# STUDY REPORT W&AR-03
# RESERVOIR TEMPERATURE MODEL

## ATTACHMENT B

## DON PEDRO RESERVOIR BATHYMETRIC STUDY REPORT

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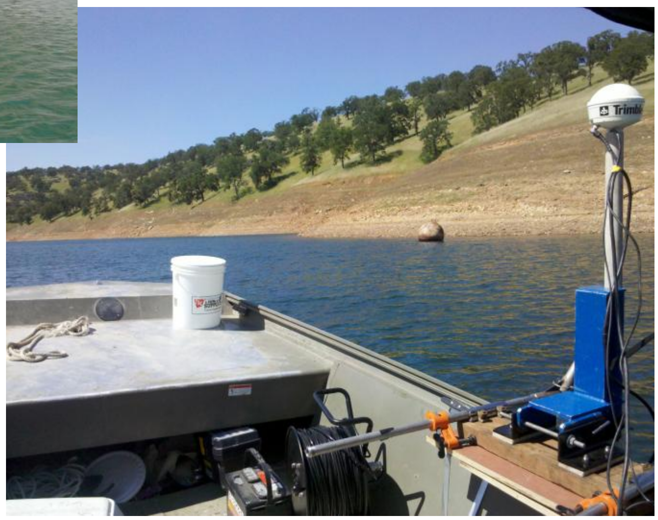


**Prepared for:**

**TURLOCK IRRIGATION DISTRICT**
**MODESTO IRRIGATION DISTRICT AND**
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October 2012

*Don Pedro Project*
*FERC No. 2299*

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# BATHYMETRIC STUDY REPORT

## 1.0 Objectives

The objective of this study was to develop an accurate reservoir geometry for the Turlock Irrigation District and Modesto Irrigation District (collectively, the "Districts") Don Pedro Reservoir (FERC No. 2299). The resulting reservoir geometry is also used to update the reservoir's elevation-storage curve and provide data on existing conditions for inclusion in the three-dimensional ("3-D") reservoir temperature model under development in support of the FERC relicensing of the Don Pedro Project ("Project").

## 2.0 Study Area

The study area consists of Don Pedro Reservoir located in Tuolumne County, California, on the Tuolumne River (Figure 2.0-1). Based on Engineer's estimates developed prior to the construction of the Project, at the normal maximum pool elevation of 830 feet (ft) (NGVD 29), Don Pedro Reservoir has a surface area of 12,960 acres and stores 2,030,000 acre-feet of water (ACOE 1972).

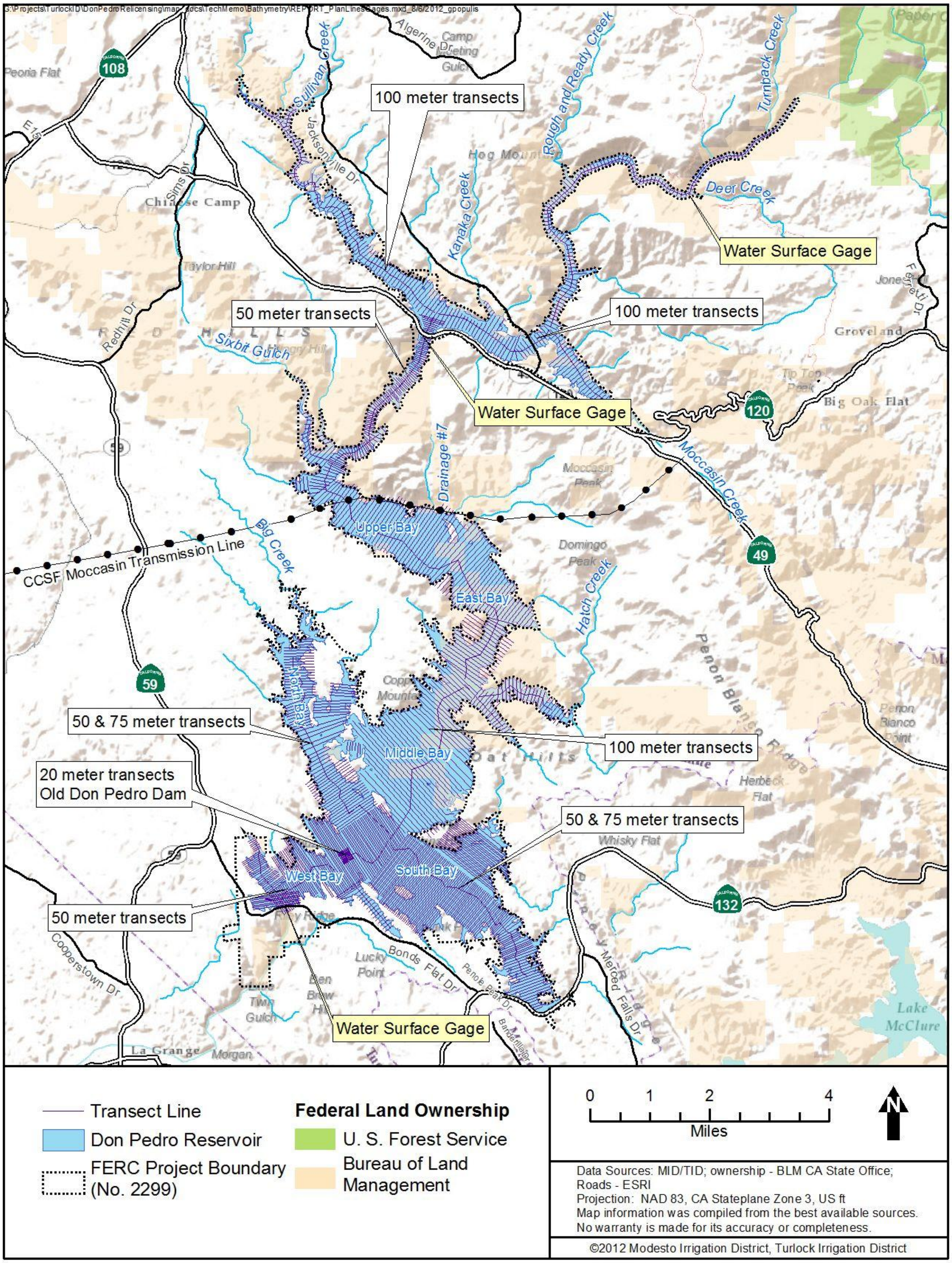


**Figure 2.0-1. Don Pedro bathymetry survey plan transects and water surface gages.**

# 3.0 Methods

Bathymetry below the full pool elevation of 830 ft was determined by two techniques: underwater surfaces were surveyed using field measurements (Section 3.1) and topographic information for surfaces above the water were obtained using radar technology (Section 3.2). Data obtained by the two techniques were synthesized into one surface using geographic information system (GIS) software (Section 3.3). Quality assurance and quality control practices are described in Section 3.4.

## 3.1 Field Survey

The field survey was performed over 16 days between May 1 and June 5, 2011, from a flat-bottom aluminum Johnboat with an outboard motor. This time period was selected due to the relatively high water levels, relatively calm weather, and low amount of recreational boater activity.

During the bathymetric data collection, Don Pedro Reservoir's water surface elevation ranged from approximately 792 ft to 805 ft. Depth data for Don Pedro Reservoir was collected using an Airmar B258 1-kW dual frequency transducer and a Foruno FCV-585 digital depth sounder (with real-time depth profile display) connected to a Trimble PRO-XR GPS and TSC1 Data Collector, capable of providing a real time differential Global Positioning System ("DGPS") data stream. The depth sounder's transducer was mounted onto the side of the boat and lowered 0.3 ft below the surface of the water. The GPS dome antenna was mounted on a platform above the level of the boat. The accuracy of the B258 transducer was ± 0.1 foot of depth (for depths roughly 4 ft or greater) and the accuracy of the PRO-XR GPS receiver was less than one meter of linear distance (with optimal satellite coverage).

Soundings were taken at approximately 1-second intervals and the boat speed was set to ensure that bottom features were appropriately sampled. The boat was navigated along the transect lines using the DGPS, and the position of each sounding was determined using the DGPS system. All depth and horizontal positioning data were recorded digitally in the field as a series of points with x-y-z coordinates, using a rugged field notebook personal computer, running Hypack Hydrographic Survey software.

A total of 1152 transects, spaced at 50, 75, 100 meter intervals and oriented approximately perpendicular to the longitudinal axis of the reservoir, were pre-located and created using Hypack. Areas of topographical concern, such as the Old Don Pedro Dam, were surveyed with greater density for added resolution. In addition to the standard transects, perpendicular "tie lines", oriented approximately parallel to the longitudinal axis of the reservoir and its tributary arms, were established to ensure inter-transect data consistency. A Furuno real-time depth profile display was deployed to identify and navigate areas of topographical concern including confined coves and bars that were found while performing routine grid transects. Transects covered the entire reservoir at the water surface elevation during the time of the field data collection (Figure 2.0-1).

Once all the data were collected, the sounder depth records were edited in Microsoft Excel to remove all but the necessary data to be matched up with a DGPS location and depths were corrected for submergence of the transducer, i.e. the “draft” or the depth from the water surface to the face of the transducer.

Reservoir water level elevations were measured throughout the study from three gages. Water surface elevations near the dam of the reservoir are routinely measured and recorded hourly by TID.[1] For this study, water surface elevation gages were also installed at two other locations, where existing benchmarks provided vertical control for combining all elevation data to a common datum: (1) the Highway 120/49 Bridge across Railroad Canyon (NGS E1389),[2] and (2) the Wards Ferry Bridge (NGS HS4439).[3] All vertical control measurements were then converted to match the vertical datum of the gage at Don Pedro Dam. These reservoir elevations were incorporated into the bathymetric model to adjust each reservoir depth measurement across the reservoir for changes in water surface elevation between the beginning and end of each survey period to the reservoir datum.

The potential existed for an energy slope to form on the surface of Don Pedro Reservoir, as relatively large rates of inflow were observed at the time of the survey.[4] (When an energy slope is present, a reservoir’s water surface elevation increases from downstream to upstream.) Hence, on May 5, 2011, a water surface elevation logger (WSEL) was surveyed near the upper end of the reservoir using the monuments at the Highway 120/49 Bridge and at Wards Ferry Bridge. Water surface elevations as detected by the new logger were then compared to the water level as detected by the gage at Don Pedro Dam. After analyzing the collected water level information, it was determined that there was not a measurable energy gradient during the period of survey. Hence, for the purpose of this data collection effort, the water surface of Don Pedro Reservoir was assumed to be flat.

## 3.2 IFSAR

Topographic information above 792 ft was obtained by interferometric synthetic aperture radar (IFSAR), which was collected by the vendor Intermap during August 2004. The water surface of the reservoir at the time the IFSAR data were collected was 760 ft and the resulting Digital Terrain Model (DTM) extends upwards to well above the reservoir’s full pool elevation of 830 ft.

## 3.3 Surface Model Generation

A contour line at the normal maximum water surface elevation of 830 ft was generated using a GIS contouring tool with the IFSAR DTM. It was visually checked and modified as needed using a horizontally more accurate hi-resolution aerial image.

1 http://www.tid.org/water/hydrological-data
2 http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=HS1389
3 http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=HS4439
4 Inflows to Don Pedro Reservoir ranged from 5,192 cfs to 12,652 cfs during this study (http://cdec.water.ca.gov/).

The bathymetric survey point data were imported into ESRI ArcGIS Desktop software where the point data was integrated with the IFSAR DTM data to make a continuous network of points below the normal maximum water surface contour. That network of points was used develop a network of bottom lines or thalwegs. The points, the bottom lines and the normal maximum water surface contour were then used as input for the ESRI surface interpolation tool “Topo to Raster”. The Old Don Pedro Dam was located during the survey and construction drawings of that dam[5] were useful to integrate that feature into the interpolated surface. Contours at 10 ft intervals were then inferred using ESRI contouring tools. The result of this analysis was a continuous surface model that will be used as input to the 3-D reservoir temperature model.

## 3.4 Quality Assurance and Quality Control

Data quality was assured by following manufacturer’s instructions and periodically verifying data values through an alternative measurement (in the field) and third-party review (in the office). Throughout the field survey, the depths measured by the sounder were periodically compared to the actual depth. The actual depth was measured by either lowering a “bar” beneath the sounder or by direct measurement of the bottom with a lead line or pole. Measurement of the “draft” or the depth from the water surface to the face of the transducer was also periodically recorded.

Quality Assurance of the bathymetric surface was performed by an independent reviewer following three steps. The first step consisted of a review of the field methods and materials. The second step consisted of checking the edited raw data. Finally, the third step consisted of verifying the methods used in the production of the final deliverable.

Review of field methods included a review of the “bar checks” performed in the field and described above. In addition, specifications of the sounder and DGPS used in the survey were reviewed to confirm the accuracy of the data as reported. The water surface elevation data at the three gages were also checked for consistency.

Next the processing of the raw data was checked. Any data with DGPS errors or sounding errors that had been flagged by the modeler were checked to confirm that the deletion was appropriate prior to interpolation. Soundings were spot checked for consistency. The crossing of transects and tie-lines was reviewed to ensure that the sounder recorded similar depths at the intersection of survey lines. If any sharp differences in depth at adjacent points were present, they were identified as either an error or a real feature.

The last step was check of the final bathymetric surface (Attachment A). Once the field methods and raw data were reviewed, the production of contours from a bathymetric surface was checked. Calculation of the bottom elevation from sounding depths was reviewed to ensure corrections for the draft and varying water surface elevation were properly accounted for. The method of interpolation and settings used in the interpolation was reviewed to ensure that reasonable contours were generated. Contours created using interpolation were checked against actual soundings to verify that the interpolated surface is reasonable. Finally, contours were checked

[5] TID and MID 1920

against the original elevation-storage curve, as well as historical United States Geological Survey (USGS) maps.

## 4.0 Results and Analysis

Don Pedro Reservoir contours at 10-ft intervals are displayed along with a shaded relief of the surface in a series of maps at the end of this report (Figures 1 through 15 in Attachment B).

Using the survey data, reservoir volume was calculated in one-foot contour intervals from the bottom of the reservoir to the normal full pool elevation. The calculated storage using the new bathymetry data is compared to the original storage capacity information in Table 4.0-1 and Figure 4.0-1. The original elevation-storage curve indicated that Don Pedro Reservoir at the time of its construction had a total storage capacity of 2,030,000 acre-feet of water at elevation 830 ft (ACOE 1972), while the new bathymetric surface indicates the reservoir holds 2,014,306 acre-feet at that elevation—a difference of less than 1 percent.

**Table 4.0-1. Don Pedro Reservoir volume comparison between original elevation storage curve and 2011 bathymetry survey data.**

| | Cumulative Volume (ac-ft) | | | | Incremental | |
|---|---|---|---|---|---|---|
| Elevation (ft) | Original Storage Curve[1] | 2011 Bathymetry Survey | Gain (Loss) in Total Storage[2] | Percent Gain/Loss of Total Storage | Gain (Loss) in Total Storage[2] | Percent |
| 550 | 158731 | 158578 | (153) | -0.01% | (153) | -0.10% |
| 570 | 212870 | 211023 | (1,847) | -0.09% | (1,694) | -0.80% |
| 590 | 274760 | 272508 | (2,252) | -0.11% | (405) | -0.15% |
| 620 | 384060 | 382330 | (1,730) | -0.09% | 523 | 0.14% |
| 650 | 517450 | 516849 | (601) | -0.03% | 1,129 | 0.22% |
| 680 | 678950 | 677807 | (1,143) | -0.06% | (542) | -0.08% |
| 710 | 869700 | 867442 | (2,258) | -0.11% | (1,116) | -0.13% |
| 740 | 1094900 | 1090096 | (4,804) | -0.24% | (2,545) | -0.23% |
| 770 | 1359200 | 1350810 | (8,390) | -0.41% | (3,586) | -0.26% |
| 800 | 1669000 | 1657028 | (11,972) | -0.59% | (3,582) | -0.21% |
| 830 | 2030000 | 2014306 | (15,694) | -0.77% | (3,722) | -0.18% |

[1]ACOE 1972 Flood Control Manual
[2] Original Survey Volume at Elevation – 2011 Survey Volume at Same Elevation

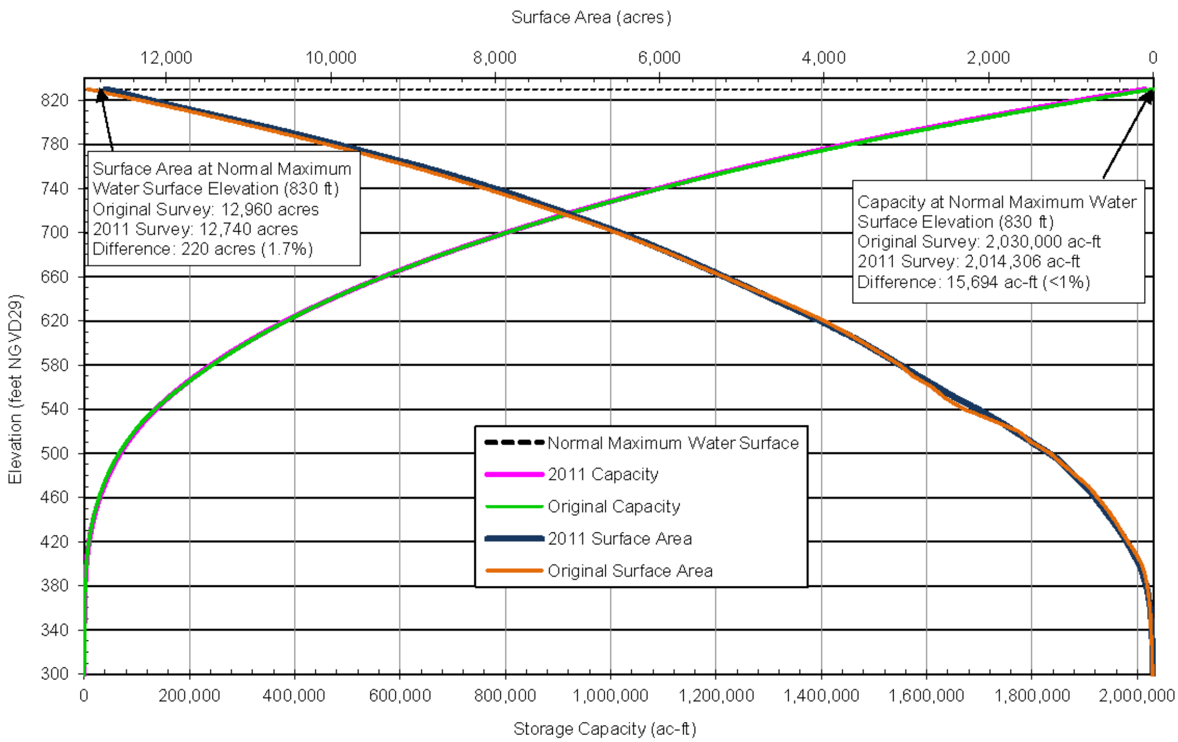


**Figure 4.0-1. Don Pedro Reservoir area-capacity curves (reference data: ACOE 1972; 2011 bathymetry study).**

# 5.0 Discussion

As demonstrated in Section 4.0, the storage volumes provided by the original elevation-storage curve and the new bathymetric surface differ by less than 1%. It is recognized that the two estimates were developed based on different survey methods and bathymetric surface calculation methodologies. Other than the elevation-storage curve itself, the input data used to generate the ACOE 1972 curve were not available. However, both methods relied on engineering standards for computations in use at the time of survey, indicating an appropriate level of computational rigor was applied to both estimates. Therefore, it is reasonable to conclude that, for all intents and purposes, the 2011 survey substantially confirms the 1972 elevation-storage information and that any loss of storage in the Don Pedro Reservoir since Project construction can be considered to be minimal.

## 6.0 References


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Intermap. Available online at: <http://www.intermap.com/>.

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