RECONNAISSANCE TECHNIQUES FOR RESERVOIR SURVEYS

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Abstract: The reconnaissance survey technique is described then applied to two large U.S. reservoirs to update bottom topography and compute sediment deposition volumes and storage capacities. Known areas of accumulated sediment were surveyed using multibeam technology. The multibeam data was analyzed to determine the locations and volumes of sediment deposits in the surveyed reaches of the reservoirs. Using state of the art collection equipment and field reconnaissance techniques can greatly reduce collection and analysis costs and still produce accurate results. Recommendations are made for expanded application of reconnaissance techniques to larger areas and more detailed study of results where applied.

INTRODUCTION

Reservoir sedimentation is an ongoing natural depositional process that can remain invisible for a significant portion of the life of a reservoir. However, lack of visual evidence does not reduce the potential impacts of reservoir sedimentation on functional operations of a reservoir (Lin, 1997). As sediment deposition depletes reservoir storage volume, periodic reallocation of available storage at various pool levels may be necessary to satisfy operational requirements of water users.

Reclamation conducts reservoir surveys with the purpose of updating the area-capacity relationship and computing annual sediment inflow to project useful operation of their existing facilities. Evaluation of reservoir sediment deposition usually involves extensive field data collection, requiring significant time and resources to complete. A complete hydrographic survey provides an accurate contour map of the reservoir bottom, current surface area and reservoir capacity, and sediment accumulation since previous surveys. However, a complete survey for larger reservoirs can be expensive, limiting the frequency of surveys.

Currently, Reclamation oversees more than 400 storage reservoirs, but only thirty percent have been resurveyed since initial filling. Of those resurveyed, about thirty percent have had multiple surveys for monitoring high sediment inflow rates. Reclamation's Sedimentation and River Hydraulics Group (Sedimentation Group) has monitored reservoir sedimentation over the last century following the closure of several dams in the early 1900's. The monitoring methodology has varied from reconnaissance level studies to detailed field data collection and analysis. The reconnaissance collection and analysis techniques presented here use modern instrumentation and analysis tools to accurately update reservoir sedimentation information in a timely and cost effective manner.

RESERVOIR SEDIMENTATION

Reservoirs come in all shapes and sizes and are designed for purposes such as retention for flood control, debris/sediment storage, irrigation and municipal water supply, power production, recreation, navigation, conservation, and water-quality control. The reservoir size, shape, and operation affect the location and nature of the sediment deposits. As rivers and streams enter a reservoir, the flow depth increases and the velocity decreases, reducing the sediment transport capacity of the flow. Decreased sediment transport capacity and the damming effect of the reservoir may cause deposition of sediment in the stream channels above the reservoir water surface and in the upper reservoir area (Figure 1).

The sediment deposition process in reservoirs generally follows the same basic pattern; coarser sediments settle first in the upstream reservoir area as the river inflow velocities decrease, forming a delta. Deposition continues in the downstream direction, with the sediment gradation becoming finer as the deposition progresses toward the dam, until the inflowing sediment is deposited throughout the length of the reservoir. Some of the inflowing fine sediments (silts and clays) typically stay in suspension and may discharge through the dam outlets. As sediments deposit near the dam outlets, they eventually will be discharged downstream as releases are made from the dam.

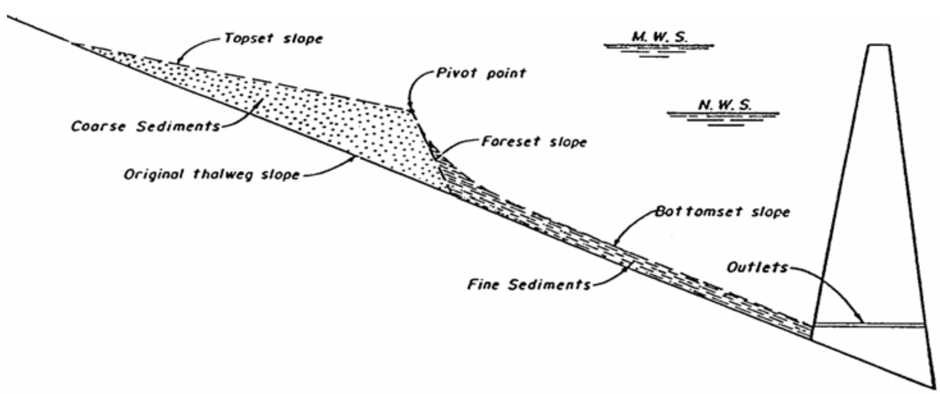

Figure 1 Profile of reservoir delta formation

Reservoir sedimentation seldom receives attention until the capacity has been significantly reduced, or the operation and surrounding area is effected. The primary objective of a reservoir survey is to measure the current area-capacity. Loss of storage capacity is generally caused by sediment deposition or shoreline erosion. Typical results from a reservoir survey and analysis include measured sediment deposition since dam closure and previous surveys, sediment yield from the contributing drainage, and future storage-depletion trends. Survey results can also include location of deposited sediment (lateral and longitudinal distribution), sediment density, reservoir trap efficiency, and evaluation of project operation.

RECONNAISSANCE SURVEY TECHNIQUE

The reconnaissance survey technique directly surveys the reservoir areas where most of the sediment is known to accumulate and uses that data to update reservoir topography and compute sediment deposit volumes for the entire reservoir. Using engineering judgment, sediment deposition in areas of the reservoir not covered by the survey can be extrapolated from the bathymetric survey data collected.

Survey data from hundreds of Reclamation reservoirs demonstrate that sediment tends to deposit along the alignment of the original river channel which is the deepest area (thalweg) of the reservoir. During a reconnaissance survey, longitudinal profiles are surveyed along the original reservoir thalweg using digital contours from the original reservoir topography to guide the survey vessel. Data from multiple profiles are used to compute the transverse slope of the sediment deposits. The measured transverse slope (which may be level) is extrapolated over the areas of the reservoir not surveyed to produce a complete surface of the existing reservoir bottom. The reservoir sediment deposit volume is computed by subtracting the original reservoir bottom surface from the new surface created from the survey data.

A complete hydrographic survey of the entire reservoir provides the most accurate means of measuring the reservoir bottom, sediment accumulation, and current reservoir capacity. However, a complete reservoir survey can be expensive and time consuming, especially for large reservoirs, sometimes limiting the feasibility and frequency of reservoir surveys. Survey technology has changed significantly over recent decades with dramatic increases in the speed of data acquisition and computer processing. These changes have reduced field data collection and analysis time and costs considerably while improving accuracy.

Following is a summary of the field collection techniques and analysis methods used for the 2001 Lake Mead and the 2004 and 2005 Lake Powell partial resurveys. In 2001, the Sedimentation Group conducted the first known multibeam survey of Lake Mead and in 2004 conducted the first known multibeam survey on portions of Lake Powell. In 2005, the Sedimentation Group participated in a Lake Powell multibeam survey that covered a larger portion of the submerged sediment deposits. The University of New Brunswick in cooperation with the National Park Service (Hughes Clarke, 2005) conducted the 2005 survey. Through reconnaissance analysis techniques, data from these surveys can be used to develop updated area and capacity tables for Lake Mead and Lake Powell.

Lake Mead 2001 Reconnaissance Survey: Reclamation’s Sedimentation Group surveyed Lake Mead Reservoir in the spring of 2001 to develop a present storage-elevation relationship. This was the first multibeam survey conducted by the Sedimentation Group and the first known extensive multibeam survey of Lake Mead. Due to the size of the reservoir and the limited budget, only the areas of known sediment accumulation were surveyed. Between 1999 and 2002, extensive sidescan sonar images, seismic-reflection profiles, and bottom sediment samples were collected on Lake Mead by the USGS from Woods Hole, Massachusetts and the Lake Mead/Mojave Research Institute of the University of Nevada at Las Vegas. This data verified that the post-impoundment sediment deposits mainly covered the floors of the former streambeds of Lake Mead (Twichell, 1999).

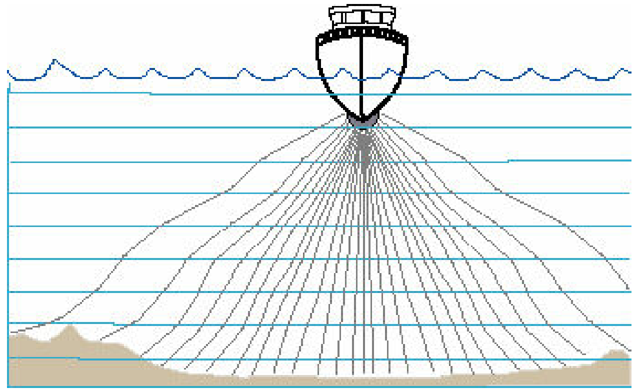

Figure 2 – Multibeam collection system

The Lake Mead multibeam underwater survey was conducted over 22 days in April and May of 2001. The Sedimentation Group used multibeam sonic depth recording equipment interfaced with GPS to obtain continuous sounding positions throughout the underwater portions of the reservoir covered by the survey vessel. The 2001 survey utilized a high-resolution multibeam mapping system for collecting x,y,z data of the Lake Mead bottom from depths of 3 meters in the upper portions of the lake to greater than 140 meters near Hoover Dam. The system consisted of a single transducer that was mounted on the center bow or forward portion of the boat. From the single transducer a fan array of narrow beams generated a detailed cross section of bottom geometry as the survey vessel passed over the areas to be mapped (Figure 2). The survey found the majority of the reservoir bottom sediment lying very flat.

The survey data analysis required digitizing the 1935 (original) Lake Mead surface topography into electronic format. These digital images were used during the survey to ensure the vessel was collecting data in the original river channel area. The new topographic map was developed from a combination of 2001 underwater measured topography and original USGS quad contours. The x,y,z data collected in 2001 were merged into the 1935 digital surfaces and provided the final 2001 surface images. Comparison of the original surface and the 2001 surface provided the quantity and location of sediment that has deposited in Lake Mead since the closure of Hoover Dam in February of 1935. The 2001 data were superimposed onto the 1935 data with the assumption that no change has occurred at elevations above the 2001 bottom survey since 1935. Reclamation's Lower Colorado Regional Office completed the GIS analysis of Lake Mead, resulting in digital images of the original and 2001 reservoir topography along with the sediment accumulation and reservoir storage volume for the areas studied. Figure 3 is a digital map developed from the 2001 Lake Mead multibeam survey data only (1935 topography not included).

The Sedimentation Group proposed to compute the 2001 Lake Mead area-capacity by measuring the storage changes on the 45 individual reservoir maps due to sediment accumulation (assuming no original surface area changes above the 2001 surveyed elevations). Even though most of the area is lost due to siltation, the 40 miles of surface area in the upper contours upstream of Pierce Basin should be included in the proposed analysis. Due to time and budget constraints, the proposed area-capacity computations were not performed. Compared to the 2001-2002 approach, this method would not likely produce a major change in the computed sediment inflow volume since dam closure, but would provide a complete reservoir volume for all reaches of the original reservoir. The only means to truly measure the current storage volume of the reservoir would be to conduct a combined above and below water survey.

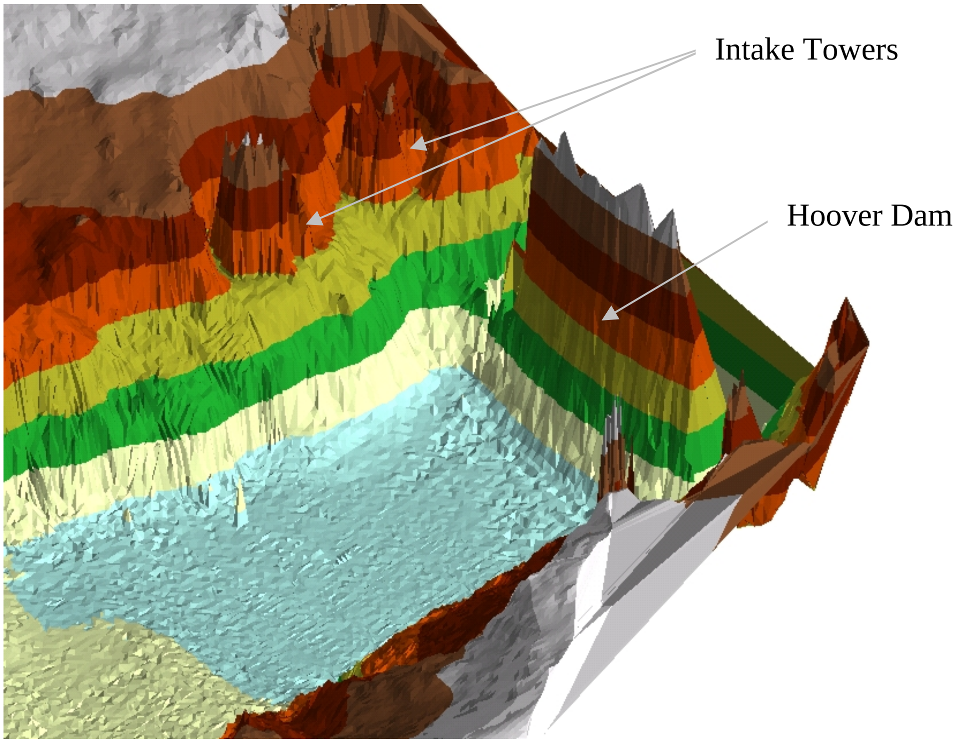

Figure 3 Multibeam image of Hoover Dam and intake towers

The Lake Mead longitudinal profile in Figure 4 compares results of the 1935, 1948, 1963 and 2001 Colorado River surveys. The 2001 profile of the Lower Granite Gorge above Pierce Basin was developed from cross section data collected by a regional contractor for studying the effects of the Colorado River and Lake Mead on bird nesting habitat. These cross sections were not tied to a true vertical datum, but with engineering judgment they were used to complete the thalweg profile from Pierce Ferry upstream (about 40 miles of the upper reservoir). On Figure 4, the 2001 bottom data plots lower than the 1948 and 1963 longitudinal profiles in the lower reservoir area. Reclamation’s 2001 surveyed bottom data were verified by other data collected from 1999 through 2002 in the same areas. It is assumed that consolidation of the previously accumulated bottom sediments has occurred over time, resulting in lower elevation measurements in 2001. There are mathematical means to compute the consolidation rate over time (Strand and Pemberton, 1982), but the limited budget did not allow the Sedimentation Group to investigate further these findings.

Lake Powell 2004 and 2005 Reconnaissance Surveys: In October 2004, the Sedimentation Group used their multibeam system to map the Colorado River thalweg from Glen Canyon Dam to Antelope Marina. This was the first known multibeam survey of Lake Powell. The boat mounted multibeam system was able to map the level sediment deposits from bank to bank with just two passes along the river channel. The 1986 Lake Powell Sedimentation survey covered 580 miles of the reservoir, including the total length of all the tributaries surveyed, in 6 months. Using the reconnaissance collection techniques employed in 2004, the multibeam system could survey the same area as the 1986 survey in less than 30 days. In cooperation with USGS Flagstaff Office, the Sedimentation Group mapped the Colorado River channel from Antelope Marina to the San Juan confluence, the San Juan River to the upper reservoir reach, and Navajo Canyon in December 2004. Reconnaissance analysis techniques were only applied to the Navajo Canyon reach of Lake Powell, but could be applied to the whole reservoir.

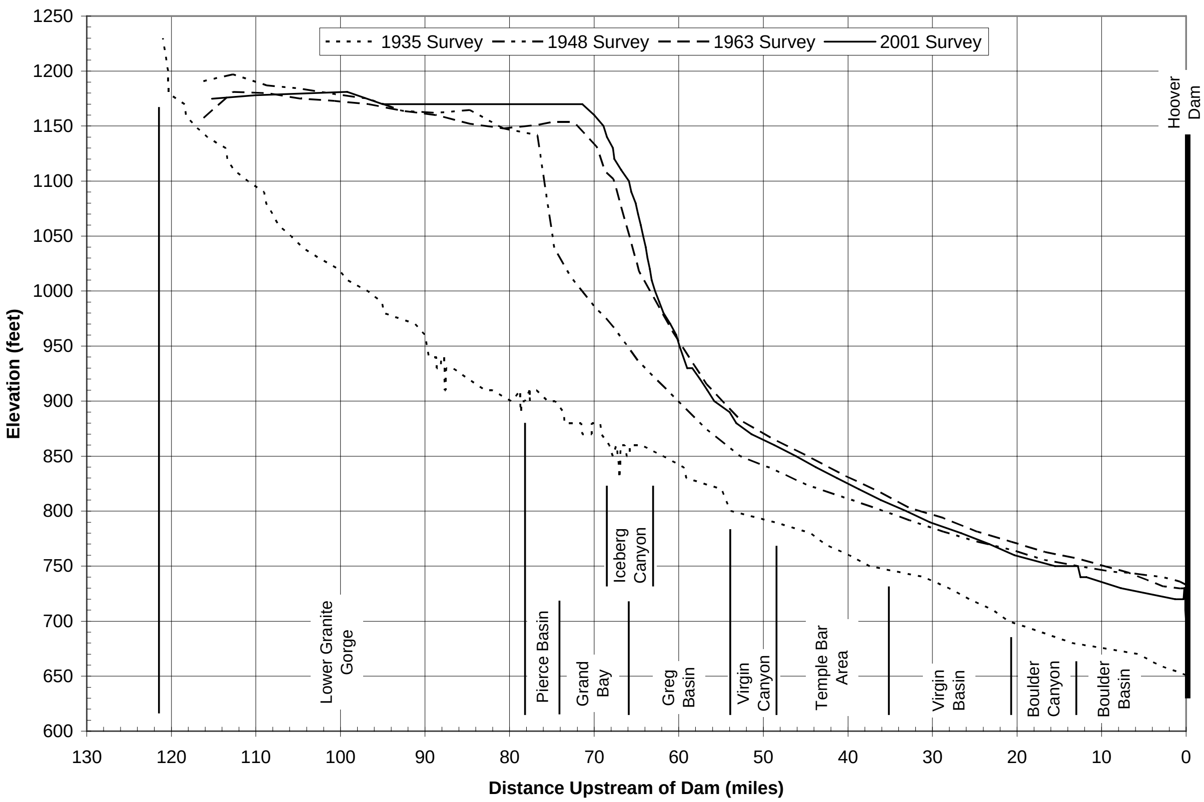

Figure 4 1935, 1948, 1963, and 2001 Colorado River profiles through Lake Mead

Navajo Canyon Area Computation: The Navajo Canyon drainage joins the Colorado River a few miles upstream of Antelope Marina and was determined by 1986 survey results to be a significant source of sediment. The survey boat was navigated along the thalweg as it maneuvered upstream and downstream in Navajo Canyon. The course along the thalweg was maintained using digitized map contours as a guide in the collection software. Figure 5 is a TIN image developed from the raw x,y,z points collected during two multibeam profiles along the canyon. The image clearly shows Navajo Canyon wall details and flat sediment deposition along the original river alignment.

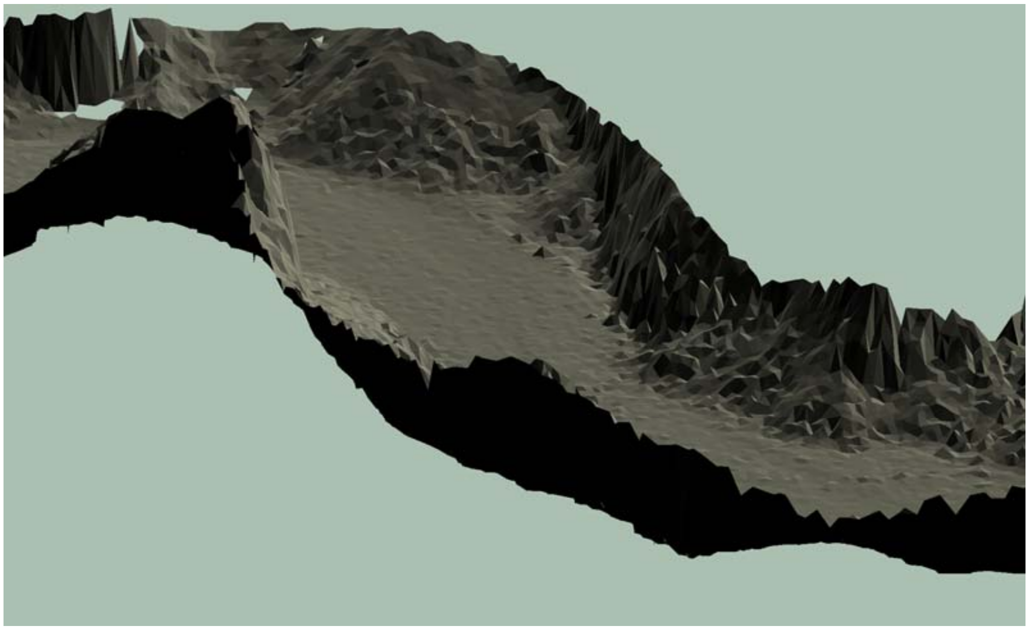

Figure 5 Navajo Canyon TIN generated from multibeam data only

The Navajo Canyon reconnaissance analysis was conducted using the original canyon topography (12 maps), cross sections surveyed in 1986, and the 2004 multibeam data. Using ARC software, cross sections were cut through the original digital contours and the 2004 multibeam x,y,z data set. The cross sections were cut in the same locations as the 1986 Lake Powell cross sections. Cross section locations were estimated using copies of the marked maps from the 1986 field collection. The resulting cross section plots show that the sediment deposition in Navajo Canyon is nearly level, with an even lateral distribution across the reservoir bottom. Figure 6 is an example of the lateral sediment distribution in Navajo Canyon.

Sediment deposit volumes in Navajo Canyon were computed from the 2004 cross sections and the original maps that form the boundary around the canyon to determine the 2004 surface areas at 20-foot elevation increments for each of the 12 maps. The original surface areas at 20-foot contour intervals were digitized and summed to determine the original reservoir surface area by elevation. The original surface areas represent contours not affected by sediment deposition. The 1963, 1986, and 2004 cross section results were used to determine the surface area changes, by map, for the 20-foot elevation increments. On some maps, the cross sections showed total loss of a 20-foot contour area due to sediment deposition. ARC GIS mapping tools were used to develop a TIN and resulting contours from the 2004 multibeam bottom data. This information was used to locate the upper end of the new 20-foot contours for each map. The resulting surface areas of the 2004 contours represent the zone affected by sediment deposition. This process was completed for each map and the summation of the surface area at each 20-foot contour interval became the 2004 surface areas for Navajo Canyon. The 2004 final surface areas provided the input for computing the new capacity of the Navajo Canyon arm of Lake Powell. According to the results, after 40 years of reservoir operation, 29,000 acre-feet of sediment has deposited in the Navajo Canyon study area from the Colorado River confluence upstream, an average of 725 acre-feet of sediment per year. Examination of Navajo Canyon and Colorado

River profiles indicates that a portion of the sediment from the Navajo Canyon drainage has deposited downstream towards Glenn Canyon Dam, outside of the Navajo Canyon study area.

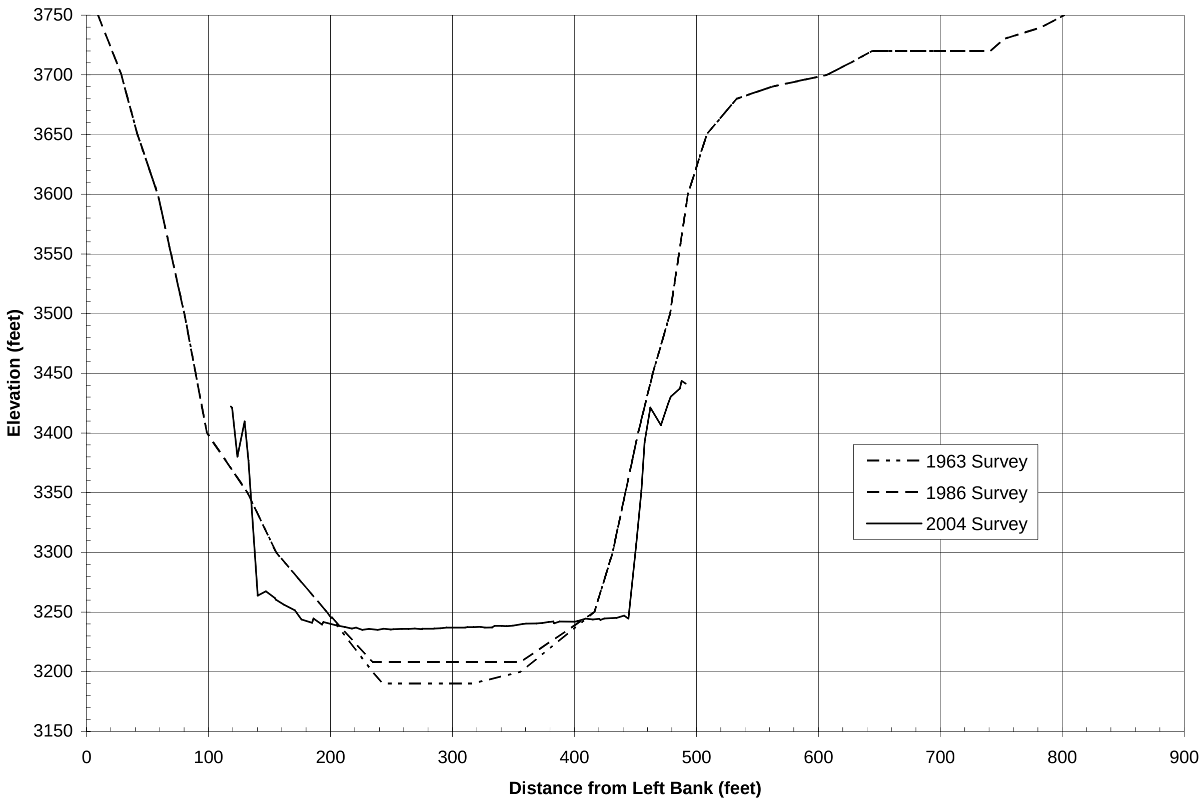

Figure 6 Navajo Canyon Range Line 422

Colorado River Analysis: Longitudinal average bed profiles for the original (1963), 1986, and 2004 Colorado River surveys were plotted from the dam upstream to the Lake Powell headwaters (over 180 miles), Figure 7. The 2004 profile ends just upstream of the San Juan River confluence where the 2004 field data collection concluded. The 1986 profile versus the 1963 (original) illustrates the upstream sediment deposition typical for this type of reservoir configuration and operation. The 2005 Hughes Clarke multibeam survey mapped from the dam upstream nearly to Hite Marina and was limited to this area due to the low lake level during their survey (around elevation 3,570 feet). The Sedimentation Group proposes to analyze the 2004-2005 data using a process similar to that used on the Navajo Canyon data, providing a complete longitudinal profile to elevation 3,570. Using results from previous studies, such as the Lake Mead and Lake Powell surveys, engineering judgment can extend the profile beyond the available 2005 data to update the current volume of Lake Powell.

SUMMARY

Reconnaissance survey and analysis techniques were outlined and applied to portions of two large U.S. reservoirs to generate updated bottom topography and to compute current area-capacity values. Compared with original reservoir topography and storage capacities, the reconnaissance survey method provides dam operators with accurate information for best reservoir sediment management practices in a shorter time at reduced cost. The reconnaissance methodology used at Navajo Canyon can be applied to the 2001 Lake Mead and the 2004-2005 Lake Powell data to compute updated area – capacity values for both reservoirs.

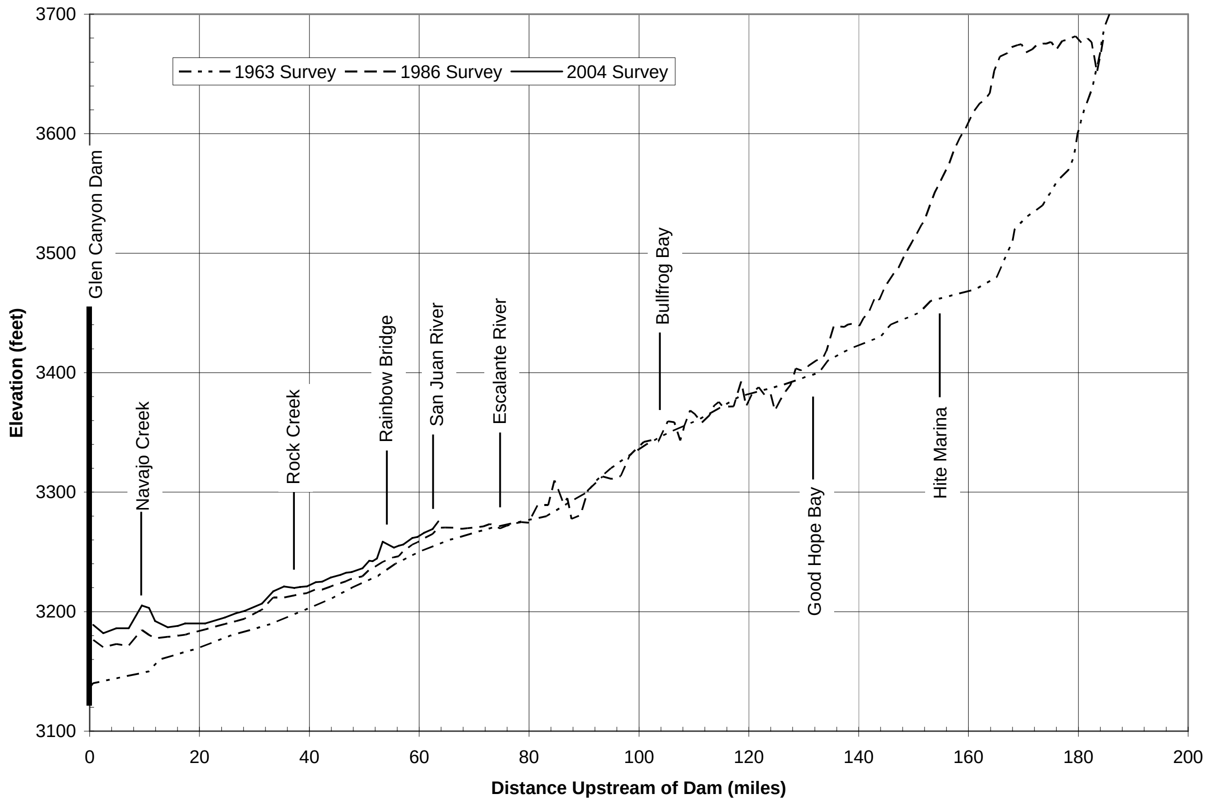

Figure 7 1963, 1986, and 2004 Colorado River Profiles through Lake Powell

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