the Colorado River in the park. The morphology of sand deposits in the reach downstream from the confluence is important to native fish, especially the endangered humpback chub, because areas associated with sandbars—backwaters, return-flow channels, channel margins—are habitats for chub hatched in the warmer waters of the Little Colorado River (Angradi and others, 1992, Valdez and others, 1992). Also, the reach includes 32 monumented cross sections established in 1992 and 1993 to monitor changes in channel sand storage. Cross sections in the A, B, and C series (sheets 2 and 3) were established and measured for the first time in June and July 1992, and those in the D, E, and F series (sheets 4–7) in February 1993. Methods of data collection and analysis for the cross-section measurements are described by Graf and others (1995).

These maps present the combined topographic and bathymetric data used to develop grids of equally spaced points representing channel morphology required for the development of multidimensional models of flow, sediment transport, and bed evolution. The topography and bathymetry are presented in sheets 2–7, and data extend from just below the Little Colorado River confluence to just above Tanner Rapids—10.3 km of reach 5 from about river mile 62 to about mile 68.5. Bathymetry in the remaining parts of reach 5 had not been mapped at the time of preparation of this report. The BOR produced 8 map sheets of the topography of reach 5. Data presented in this report cover part of BOR map sheet 3 (sheet 2) and 8 (sheet 7) and all of map sheets 4–7 (sheets 3–6).

Data used to produce the maps have been used to generate two–dimensional arrays of equally spaced elevations (grids) used to provide channel geometry for multidimensional models of flow, sediment transport, and bed evolution (Wiele, S.M., Graf, J.B., and Smith, J.D., research hydrologists, USGS, written commun., 1995). The maps also serve as base maps for precise location of measurements and sample locations with respect to important geomorphic features.

[2] Locations of features along the Colorado River in the study reach typically are given in miles downstream from Lees Ferry, Arizona. River miles are used in this report for consistency with local convention.

Acknowledgments

Kenton Grua operated the boat during the bathymetric surveys and the cross-section measurements. His patience and skill made it possible to collect the high-quality data required for the study. Trine Christiansen, Mikkel Christiansen, and James J. Duncker volunteered their time to help collect the bathymetric and cross-section data. Franklin R. Protiva, Fidel M. (Mark) Gonzales, and Robert C. (Chris) Brod did the survey required to tie the data to the GCES control network and provided other surveying assistance. Patrick J. Wright, BOR, provided topographic data.

METHODS

Bathymetric Surveys

Bathymetric surveys of 10.3 km of reach 5 were made in June and July 1992 and April and May 1993 (see index map below). Bathymetric data were tied to the Arizona State Plane Coordinate System using a network of control points. The control-point locations were determined by USGS surveys and verified by other GCES surveys. During the bathymetric surveys, the position of a target mounted to the top of the depth-sounder transducer on the boat was measured and combined with depth data measured at the same time.

The area covered by the topographic data is largely bedrock, talus, and gravel in cliffs, gravel bars, debris fans, and talus slopes. These features were not altered significantly by river flows that occurred from the time of the aerial photographs until after the second bathymetric survey. The area covered by the bathymetric surveys is subject to greater and more frequent changes than is the area covered by the topographic data.

A flood of moderate peak discharge but long duration—3 weeks—occurred on the Little Colorado River in January 1993, between the two bathymetric surveys. The flood contributed an estimated 4.17 Tg (about 4,600,000 tons) of sand to the study area and caused aggradation of the bed at many of the monumented cross sections in the A, B, and C series (sheets 2 and 3), which were the only sections measured before and after the flood (Jansen and others, 1995; Graf and others, 1995). Sand contributed by the flood in the Little Colorado River in January 1993 was initially deposited in the vertical and lateral channel expansions typically found in pools just downstream from the constrictions formed by debris fans (see cross section LA1 before and after the flood on sheet 1. Graf and others, 1995; Wiele, S.M., Graf, J.B., and Smith, J.D., research hydrologists, USGS, written commun., 1995). Much of the sand deposited by the flood was moved downstream in the months following the flood (Graf and others, 1995).

Bathymetric data were collected using two generations of manual-tracking range-azimuth positioning systems. Both systems consist of a laser electronic-distance meter (EDM) mounted above an electric theodolite. The EDM used in these systems was designed to allow continuous tracking of a moving boat. The laser-beam width was 2° or 8°, depending on the system, and the frequency of position update was five times per second—larger than for systems designed for location of stationary targets. Range uncertainty in tracking mode is given by the manufacturer as ±0.15 m from 1.5–610 m and ±0.23 m from 610–1,245 m. Position uncertainty achieved in the field has been found to be about double that of the manufacturers specifications (Mark Landers, hydrologist, USGS, written commun., 1992). The positioning system was used in a mode that recorded the boat position every 0.7 seconds.

Depth was measured with a sonic depth sounder, and the digital position and depth data were sent directly or by radio modems to a datalogger or laptop computer. Depth also was recorded on paper charts. The two positioning systems had different depth sounders. The unit used in 1992 has a manufacturer's specified accuracy of ±0.5 percent ±0.025 m of indicated depth. The unit sounds the depth about nine times per second and was used with a transducer that had a beam width of 8°. The unit used in 1993 had a manufacturer's specified accuracy of 0.02 m ±(depth/1000). Depth was sounded 5–10 times per second, and the transducer beam width was 9°. Both units were calibrated in the field before the surveys by suspending a lead weight or plate at known depths that ranged from about 2–9 m below the transducer. Adjustments were made to the speed-of-sound constant in the instrument to match the recorder depth to the depth of weight at the deepest calibration depth.

Verification of Bathymetric Data

Incorrect position information is recorded when the instrument operator fails to track the boat within the preset tolerance of the instrument, or the operator loses sight of the boat as it passes behind a rock outcrop, or when the laser reflects off an object other than the target such as a tree or a cliff face beyond the boat. Interference occasionally can cause the radio modems to send spurious numbers to the recorder. Incorrect points are typically off the line of data defining the path of the boat and are easily identified during plotting of a planimetric map of the data. The digital depth sounder can send incorrect digital depth values to the recorder if the water is too shallow, if strong turbulence or air bubbles in the water column reflect the transducer signal, or if the depth changes too quickly for the digital recorder to track.

The digital data collected in the field were edited to identify and remove data with incorrect boat position and (or) incorrect depths. Points with incorrect positions were found through the use of computer programs that flagged points more than a selected distance from points collected previously and by inspection of plotted values. Large sets of points with incorrect positions and individual points with incorrect positions and depths were deleted from the data set. When small groups of points with incorrect positions but correct depths were found, the depth information was retained and new positions were calculated by linear interpolation between the two positions on either end of the gap along the boat track. Over distances of a few meters, the interpolated positions are within the accuracy of the bathymetric survey.

Incorrect depths were found by comparison of the digital record with the paper-chart record collected at the same time. The digital recorder stores only the first signal returned, but the paper-chart record typically contains a record of the channel bottom as well as any material within the water column that reflects the signal (air bubbles, algae, and (or) fish). Where the channel bottom was recorded on the paper chart but the digital record contained incorrect depths, the paper-chart record was digitized and the incorrect depths were replaced with the digitized depths. The data were deleted in a few cases for which the bottom was not recorded on either the paper chart or the digital recorder.

Contour Generation

After verification of position and depth data from bathymetric surveys, the positions of the data points were converted from the arbitrary x,y coordinate system in which they were collected into the Arizona State Plane Coordinate System used in the GCES GIS data base (Werth and others, 1993). For the surveys made in 1993, depth data were converted to elevation using the water-surface-elevation data collected at the time of the survey. Each pool reach was surveyed separately and a single water-surface elevation for the pool was used to convert the data. The water-surface elevation in the pool was determined from depth measured by a temporary gage that consisted of a pressure transducer and recorder. Depth data were related to a datum of known elevation. The water-surface elevation for the mean time of the survey was used to adjust the bathymetric data. Because the adjustment was made on a pool-by-pool basis, the water-surface elevation change during each survey was not significant. Although the plan had been to make the adjustments for the surveys done in 1992 in the same manner as was done for the 1993 surveys, uncertainties in the control survey done at the time of the 1992 bathymetric survey made the water-surface elevation measurements unreliable. The 1992 bathymetric data were adjusted to elevation by adjusting the data from each pool survey until the best match in elevation with the topographic data was obtained. The best match was determined by visual comparison of elevation at points in the bathymetric data set with topographic contours. This method proved satisfactory because the topographic data were obtained at a lower discharge than the bathymetric surveys, and the two surveys overlap in many areas especially in gently sloping areas such as debris fans.

Data from the two bathymetric surveys were combined with topographic data for contouring and plotting. Because of real differences in elevation that were a consequence of channel changes over time and apparent differences caused by position uncertainty, points in areas of overlap between the topographic data and the bathymetric data sometimes differed significantly in elevation. In those cases, points from the bathymetric set in the area of overlap were deleted because those points had a greater position uncertainty.

To generate contours, a network of triangles (TIN) was created from the combined topographic set using the Delaunay method of triangulation (McCullagh and Ross, 1980) implemented by the ARC/INFO software. Because the high density of data points from the bathymetric surveys along traverse lines created a point distribution that produced unrealistic contours, the set was filtered to remove points within a given radius of the previous point. Unrealistic contours—with sharp breaks or many small closed contours not supported by the data—were generated by the software when the TIN contained many extremely long, narrow triangles. A point spacing of 4 m was determined best for these data because that spacing produced a TIN with the best geometry—closest to a network of equilateral triangles—and contours that were best supported by the data. An outer boundary close to but outside of the outer points was used to define the external boundary of the network. Once the TIN was developed, an interpolation algorithm using a bivariate fifth-degree polynomial in x and y (Akima, 1978) was used to compute contour-line positions from the network. Contours were evaluated for accuracy by comparison to contours developed photogrammetrically for the topographic data set. Resulting contours closely match the original topographic contours (see inset on sheet 3). In some places, including areas of very steep or shallow slope and areas of sparse data, unrealistic or incorrect contours were generated. These contours were edited to better represent the real topography.

A contour interval of 1 m was used wherever feasible. On sheets 2 and 3, an interval of 5 m was used for contours above 830 m because the extremely steep slopes in those areas made the 1-meter contours unreadable. In some areas, the contours at the outer edge of the map end abruptly and appear to be cut off. In these areas, the topographic data ended abruptly, and no information was available to generate contours beyond these points. In most cases, these abruptly terminated contours abut near-vertical slopes, and these areas are indicated by cliff lines on the map.

DATA PRESENTED

Contour maps (sheets 2–7) were developed from combined bathymetric and topographic data for the Colorado River in a 10.3-kilometer reach downstream from its confluence with the Little Colorado River.

The positions of monumented cross sections on the maps, and the cross-section geometry for a single survey at each of these sections is shown to illustrate the channel geometry. Cross sections shown may not agree exactly with the geometry shown by the contours because the bathymetric surveys and cross-section measurements have different accuracies and were made at different times.

Bathymetry of the area upstream from a point 0.7 km upstream from Carbon Creek (sheet 4) was mapped before the Little Colorado River flood of January 1993, and the area downstream from that point was mapped 3–4 months after the flood. The index map below and on each sheet shows the area and dates of the two bathymetric surveys, and the boundary between the surveys is shown on sheet 4.

The surveyed area is indicated by the location of data points from the bathymetric surveys used to generate the contours. Areas in the channel not covered by surveys were either very shallow or are areas of rapids or riffles where water velocity and turbulence was too high for the depth sounder to return a bottom signal. To help the reader visualize the channel, the extent of the water surface at a discharge of about 142 m^3/s in 1989 also is shown. The water-surface data were obtained by the BOR from aerial photographs taken at that discharge and are shown on sheets 2–7 without modification. River miles also are shown on the maps because they are a commonly used system of documenting locations along the river.

REFERENCES CITED

Akima, Hiroshi, 1978, A method of bivariate interpolation and smooth surface fittting for irregularly distributed data points: ACM Transactions on Mathematical Software, v. 4, p. 148–159.

Angradi, T.R., Clarkson, R.W., Kingsolving, D.A., Kubly, D.M., and Morgensen, S.A., 1992, Glen Canyon Dam and the Colorado River—Responses of the aquatic biota to dam operations: Arizona Game and Fish Department, Glen Canyon Environmental Studies Technical Report AQU0317, 155 p.

Environmental Systems Research Institute, Inc., 1991, ARC/INFO User's Guide—Surface Modeling with TIN™:, Redlands, California, Environmental Systems Research Institute, Inc., v.p.

Graf, J.B., Marlow, J.E., Fisk, G.G., and Jansen, S.M.D., [in press], Sand storage changes in the Colorado River downstream from the Paria and Little Colorado Rivers, June 1992 to February 1994: U.S. Geological Survey Open-File Report 95–446.

Jansen, S.M.D., Graf, J.B., Marlow, J.E., and Fisk, G.G., 1995, Monitoring channel sand storage in the Colorado River in Grand Canyon: U.S. Geological Survey Fact Sheet FS-120-95, 1 p.

McCullagh, M.J. and Ross, C.G., 1980, Delaunay triangulation of a random data set for isarithmic mapping: Cartographic Journal, v. 17, p. 93–99.

Schmidt, J.C. and Graf, J.B., 1990, Aggradation and degradation of alluvial sand deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona: U.S. Geological Survey Professional Paper 1493, 74 p.

Valdez, R.A., Masslich, W.J. and Leibfried, William, 1992, Characterization of the life history and ecology of the humpback chub (*Gila cypha*) in the Grand Canyon: Logan, Utah, BIO/WEST Report No. TR 250-04, also indexed as Glen Canyon Environmental Studies Technical Report AQU0701, 222 p.

Werth, L.F., Wright, P.J., Pucherelli, M.J., Wegner, D.L., and Kimberling, D.N., 1993, Developing a geographic information system for resources monitoring on the Colorado River in the Grand Canyon: Denver, Colorado, Bureau of Reclamation, Report Number R-93-20, 46 p.

Wilson, R.P., 1986, Sonar patterns of Colorado River bed, Grand Canyon: Fourth Federal Interagency Sedimentation Conference, Proceedings, v. 2, Las Vegas, Nevada, March 24–27, 1986, p. 5-133 to 5-142.

CONVERSION FACTORS

Multiply metric unit	By	To obtain inch-pound unit
meter (m)	3.28	foot
cubic meter per second (m^3/s)	35.3	cubic foot per second
kilometer (km)	0.621	mile
teragram (Tg)	1.103×10^6	short ton

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