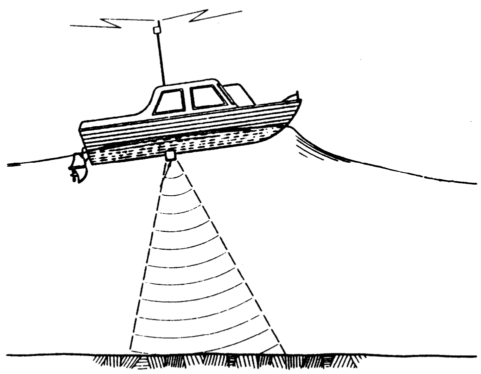

PROCEDURES FOR MONITORING RESERVOIR SEDIMENTATION

Technical Guideline for Bureau of Reclamation

U.S. Department of the Interior
Bureau of Reclamation

PROCEDURES FOR MONITORING
RESERVOIR SEDIMENTATION

by

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Technical Guideline for

Bureau of Reclamation

DIVISION OF PLANNING TECHNICAL SERVICES
HYDROLOGY BRANCH
SEDIMENTATION AND RIVER HYDRAULICS SECTION
ENGINEERING AND RESEARCH CENTER

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I. INTRODUCTION

A. Purpose and Scope of Guide

This technical guide provides information and instructions for use by Reclamation (Bureau of Reclamation) personnel in planning and conducting reservoir surveys. Most procedures described are from experience gained on numerous reservoir surveys. Other available methods and procedures which have not been utilized by Reclamation are mentioned but not described in detail. More detailed descriptions of other agency methods are given by Gottschalk (1952), U.S. Army Corps of Engineers (1961), U.S. Soil Conservation Service (1968), and by joint working group efforts of American Society of Civil Engineering (1975), and Subcommittee on Sedimentation, Interagency Advisory Committee on Water Data (1978). The guide should be used in conjunction with RI (Reclamation Instructions), Series 550, Bureau of Reclamation (1965). The report entitled "Tentative Instructions for the Establishment of Sediment Ranges and Reservoir Survey Markers," dated June 15, 1948, listed in Planning Instruction PI80-34 (7114), U.S. Bureau of Reclamation (1980), is superseded by this guide.

The guide is issued for the instruction of regional and project office personnel having responsibilities for the original sediment range survey, the operation and maintenance of Reclamation reservoirs, and for survey personnel participating in field surveys.

B. Objectives of a Reservoir Monitoring Program

The primary objective of a monitoring program is to determine current reservoir capacity. Because the major cause of change in storage capacity is the deposition of sediment, the monitoring program also determines sediment accumulation. During the initial stages of any project investigation involving a storage reservoir, Reclamation determines, if necessary, a storage allotment for sediment within the reservoir. The criterion is that an allotment is made for sediment storage when the total sediment inflow to that reservoir is estimated to exceed 5 percent of its total capacity at normal water surface during the economic life of the reservoir (usually 100 years).

A secondary objective of the monitoring program is to provide data necessary to determine various sedimentation factors such as annual yield rates, sediment densities, and lateral and longitudinal distribution of deposited sediment. These factors are beneficial, both in describing existing conditions relative to the specific reservoir and for planning of other reservoirs.

II. SELECTION OF SURVEYING METHOD

Prior to any impoundment, a decision should be made as to which of two basic methods of survey should be used for comparison with future surveys: the contour method or the range-line method. The selection should depend on the original survey data available, reservoir size, the reservoir operation plan, and accuracy requirements to define change in storage volume or volume of sediment accumulation.

A. Contour Method

The contour method usually is chosen (1) for small reservoirs, (2) for reservoirs that occasionally may be near empty or at a low stage, or (3) when the highest degree of accuracy is desired. To develop a reliable contour map, the reservoir must be either empty or at a low stage to derive contours by conventional land survey procedures or by photogrammetric methods described by Wolf (1974). For small reservoirs, underwater contours may also be developed from hydrographic survey data obtained by an automated survey system, producing closely spaced gridlines or random survey points. The selection of contour intervals is the same as given for an original mapping requirement with suggested intervals not to exceed 5 feet and 2 feet for large and small reservoirs, respectively. The controls for most contour mapping are usually by second order methods; however, to define changes in storage or sediment accumulation for most reservoir surveys, third order accuracy for the basic horizontal and vertical controls is adequate.

With development of more sophisticated land surveying and photographic equipment, photogrammetric methods are being used on many reservoirs. A limited number of ground control points must be surveyed by land surveying methods and then paneled for photographic identification. The below-water storage area is surveyed by hydrographic survey methods. If the underwater area is relatively small, then data from the hydrographic survey are used to develop a contour map similar to that determined from the photogrammetric survey. Where the underwater portion is large, the range-line method is used to compute the underwater areas which are then coordinated with the above-water areas in computing the available storage.

B. Range-line Method

The range-line method is most often used for medium to large reservoirs requiring underwater surveys and the use of hydrographic surveying equipment. This method consists of determining the existing water and sediment depths along established range lines and using the acquired profile information with an appropriate mathematical procedure to produce a revised contour area versus elevation tabulation.

For those Reclamation reservoirs where a storage allocation is made, RI 114 require that a system of sedimentation ranges be established for the reservoir prior to initial filling. The original survey of the range lines provides the base survey against which future reservoir surveys will be compared.

III. BASE RESERVOIR DATA

A. Original Reservoir Topography

The task of monitoring changes in reservoir capacity due to sediment deposition is enhanced by providing an accurate reservoir contour map during the preconstruction period. This map can be used to determine the initial reservoir capacity and may serve as the map upon which to locate sediment ranges as well as the base topography against which all future resurveys are compared.

Requirements for topographic surveys and mapping for Reclamation reservoirs are given in RI 554. Except for rough appraisal level surveys, Reclamation topographic surveys should be tied to the Coast and Geodetic Survey horizontal and vertical control nets. Customarily, Reclamation surveys will tie to, and use the State plane rectangular grid coordinate system, local zone, for the area to be mapped. Occasionally, a modification of the State plane grid or a local grid may be preferred.

The scales and contour intervals prescribed for Reclamation reservoir topography fall within the following suggested range:

Stage	Scale	Contour interval (ft)
Appraisal	1:12,000-1:24,000	10, 20, 40
Feasibiity and final	1:4,800-1:12,000	2, 5, 10

The choice depends upon local or project conditions such as size of the reservoir or relief of the terrain.

The topography should cover an area which includes the dam axis and extend upstream on the main stem and tributaries to an elevation high enough to include all surcharge storage.

B. Establishment of a Sediment Range System

1. Objectives. - Reclamation's objectives for establishment of sedimentation ranges and range end markers are defined in the Commissioner's Circular Letter No. 3526, dated June 23, 1948, addressed to all offices. These objectives are to provide:

a. Factual data for litigating claims against the Government.

b. Information for future changes or improvements that may be required.

c. The data base for operation purposes in determining sediment accumulation effects on area-capacity relationships.

d. Information relative to the effect on structures and upstream or downstream development due to changes in stream regimen.

e. Information that will aid in future planning.

2. General location of ranges. - In selecting a range-line network for a new reservoir, care should be exercised to provide the minimum number of range lines necessary to attain the monitoring objectives because of the relative cost of the initial survey and future resurveys. The relationship of reservoir surface area versus number of range lines on figure 1 was developed by regression analysis on 57 Reclamation reservoirs

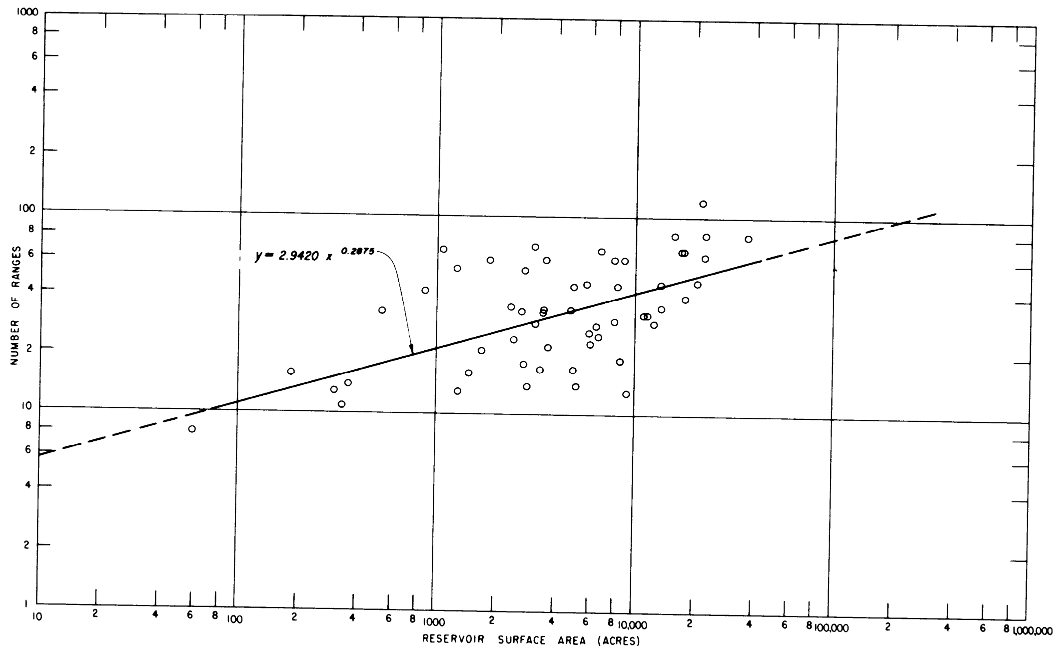


Figure 1. - Number of range lines versus surface area.

having sediment ranges. This relationship may be used to estimate the number of range lines required.

In order to meet requirements of a monitoring program within a reasonable standard of accuracy, the following guidelines should be adhered to in locating range lines:

a. Range lines should be located normal to streamflow and the valley where practicable.

b. Range lines should be spaced so that the average section end areas of adjacent ranges represent the valley or stream reach between them.

c. A range line should be located across the mouth of each principal arm of the reservoir, and a range network should extend up the tributary in a manner similar to that on the main stream.

d. The range nearest the dam should be located to show average valley conditions and should not intercept the toe of the dam.

e. Range lines should be located at a sufficient distance both above and below the dam to ensure adequate data for measuring unnatural changes in stream regimen due to construction of the dam.

f. Spacing of range lines in the delta area of the reservoir and some areas of special interest may need to be closer than in other areas to adequately monitor changes which may occur in the reservoir.

g. Generally, the range-line network below the dam should cover a reach extending downstream as far as degradation and/or aggradation within the stream valley have been predicted in the planning studies.

h. Specifically, the first range below the dam should be located immediately below the confluence of the outlet channels. Range lines should also be located near any tributary confluence, sewer outlets, pumping intake structure, bridges, or other structure that may be affected adversely by construction of the dam and resulting change in the stream.

A typical sedimentation range layout for medium and large storage reservoirs is shown on figure 2. Although this layout shows range lines located on all tributaries leading into the reservoir, the watershed for the small tributaries should be considered and the relative sediment yield determined before locating range lines to monitor any tributary arm.

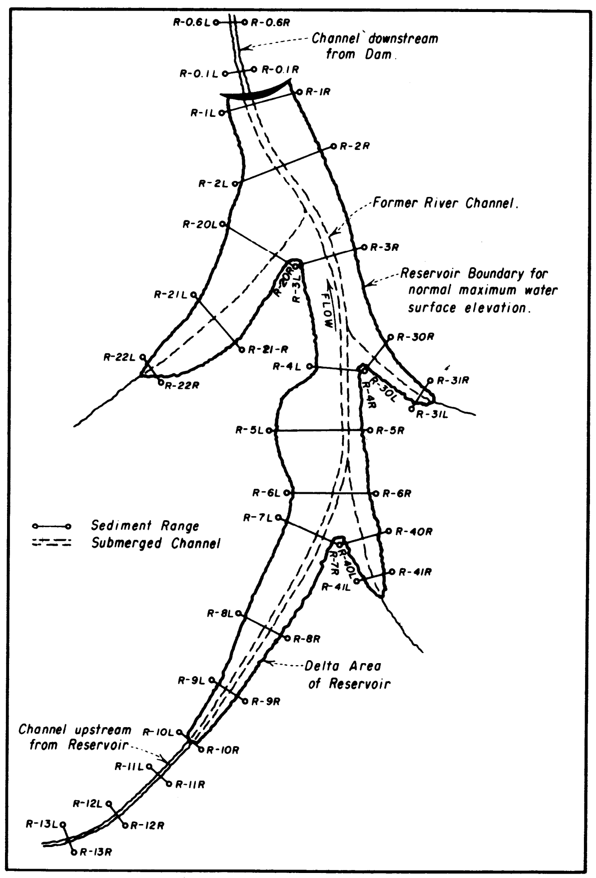


Figure 2. - Typical sediment range location map.

For small reservoirs where the bank contours are relatively straight and parallel, the range system suggested by Heineman and Dvorak (1965), shown on figure 3, may be preferable. By establishing base lines by ground survey methods roughly parallel to the main valley and tributary valleys, a sufficient number of range lines may be struck off the base lines to cover the reservoir. This range system would be appropriate for reservoirs above diversion dams, in powerplant forebays, and in settling basins near canal headworks.

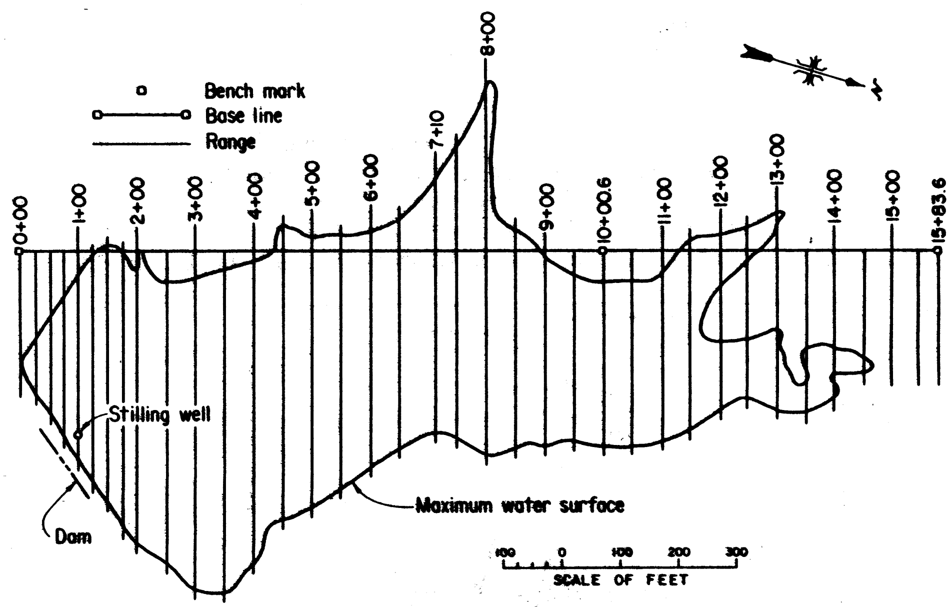


Figure 3. - Typical sediment range layout for small reservoir.

3. <u>Numbering system</u>. - A recommended range numbering system is shown on figure 2. In this system, Range 1 is on the main stream of the reservoir immediately above the dam. Ranges in the main stream are numbered in numerical order ascending upstream from the dam. The tributaries are also numbered in this order, ascending upstream from the mouth of the tributary in the order that the streams empty into the reservoir above the dam.

It is recommended that the numbering system for range lines below a dam be expressed in miles to indicate the distance below the dam.

4. <u>Range monuments</u>. - The ends of each range should be permanently marked by concrete monuments and brass caps which are stamped to show USBR, the range identification number, and a designation left or right. It is recommended that the left and right ends of all ranges be established by the observer facing in the downstream direction. The elevation of each brass cap and the adjacent natural ground surface should be recorded in the field notebooks. This will assure that the vertical and horizontal controls used in resurveys will conform to those which governed the initial range establishment. Standard engineering practices should be followed in establishing these monuments. It is preferred that the sediment range monuments be tied to bench marks and horizontal control networks previously established in connection with the reservoir area surveys. The monuments should be located above the maximum high-water

line, within the reservoir property line, and well back from any potential bank erosion. The base of the monument should extend below the frostline. Details on constructing the monuments are given in RI 550.

5. Survey control. - Sedimentation ranges should be tied together by an accurate triangulation network expanded from a measured and checked base line. Control points in the network should be referenced to property corners, section corners, prominent topographic features, and structures.

The vertical datum for all range-line elevations should be identical to that used for the reservoir gage and outlet structures on the dam. Any differences between this vertical datum and other control datum in the area, such as the U.S. Coast and Geodetic Survey datum, should be carefully checked and noted in the survey records.

The survey of each sedimentation range line should be according to standard engineering practices accurately showing all breaks in ground profile, assuring that subsequent resurveys would show true changes in the reservoir bottom and not survey errors.

6. Standards of accuracy. - The accuracy of the control and range-line surveys should be within the following limits defined by the Federal Geodetic Control Committee in the publication "Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys"(1980):

a. Triangulation - second order.

b. Traverse - third order.

c. Leveling - third order.

d. Base line - third order.

7. Scheduling the range-line survey. - The original survey of range lines should be completed by construction survey personnel near the close of the dam's construction period and prior to initial filling. Any borrow areas or excavated channels crossed by range lines should be documented by the survey.

8. Records of original range survey. - A complete record of the survey should be kept as prescribed by RI 550. The record should include (1) field notebooks, (2) computations, (3) memorandum of survey, and (4) monumentation records.

To resolve questions and problems, all range cross-section data should be examined before plotting final sections.

A location map showing the final location of sediment ranges and range end monuments should be prepared. For large reservoirs, the details shown on the map should be sufficient to show general location of the range monuments relative to the elevation contour marking the top of active conservation. For small reservoirs, an adequate location map would consist of the range lines and range monuments plotted on 7.5-minute topography taken from U.S. Geological Survey quadrangle maps.

Because of the many years which may elapse before the sediment ranges are resurveyed, special care should be used in organizing the survey records and storing them for future use. The original field books containing triangulation, traverse, and level notes and all original range plots and range location maps developed from the original survey should be itemized and placed in a secure storage facility where they will be accessible for subsequent surveys. Duplicate copies of original field books, range monument location data, and final range location maps should be placed on file at the E&R (Engineering and Research) Center, Division of Planning Technical Services, Hydrology Branch, to avoid loss of the records by fire or other causes.

IV. HYDROGRAPHIC SURVEYS

A reservoir resurvey usually involves both an above water and an underwater survey. The term hydrographic is used in this report to refer to the entire reservoir survey, both the above and underwater portions. The term bathymetric specifically refers to underwater survey involving water depth measurements.

A. Planning

A decision to resurvey a reservoir may be prompted by a variety of circumstances. The frequency of resurvey usually depends on the estimated rate of sediment accumulation in the reservoir. Some percentage reduction in reservoir capacity may be used to determine the time period between surveys.

Applying the original estimate for the 100-year sediment accumulation, an allowable 7.5 percent storage reduction between surveys has sometimes been used to estimate the frequency of surveys. Often, however, the decision to resurvey is prompted by some actual or proposed event in the basin such as the occurrence of a large flood, a severe drawdown of the reservoir, or the planned construction of a dam upstream requiring an update of storage capacity. In the case of Elephant Butte Reservoir on the Rio Grande, the frequency of survey is set by a compact agreement between the state and national governments contiguous to the river basin. Other concerns which may require an updating of storage capacity by resurvey are the loss of a recreational area due to sediment encroachment, a change in the erosional characteristics of the basin due to land use change or strip mining, and plans for raising the dam or changing reservoir operations.

The quality of the resurvey depends, to a large extent, on the planning which precedes the field work. The bar graph shown on figure 4 describes a typical plan of activity for a medimum size reservoir. At the beginning of the planning process, a rough cost estimate for the complete survey must be made to secure funding. Simultaneously, the original base data should be acquired and an evaluation made of its reliability as a standard for comparison. The base data include survey records for the original range line survey, the base topography used to compute reservoir capacity, and all pertinent vertical and horizontal control information for the vicinity of the reservoir.

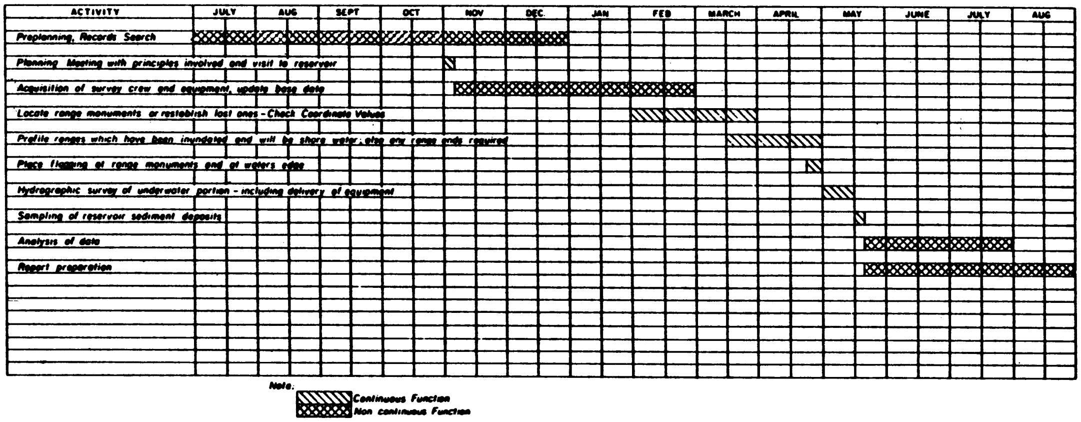


Figure 4. - Typical schedule for completing survey.

Assuming that the base data prove reliable and an original set of sediment ranges exists, the field work can be planned to measure changes which have occurred along each range line since the original survey. The planning should include a scheduling of work so that the ground survey and bathymetric survey coincide with optimum reservoir levels. To ensure some data overlap, the bathymetric survey usually is scheduled when the reservoir is near maximum level for the water year and the ground survey is scheduled earlier the same year when the reservoir pool is at a lower level. Also, planning should indicate requirements for, and availability of, survey personnel and equipment.

Circumstances may be favorable for making a photogrammetric survey of the above water area of the reservoir. Any extreme drawdown of the reservoir during a season of reduced ground cover offers the opportunity for making such a survey. A photogrammetric survey may be preferred because of a need for more topography at higher elevations or more accurate defining of the delta area of the reservoir. If the photogrammetric method is chosen, the data on the above-water portions of established sediment range lines should be obtained from aerial photographs and combined later with data obtained by a bathymetric survey.

Evaluations made during the planning process regarding the nature and quality of the base data, manpower and equipment needs, work scheduling, and processing of the survey data aid in making an adequate cost estimate for the survey. Total costs vary considerably from reservoir to reservoir. Costs usually depend on the scope of the particular survey and the amount of preliminary field surveys and line clearing required. In recent Reclamation resurveys the cost for all of the preliminary field work, including above water surveys, represent from 60 to 70 percent of the total cost, while the hydrographic survey, analysis of data, and preparation of report are 30 to 40 percent of the cost. A work item and cost item checklist is given in appendix I.

At this point in the planning process, the decision should be made either to use Reclamation personnel to conduct the survey or to contract for all or part of the work. If some or all of the work is conducted by contractors, the work order and specifications should be written and plans for field checks made to guarantee the quality of the survey. The following discussion on survey crews and their work assumes that all work will be done by Reclamation personnel.

B. Survey Crew

Survey crew size and makeup may vary depending on labor policies, reservoir size, equipment used, and required deadlines. For a small reservoir, the survey along range lines may be accomplished by a minimum of three or four crew members using standard land surveying equipment and some physical means for sounding depth from a small boat. The minimum requirements for a large reservoir would be a land survey party of four to six members and a bathymetric survey crew of three to four members assigned to the survey boat.

Because the usual sequence of work results in completion of most above-water surveys prior to the underwater survey, only those survey personnel necessary to support the bathymetric crew need remain for the underwater survey. For large reservoirs, the minimum carryover from the land survey party is one qualified instrument man and a rod man. Some carryover is needed to assist in locating control points and establishing any additional points which may prove necessary.

The minimun hydrographic survey crew and their necessary qualifications are:

The hydrographic crew chief. - Should be experienced in operation and maintenance of the positioning and sounding equipment and in all phases of the field operations.

The boat operator. - Should have adequate experience to operate the survey boat, while assuring safety of personnel and equipment onboard. He should be able to perform minor repairs to boat engine and related equipment.

Land survey party chief. - Should be experienced in all phases of land survey and knowledgable in the relationship between the land survey and bathymetric survey.

C. Survey Equipment

The equipment used in a hydrographic survey varies depending on the reservoir size and field conditions at the time of the survey. For establishing control and ground surface profiling, standard transits, levels, plane tables, alidades, steel tapes, and level and stadia rods are useful. However, several of these items of equipment have been replaced by electronic all-purpose land survey equipment, which usually is faster and more accurate than the older equipment.

A boat or raft is required for surveying the submerged part of the reservoir. The choice of vessel size and construction should be determined by the size and physical features of the reservoir, personnel and equipment requiring housing or transportation, and the degree of safety required. On small reservoirs, where relatively lightweight measuring equipment may be used, a small, shallow draft boat or raft may be adequate and provide the maneuverability and safety required. On large reservoirs, where time of travel and safety considerations are more important, a larger, faster, and more seaworthy boat may be required.

To allow surveys to continue during wet or cold weather conditions, it is often necessary to house some of the electronic survey gear in a closed cabin as illustrated by the Reclamation survey boat shown on figure 5.

Figure 5. - Surveying range line at Theodore Roosevelt Lake.

An auxiliary small boat usually is required on a large reservoir for moving men and equipment and as an additional safety measure. Because of their stability, a raft or barge is recommended when a stable platform is required for conducting sediment sampling in the inundated part of the reservoir. A multiple-hull boat also may be used for sampling if it provides the necessary stability.

Sonic sounding equipment is preferred for use on most reservoirs for measuring depth. For small and shallow reservoirs, the sounding can be accomplished mechanically by slightly modifying land survey equipment. However, scientific depth sounding equipment is preferred because it provides a continuous record or chart of the bottom profile. The basic components of this equipment are the recorder, the transmitting and receiving transducer, and the power supply. By careful calibration, a high degree of bottom profile accuracy can be maintained.

Determining position of the sounding boat, as it moves across the reservoir, can be accomplished by using standard land surveying equipment, specially designed mechanical instruments, or sophisticated electronic distance measuring systems. One of the most frequently used methods is the "cutting in" method employing one or two transits used to turn angles from a baseline to the sounding boat as the boat proceeds along a given line. On small reservoirs with short range lines, position can be measured by means of the stadia rod or by stringing a tag line or calibrated cable along the range line. The distance wire measuring wheel is a mechanical device frequently used in reservoir resurveys. The device is designed to play out a fine wire around a rotating, calibrated wheel which records the amount of wire released. The wire, which is tethered on one shoreline near water's edge, may be strung out over a few miles and suspended near the water surface by floats.

The present trend is toward use of electronic positioning equipment in reservoir surveys. The electronic systems are less labor intensive than the older mechanical positioning methods and are very adaptable to computer processing of measured data. These factors, plus the accuracy attainable through electronic methods, are making the electronic systems more attractive. The equipment components vary according to the particular method used and the degree to which data are processed on the survey boat. Capabilities of available electronic positioning system are best described by Hart and Downing (1977).

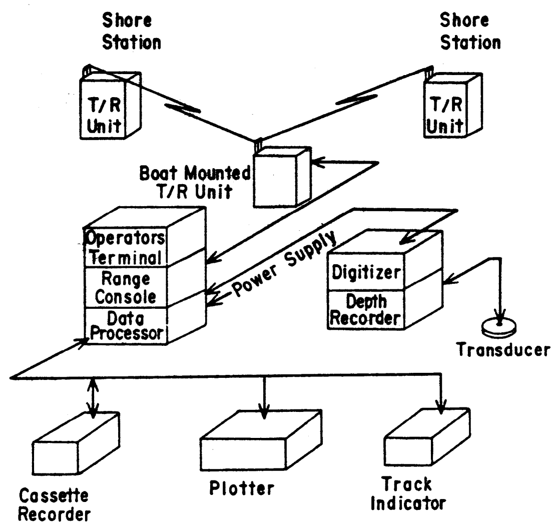


Figure 6. - Components of automated survey system.

Reclamation now uses an electronic positioning system for reservoir surveys which employs the range-range method. Components of the system are shown schematically on figure 6. The system includes a console, a data processor, an operator's terminal, an onboard receiver-transmitter for sending and receiving microwave signals, a tape recorder for storing range profile data, a track indicator for positioning the boat on-line, a depth recorder, a sounding transducer, a depth digitizer, a plotter which tracks in real time and post plots each profile, three shore stations, and an a-c/d-c power source. Figure 7 shows several parts of the system which are mounted in the cabin of the survey boat. Each shore station (see fig. 8) is powered by a portable 24-volt battery pack which can operate for 8 to 10 hours between charges. For stations set up in very remote areas, a bank of 12-volt auto batteries can be used to power the unit for several days.

Detailed descriptions of how various positioning equipment are used to fix the position of the sounding boat in the reservoir are given in part F.4, Positioning.

D. Preparatory Field Work

Some preparatory field work is necessary before beginning the hydrographic survey of range lines. After obtaining the original range location map, plane table sheets, and field notes, the survey crew should begin a ground search for all existing range end monuments. Any missing monuments should be replaced by reestablishing a point on-line and recording any change in range stationing or elevation of the point. As each monument is located, it should be marked by flagging to allow visual spotting from the reservoir.

In reservoir areas where land subsidence is known or suspected to occur adequate control leveling should be conducted to determine if subsidence has affected any control points established at the time of the original survey.

In some geographical areas, the growth of phreatophytes and other vegetation in the reservoir area may cause visibility problems for line-of-sight survey work. When this condition exists, lines may have to be cleared in order to provide access and adequate visibility.

Depending on methods used to obtain position control during the underwater survey, it may be necessary to establish temporary points at stations on the range line near water's edge on each bank. The location of these points should be chosen for easy access from the reservoir surface and at an elevation above the projected reservoir level at the time of the underwater survey. These points serve to tie both the water's edge and the sounding position during the underwater survey to the original range stationing. These points should be staked as temporary points and marked with flagging.

For underwater survey using a range-range or similar electronic method for positioning the sounding boat, the placing of control points near water's edge is not necessary unless required to carefully tie the underwater survey to the water's edge. If these points are not required, it is necessary only to place flagging at a point on-line near the water's edge on each side of the reservoir.

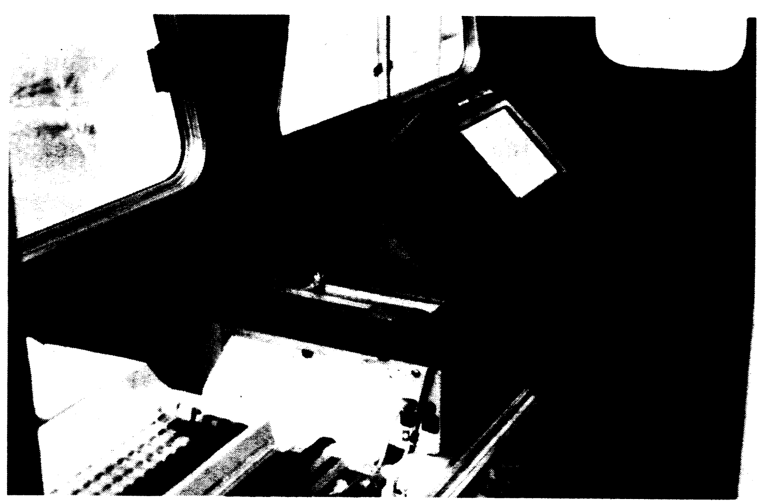


Figure 7. - Photograph of system components housed in work boat.

Figure 8. - Photograph of shore station installation.

Additional control points may have to be established in preparation for the underwater survey depending on survey methods to be employed and difficulties in obtaining continuous line-of-sight visibility from the shore-based instruments to the sounding boat.

E. Above-water Survey

All reservoir sediment ranges, or portions thereof, which have been inundated frequently by the reservoir or by reservoir induced backwater, should be profiled during the hydrographic survey. That portion of the range lines which cannot be profiled during the underwater survey may need to be profiled by standard land survey methods.

Because of the time required to clear range lines and profile the lines by land survey methods, those portions of the lines which have never been inundated usually may be excluded from the full survey. The change occurring along an eroding reservoir bank can often be determined by establishing a station near the top edge of the eroding bank and profiling the line from that point to the edge of water. The unaffected natural ground above the station would not have to be profiled.

The decision whether to survey all or portions of lines which are above water should be made after careful consideration of any changes which may have occurred along the lines, due to the reservoir, which could have altered reservoir storage.

Because of some inadequacy in the original survey, such as having original range lines taken from reservoir topography instead of actual surveyed profiles, the resurvey of the complete range lines may be necessary to acquire a new base survey against which future surveys will be compared.

F. Bathymetric Survey

1. General. - The bathymetric survey consists of depth sounding by manual or electronic sonar equipment and position determination relative to measured depth by one of many positioning systems. The methods selected usually are determined by the physical characteristics of the reservoir, the equipment which is available to the survey crew, and the required accuracy.

The physical setting of reservoirs varies from that of a narrow, steep-walled canyon environment to that of a wide-open valley, shallow water, and mildly sloping bank environment. Some reservoirs may exhibit both extremes, e.g., Lake Mead on the Colorado River and Bighorn Lake on the Bighorn River. How the varied physical characteristics of the reservoir affect this selection will be explained more fully in part 4, of this section, where the various positioning methods are described.

Economics usually determine the availability of equipment. In order to minimize overall costs to the agency and to maximize use of the agency's survey equipment, Reclamation maintains hydrographic equipment at the E&R Center which, together with a trained operator, is made available to other Reclamation offices on request.

Some of the survey methods are inherently more accurate than others in defining the bottom surface of a reservoir. The problems of accuracy in a bathymetric survey, which are quite complex, are covered in more detail in parts 3 and 4 of this section. The methods selected for the bathymetric survey should provide as accurate data as are needed to achieve the survey objective.

2. Depth sounding. - The reservoir depth along range lines usually is determined by a sonic-sounding instrument. Occasionally, in very shallow water conditions or when sounding through ice cover, manually operated sounding lines or sounding poles are practical for detecting change but not for complete surveys.

To achieve accurate measurements of the reservoir depth by sonic sounding, the instrument must be calibrated for the range of depths encountered during the survey period. The calibration is accomplished by bar checks made on a frequency of at least twice a day, once at the beginning of a day's survey and following the noon break. A bar check consists of lowering an acoustic reflector, such as a flat metal plate or I-beam, to a known depth below the transducer and adjusting the instrument to produce an equivalent depth reading. The bar check must be conducted in fairly calm water with minimum wind conditions. Mild to strong wind will shift the sounding vessel so that the calibrating bar will be suspended at an angle from vertical causing the narrow signal beam from the transducer to miss the bar. Figure 9 shows a typical chart produced during a bar check.

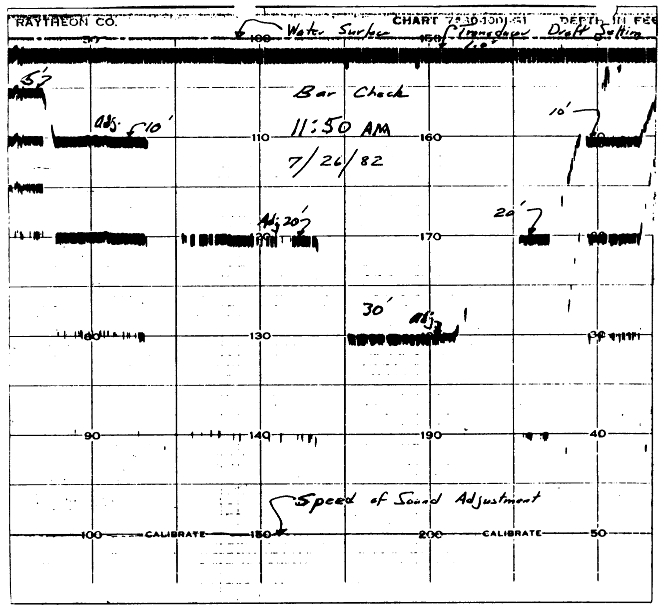


Figure 9. - Bar-check calibration of sounding instrument.

When operating normally, a continuous record of the soundings is traced on a scaled chart. The chart becomes the official record of the depth measurements and should contain range-line identification, date, time of day, changes in chart speed, changes in vertical scale, water surface elevation, and any other information needed to interpret the charts. A typical range sounding chart is shown on figure 10.

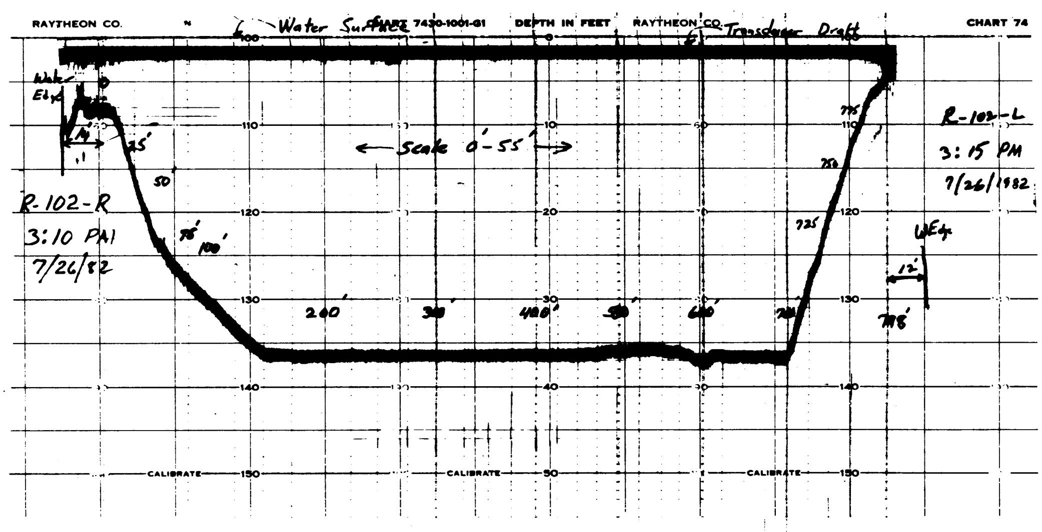


Figure 10. - Sounding chart for range-line survey.

In sounding many Reclamation reservoirs, the water depths are sufficient to require several changes in vertical scale on the sounding chart. For steep underwater banks in some reservoirs, the rapidly changing bottom elevation requires constant attention to depth scale in order to achieve a constant bottom trace. Although the normal practice is to maintain a constant boat speed between 3 and 7 feet per second, some speed reduction while crossing above steep reservoir slopes may help to achieve a continuous bank trace.

3. <u>Errors in depth measurement</u>. - Factors leading to possible errors in depth measurement should be considered in conducting a bathymetric survey and in analyzing the survey charts. For a more detailed description of these factors, see Hart and Downing (1977). Some of the most significant factors are as follows:

a. Signal transit time. - The measured depth is determined by the measure of transit time for a signal to be emitted from a transducer on the boat to reflect off the bottom surface and return to the transducer. With the high quality instruments available today, errors in time measurement are negligible.

b. Acoustic velocity propagation. - The velocity of sound through water varies with temperature and salinity. For most Reclamation storage reservoirs, the variations in salinity can be considered negligible. However, reservoir water temperatures can vary in the summer season by as much as 45 °F between the surface and deep water. The bar checks described above are designed to correct the measurements for variation in temperature and salinity and are essential where any significant variation exists.

c. Transducer location. - The draft or vertical location of the transducer's bottom face with respect to water surface, can be set into most high accuracy sounding instruments. As shown on figure 11, the location of the transducer face with respect to static water surface is different when the sounding boat is in motion. This effect of the boat motion on draft may be corrected in each calibration of the instrument.

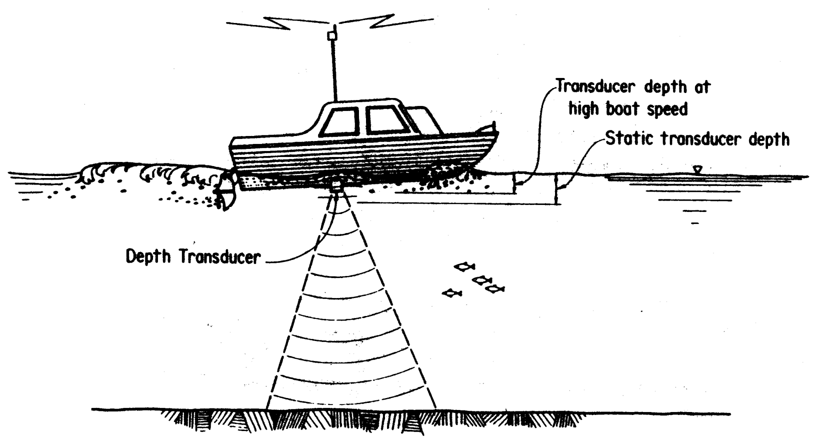


Figure 11. - Motion effect on depth measurement.

d. Wave action. - The vertical and rotational motion of the boat due to wave action, as shown on figure 12, can result in severe fluctuations in the bottom trace. To assure the safety of personnel and equipment when working in relatively small boats, the underwater survey should be temporarily halted when the wind-generated waves exceed 2 feet in height. All wave-produced fluctuations in the bottom trace should be smoothed during data processing to produce acceptable data.

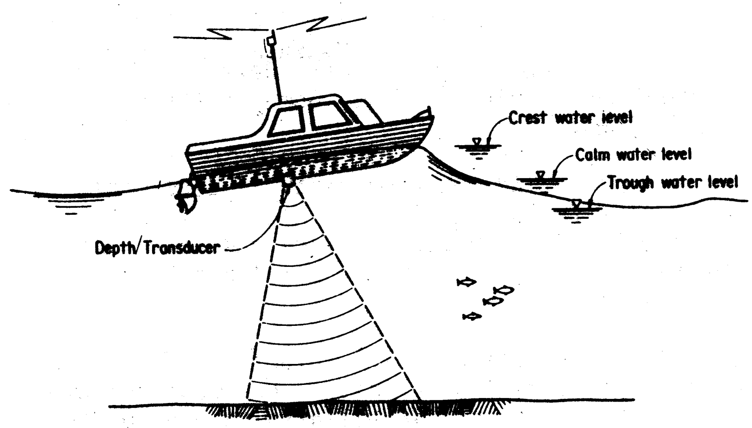


Figure 12. - Wave effect on depth measurement.

e. Bottom conditions. - The reflective surface on the reservoir bottom may vary widely as illustrated on figure 13. Vegetation attached to or suspended above the bottom and isolated boulders or manmade objects produce false depth measurements which should be eliminated from the data. Very low density sediment, suspended as a fluff above more compacted sediments, can result in dual depth readings unless the condition is anticipated and the sensitivity of the sounding instrument is adjusted.

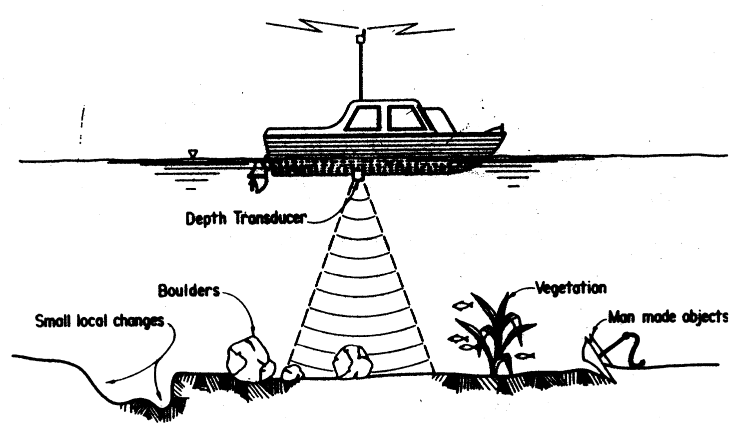


Figure 13. - Bottom condition effect on depth measurement.

f. Other causes. - Errors in depth measurement may occur due to special circumstances not always encountered in reservoir surveys. Reservoir level fluctuations due to inflow and outflow may change the vertical control during the survey period and introduce depth errors unless considered. Backwater effects in narrow canyon areas or in river portions above the main body of the reservoir may produce a water surface slope or change in stage which negates use of reservoir water surface for vertical control. Constant wind blowing from one side of a reservoir to another may cause some reservoir level changes on each side of the reservoir which should be considered when operating in high wind conditions.

4. Positioning. - A variety of methods are used to determine horizontal position of the sounding boat as it moves across a range. The method chosen should be determined by the accuracy required, existing reservoir conditions, and available equipment. The factors affecting positioning accuracy are discussed in part 5 of this section. Reservoir conditions may vary considerably from one part of a reservoir to another. Large open-water areas may be surveyed by one of several methods, whereas the physical conditions in a shallow, heavily vegetated delta area or a narrow, steep-walled canyon area may dictate different methods. Due to the cost of equipment, the survey may have to be accomplished by tailoring the methods to fit the equipment which can be obtained within cost constraints.

The four principal positioning methods employed in Reclamation resurveys are described in detail below. Descriptions of other acceptable methods are given in chapter 3 of the U.S. Government Handbook (1978).

a. Transit intersection or "cutting-in" method. - This method requires that plane table or transit control points be established which can be used for "cutting-in" the survey boat to obtain horizontal position along the range while sounding. By making use of preestablished range monuments and their coordinates as much as possible, the time and cost for establishing required points can be reduced substantially. The method is shown graphically on figure 14. The object is to determine the position of the sounding vessel, at X_i, as it moves continuously across range line AB. Knowing the baseline distance AC and the angle BAC, distance from origin to the boat can be determined by turning the angle ACX_i and solving for the leg of the triangle, AX_i. To begin the range line survey, a transit or theodolite is set up at C with an instrument man and a notetaker to measure and record the angles. Another telescopic instrument is set up at A by a surveyor who sights down the range line and maintains radio contact with the boat operator to keep the survey boat on-line. As the survey commences, the boat is pulled close to shore and on-line. Angles are then turned from the base line to water's edge and to a flag mounted on the boat near the transducer. The sounding instrument is turned on, and a mark is placed on the sonar chart to mark the starting position and depth. The transit at C is unlocked and turned ahead by some predetermined interval and locked in place to wait the arrival of the boat flag at the instrument crosshairs. When the boat flag reaches that position the instrument man at C tells the hydrographer on the boat by radio to mark

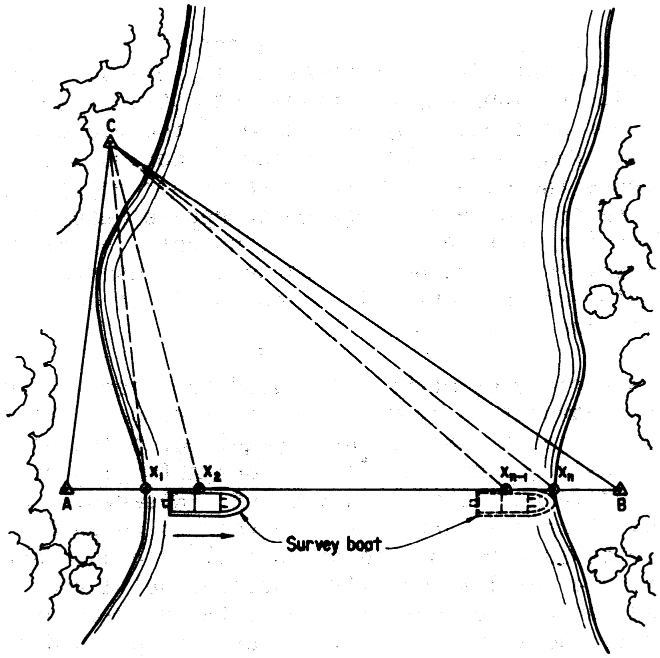


Figure 14. - Positioning by transit intersection.

the chart. The angle is then read at C and recorded; the instrument is again unlocked and moved ahead by another interval. This process is continued until the boat touches the opposite bank. At that point, final angles to the boat and to the water's edge are measured and recorded.

By selecting the location of C to maintain adequate geometry for triangulation and by high precision angle measurements, this method usually gives satisfactory results. The major disadvantages of the method are the possibility of error and the office time required to convert all of the data.

b. Tethered piano-wire method. - This method employs a mechanical device designed to release from a reel mounted on the sounding boat a fine piano wire tethered to one bank and capable of measuring distance from a known point onshore to the sounding boat (fig. 15). The wire passes around the rim of a calibrated measuring wheel, rotating the wheel as the boat moves out, thus activating a mechanical counter which indicates the distance traveled. The measuring wheel and motor-driven winch are mounted near the rear of the sounding boat. To begin a line survey, the boat is positioned on-line at the closest practical point to shore, the counter is set to zero, and the loose end of the wire is pulled out and fastened to a pin driven on-line near the shore. The distance to the pin and the water's edge is recorded on the chart. The sonic instrument is turned on, and the boat moves out on-line toward the opposite shore. One person is assigned to operate the machine, read the mechanical counter, and announce the distance at predetermined distance intervals. Another person, operating the

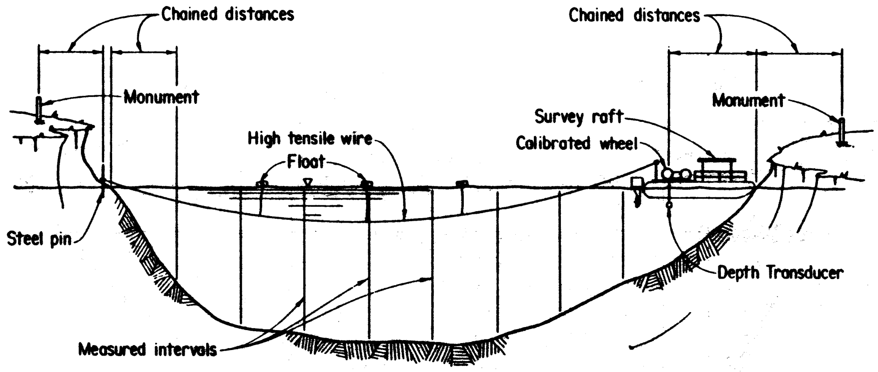


Figure 15. - Distance measurement by tethered wire.

sonic instrument, flicks a switch on the recorder placing a line on the chart enabling a correlation of depth with distance along the range. The distance also is marked on the chart which later is converted to range stationing. Another person attaches styrofoam floats to the wire and drops them overboard at 100- to 300-foot intervals to reduce sag by holding the wire near the surface. When the boat touches the opposite shore, a final line is placed on the chart and the sonic sounder is turned off. The final reading on the mechanical counter is written on the chart. Using chain or tape, the distance from water's edge and from the station near the water's edge to the centerline of the measuring wheel is determined and placed on the chart. By radio communication, the survey crew member on the opposite shore is told to release the wire from the pin. Using the motor-driven winch, the piano wire and buoys are retrieved after which the sounding boat may proceed to another range line.

Positioning by this method usually is more accurate than the "cutting-in" method . The major disadvantages are the time required to survey the line and retrieve the wire and the frequent delays caused by the wire breaking as it is played out and retrieved. Under the best conditions, only 4 to 6 miles of range length can be surveyed per day.

c. Calibrated cable. - A third mechanical method for position fixing while sounding is by means of a calibrated cable or tag line stretched taut across the range and secured on either side (fig. 16). The line is suspended above the water to permit the sounding boat to move along underneath. The necessity for suspending the cable above water limits range length to less than 1,000 feet. The boat is positioned under the cable near shore so that one marking bead is above the transducer. The station for this mark and for water's edge is determined from an established surveyed point near water's edge. The sonic instrument is then turned on, and a line is placed on the chart corresponding to the overhead cable mark. As the boat proceeds across the range, one person calls out each marked distance, and by a switch on the recorder, a corresponding line is placed on the sonar chart. On touching the opposite shore, a final line is placed on the chart and the sonic sounder is turned off. The distances from the transducer to water's edge and to the established station near water's edge are then measured. The cable is then released and reeled in, using the boat to keep it out of the water as much as possible.

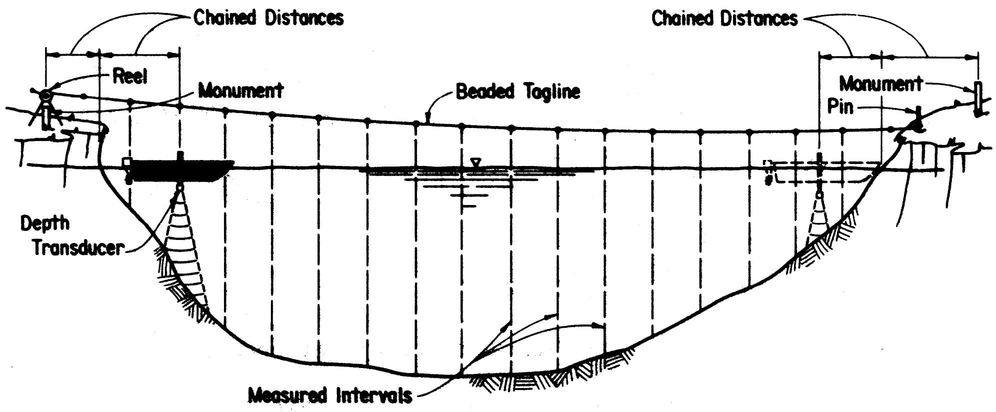


Figure 16. - Distance measurement by calibrated cable.

This method has been used successfully for the survey of ranges on flowing streams and on reservoir ranges having sheer walls at both ends of the range. It is also advantageous for short ranges of 1,000 feet or less where dense vegetation along the shoreline precludes the "cutting-in" method or electronic positioning.

d. Automated positioning. - The DME (distance measuring equipment) used by Reclamation in most reservoir resurveys is part of an automated survey system involving both sonic sounding and line-of-sight microwave signaling to determine the ground profile along an established range line. The system uses a range-range method of tracking as shown schematically on figure 17. The shore stations are set up at fixed

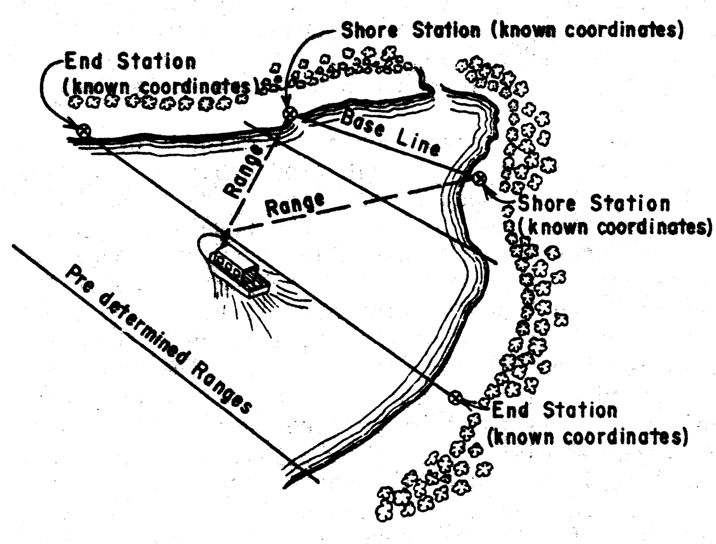


Figure 17. - Range-range tracking of survey - boat on predetermined lines.

locations where elevation and grid coordinates are known. In addition, the water surface elevation, the height of the mobile RT (receiver-transmitter) on the boat, and the range end grid coordinates must be known. The elevations of the shore station and mobile RT are used by the system to correct measured range distance for vertical angle.

Care must be exercised in selecting shore stations to ensure that good geometry is maintained. The accuracy of positioning depends in part upon the varying angle measured at the boat and formed by the two lines extending from the mobile unit to the shore stations. The recommended variation of that angle is from 30 to 150° with 90° being the angle of greatest accuracy. Due to this angle limitation, the mobile unit must not approach or cross the baseline during a range line run; the baseline being defined as the line between the two shore stations. The region of acceptable geometry is shown as the shaded area on figure 18.

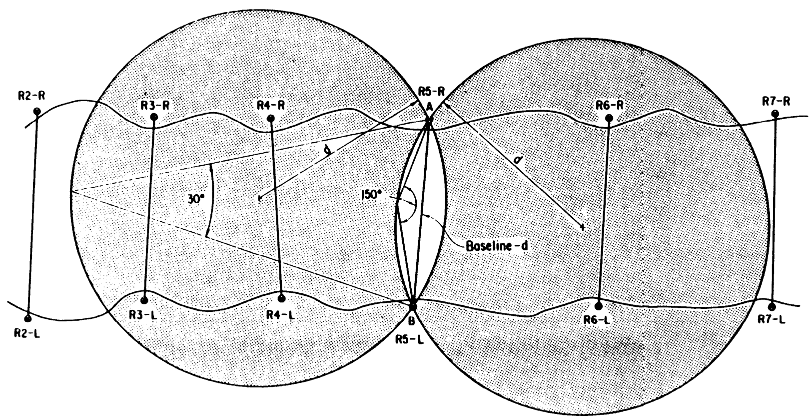


Figure 18. - Survey area for range-range method.

The vertical and horizontal beam angle transmitted from the shore units also must be considered in selecting the shore station locations. As the mobile unit traverses a range line, the unit always must be clearly within an 80° horizontal signal beam eminating from the shore stations. If the 80° beam width occasionally creates a problem at a shore station, it is possible to rotate the shore unit on its mounting to keep the mobile unit within the required angle. In addition, the vertical angle measured from the shore station between a horizontal line and the mobile unit should not exceed 7.5°. The shore station should be located at a point to ensure that a distance greater than 300 feet exists at all times between the shore station and mobile unit as a range is being surveyed. In a critical situation where it is difficult to find a good shore station location, one of the range end monuments for the line being surveyed may be used as a shore station as long as the distance exceeds the minimum, and the other criteria are met. A method for relating distance from the shore station to difference in elevation between mobile and shore RT units is shown on figure 19.

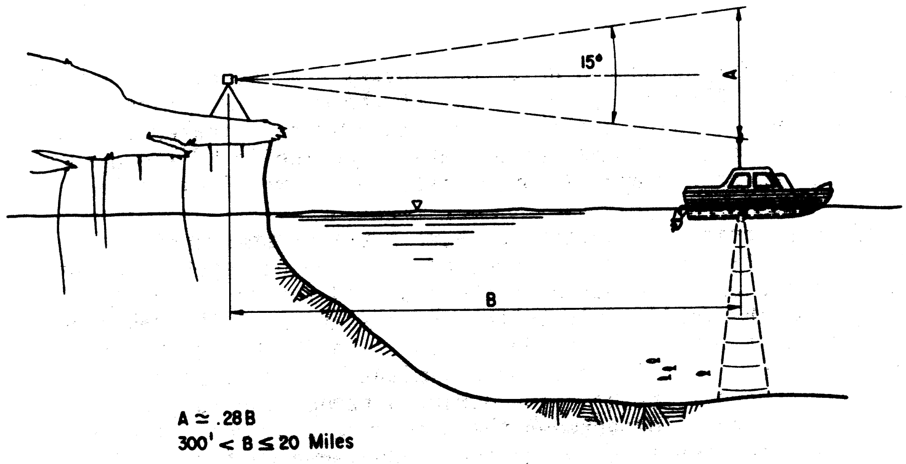


Figure 19. - Shore station distance and elevation limits.

Because of the 20-mile maximum-range capability of the system, it is preferable to find several shore station sites of known location on high points within clear view of the reservoir to permit many lines to be run with as little movement of the shore stations as possible. In planning a survey, all existing known points in the area should be examined critically for selecting shore station sites before any additional points are surveyed.

After placing the shore stations and activating the system, the operation of the system is conducted through a series of modes dictated by a survey package incorporated in the onboard data processor. Control of the operation is managed by one person at the control terminal and a second person operating the depth recorder. Data entry is made either at the terminal or from data prestored on magnetic tape and read back into the memory of the data processor. The memory unit in the processor can store range-line control data for 46 range lines and shore-station data for 16 site locations.

Control data entered in memory for range lines and shore stations must be of a common grid coordinate system and have a common reference datum plane. If erroneous grid coordinates are assigned to a shore station or range end, the error can only be detected by careful scrutiny of input data or by some physical feature such as a monument or flagging placed on shore near the water's edge to indicate correct line.

The system is designed to operate in the following manner. The omnidirectional, mobile RT unit on the boat interrogates the shore stations in turn and measures the elapsed time for the round-trip interrogation. The elapsed time from each measurement is an effective measure of distance since velocity of electromagnetic energy through air is known. Interrogations of the shore stations are coded so that responses can be identified as to origin and displayed in digital form according to the selected channels, Hart and Downing (1977). Range distances are transmitted automatically to the data processor and by triangulation the distance along the range line and the grid coordinates for location are computed. The computed coordinate position, time of day, maximum, average, and minimum depths, and any manual event marks are then displayed on the control terminal printout. The operator may choose an alternative printout of either range stationing and line offset or the range distance to each shore station. When the tape recorder is in the "write" mode, horizontal and coordinate depth data are stored on magnetic tape for later processing. The positioning data are fed automatically to a track plotter which tracks the boat position relative to true line on scaled grid paper. The chainage and offset distance also are displayed automatically by a track indicator mounted in front of the boat operator to assist him in maintaining line.

Following the survey of one or more range lines, the data tape can be rewound to the beginning of the data files and read back into the processor's memory, where it may be used to plot either profiles or digital depth data against track lines on the track plotter. Those plots give the operator a check on quality of the survey work and are a first step in the analysis of the data.

In addition to surveying along established range lines the offset capability of the system can be used to survey other lines offset at specified distances from a control line. With only one control line and with two shore stations in place, a large area of particular concern can be surveyed as shown on figure 20 and the data used to plot underwater charts of the area. A contour map may be produced manually by drawing contour lines through the plotted depth data on the plot.

5. <u>Errors in positioning</u>. - Factors leading to errors in positioning should always be considered in conducting the survey and analyzing the results. Some of these factors will exist regardless of the method of underwater survey employed while others relate to specific methods. Some of the more significant factors are:

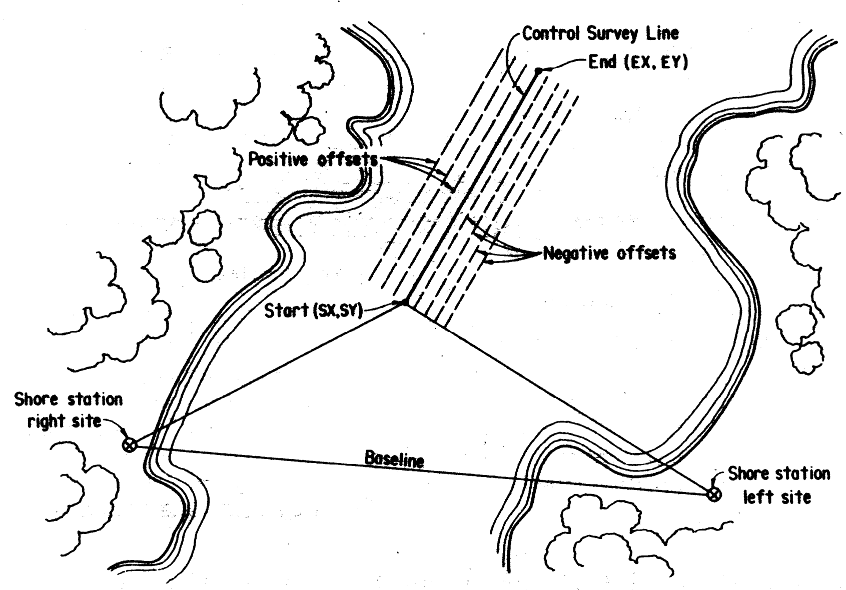


Figure 20. - Typical layout for offset line survey.

a. Speed of boat. - The measured position of the boat as it relates to the measured depth can be in error due in part to the speed of the boat as it traverses a line. With mechanical positioning methods, the necessity for voice communications prior to marking the chart results in some position error due to human reaction time. The error increases as the speed of the boat increases. The pulse-type, microwave DME employed by Reclamation with its automated system has a measurement cycle time of about 0.5 microseconds; thus, the related boat speed affect on accuracy is quite small. The sample interval chosen during operation of the system can be either a time period or a constant distance traveled. When distance is used, the effect of boat speed on accuracy is minimal. When a time interval is used, the distance traveled in the interval varies with speed. Because the system only records the maximum, minimum, and average depth measured during the interval a longer distance traveled may increase the error of position relative to depth.

b. Effect of depth transducer beam width. - A horizontal position error can be introduced by the depth measuring system under bottom conditions similar to those shown on figure 21. As the boat passes over the steep side slopes on a range line, acoustic reflections are received from the high, intermediate, and low points within the transducer beam. The depth measurement recorded actually may be skewed relative to true position. These errors can be significant in deep, steep-walled reservoirs, the error may be critical if the survey is intended to accurately define side slopes or detect bank erosion or sloughing. Selection of a narrow beam transducer helps reduce this offset error. Usually in steep-bank reservoirs, the sediment deposits from the bottom of the range upward forming a fairly level surface line in the transverse direction and little if any sediment is deposited on the side slopes.

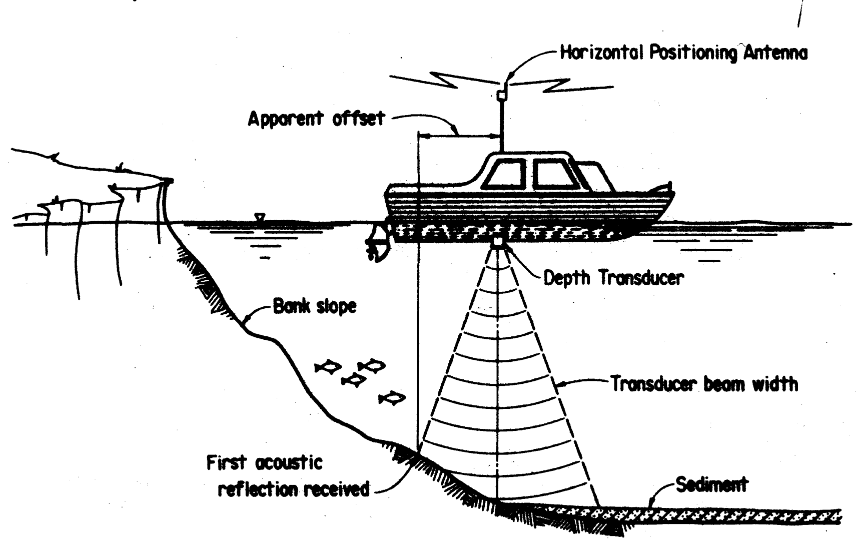


Figure 21. - Position error due to side slope effect.

c. Geometry. - The geometry of the system may cause some error in measured position in either the triangulation cutting in methods or in the automatic range-range method of survey. For the range-range system, the areas of acceptable geometry are shown shaded in figure 18 for a particular location of the shore stations. The greatest position accuracy for a given range occurs along an arc in the area where the range vectors intersect at right angles. The worst case conditions occur within the area where the range vectors intersect at angles approaching 30 and 150°. For the latter angles the potential error is approximately four times the basic range accuracy. Assuming good range calibration procedures the manufacturer claims a basic position accuracy of plus or minus 2 meters. When using the cutting in method of survey the angle AXC (fig. 14) should be held to some value between 30° and 150°, and the angle should be read to the nearest minute on a 20-second transit to avoid excessive error.

d. Alinement. - In all of the positioning methods described above, some positioning error usually is introduced due to difficulties in maintaining a control line while crossing a reservoir. The error can be reduced by allowing the boat operator time to become familiar with operation of the boat and by providing him careful steering directions, either from shore, in the case of the mechanical survey method, or by a track indicator, in the case of the automated positioning system. Should the boat move offline an unacceptable distance, survey of the line should be repeated. Usually, the underwater profile data are reduced to a straight line in the analysis and most of the alinement induced error is retained.

f. Other factors. - Some other factors which may introduce positioning error are: (1) the pitch, roll, and yaw of the boat causing a dislocation of the DME antenna relative to the depth transducer; (2) the horizontal mounting offset of the DME antenna relative to the depth transducer; (3) inaccuracies in shore station positions and range end positions; and (4) atmospheric conditions which may affect wave velocity propagation.

For a more detailed discussion of positioning accuracy employing automated positioning equipment see Hart and Downing (1977).

G. Sediment Sampling

Another feature of many reservoir surveys is the acquisition of samples from the deposited sediment to determine its physical characteristics. Samples obtained at selected locations are used to determine size gradation and density variations within the reservoir. The information on density and particle size distribution also is used to convert sediment loads in mass or tons to storage volume and to determine proper distribution relationships. The data also becomes part of a body of information used to develop empirical relationships and to establish criteria for predicting sediment deposition and distribution characteristics.

The variety of equipment used for collecting sediment samples in reservoirs is best described in the American Society of Civil Engineers Manual

(1975). The equipment chosen for a sampling program should be related to particular problem area needs. There may be a need for data from the reservoir delta for predicting delta growth, or near shoreline for predicting beach or bank erosion, or the deep-water sediment deposits near the dam for assessing sediment effects on outlet structures. The equipment needed to sample delta deposits or areas of beach erosion may involve sampling similar to that used for river conditions employing bed material samplers such as the U.S. BM-54, U.S. BMH 60, or a BMH-80 sampler. These particular samplers are used to obtain surface samples of the stream bed or reservoir banks which are representative of the materials transported along the surface or being resuspended. For the deep-water sediment deposits, the gravity core sampler, as shown on figure 22, will obtain samples which provide a good measurement of the particle size in those deposits. Samples obtained with the gravity sampler also can be used for determining density or unit weight of the sediment deposits. However, because of compaction during penetration, the accuracy of the density measurements may be questionable. On large reservoirs a piston core sampler operating from a barge (fig. 23) can provide samples of the sediment deposits for both density and particle-size distribution.

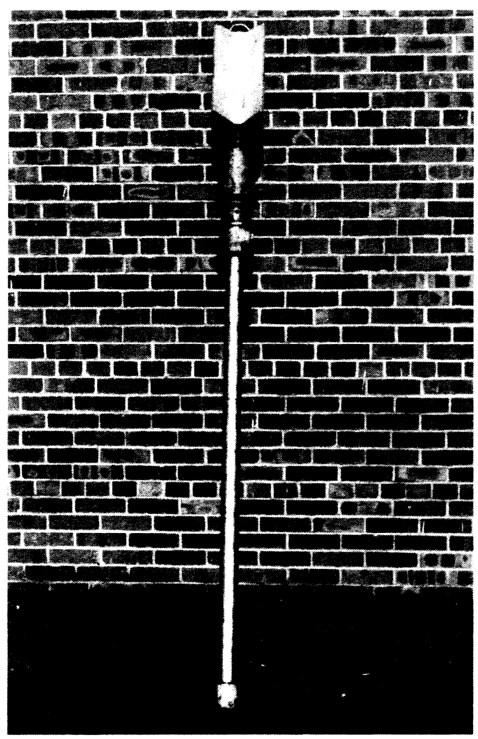


Figure 22. - Gravity core sampler.

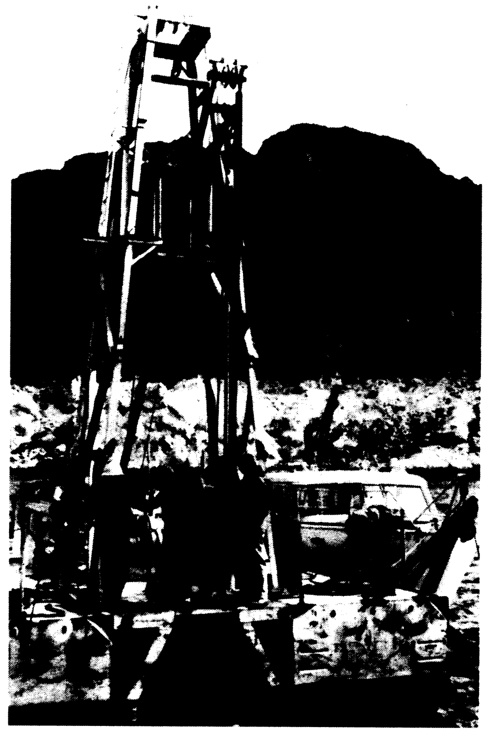


Figure 23. - Piston core sampler in 1964 Lake Mead survey.

For density measurements, another specialized piece of equipment is the radioactive sediment probe which provides the best "in situ" measurement. However, operation costs increase when the probe is not being used on a regular basis because new calibrations are required due to reduced strength of the radioactive source. This problem, along with that of providing radiologic safety during use of the probe in reservoir waters, has limited the use of this method.

The collecting of samples by the gravity core sampler is accomplished by a retrieval system such as that shown mounted on Reclamation's survey boat on figure 24. After the boat reaches a sampling position the sampler is lowered to a predetermined depth and then allowed to fall freely into the sediment deposits. The depth to the sediment surface at the point of sampling is recorded and the sampler is raised to deck level. After removing the cutting shoe, the plastic inner liner containing the sample is capped at the bottom end, removed from the sampler, cut off down to the surface of the sample, and capped at the top end. Both ends of the sample tube are sealed with waterproof tape and information necessary to identify the sample is written on the tube.

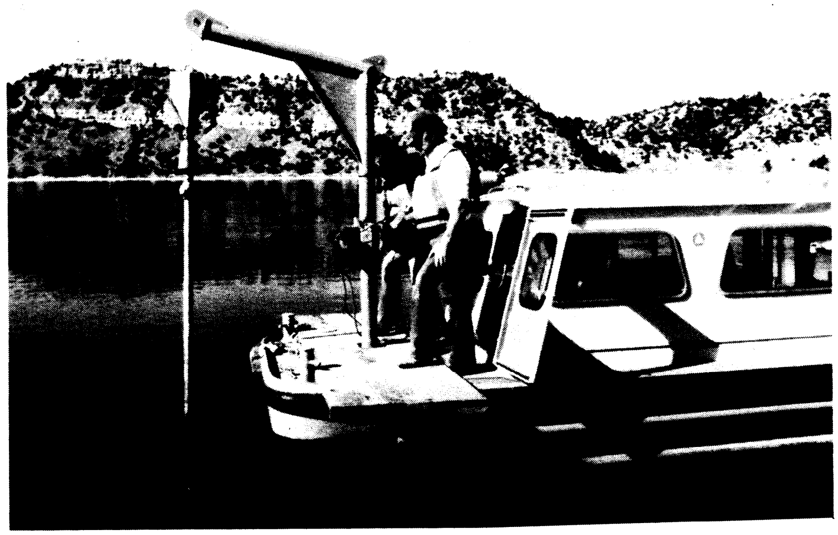


Figure 24. - Gravity core sampler and retrieval system.

In conducting a data collection program involving sampling of reservoir deposits, a sufficient number of samples should be collected to be either representative of the whole reservoir deposits or representative of the area under investigation. The most common pattern of particle size distribution is exemplified by figure 25. Coarser sediments are encountered in the delta because those sediments with greater fall velocities settle out first. The manner in which the reservoir is operated influences the location and shape of that delta. The frequent or severe drawdown of a reservoir causes the delta to move progressively farther into the reservoir and produce a broader mixing of both coarse and fine sediments in the reservoir. A knowledge of these variations is important in the collection of representative samples.

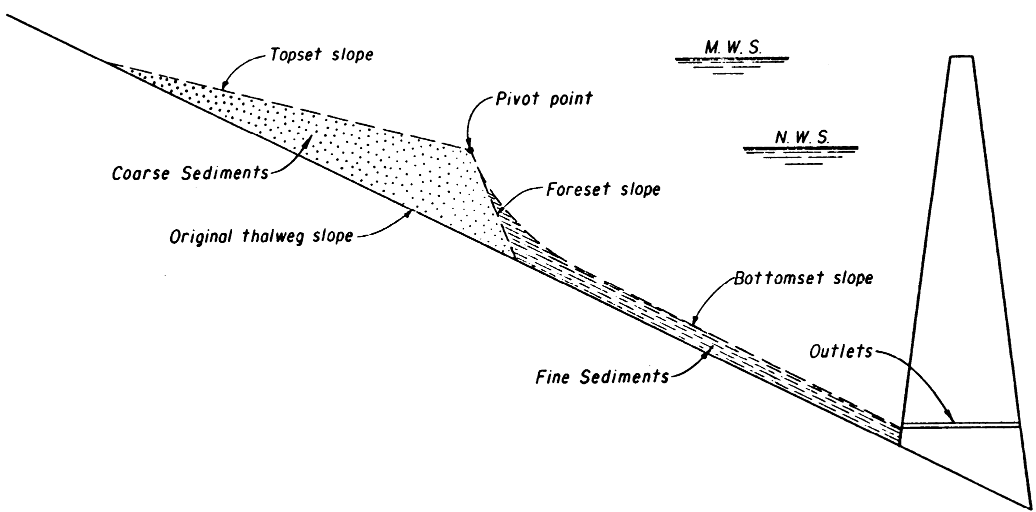


Figure 25. - Profile of sediment deposits in a typical reservoir.

H. Reservoir Volume Computations

After completion of the field surveys and sampling program, the accumulated data must be assembled and analyzed for the purpose of determining a new elevation versus storage volume relationship for the reservoir. An important product of this analysis is usually a set of updated area-capacity tables for reservoir operations. By comparing the new storage volume with that from a previous survey the volume of accumulated sediment can be determined.

The computation procedures for determining storage volumes depend upon the type of survey conducted, whether by the contour method or range-line method. Several techniques in common usage are described in the American Society of Civil Engineering Manual (1975), or Eakin (1939) .

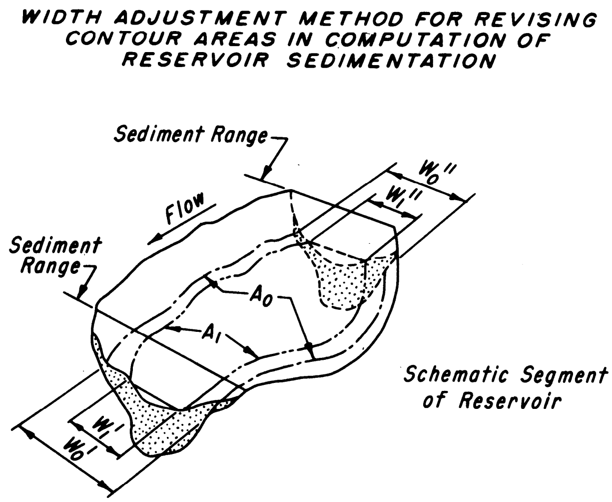
1. Reservoir capacity. - Most reservoir capacity computations are developed from topographic contour maps utilizing an average contour-area method. The method entails measuring the surface area enclosed within each contour by planimeter or electronic digital equipment. The average area between successive contours is then multiplied by the contour interval to compute the incremental volume. An accumulative sum of incremental volumes from the reservoir bottom to maximum water surface defines the elevation-capacity relationship.

On some small reservoirs with closely spaced range lines or larger reservoirs where the range lines are approximately 200 feet apart or less, the Range Formula by Eakin (1939) which is an average vertical end area method may be adopted for computing storage volumes. The disadvantage of this method is that it produces no information on reservoir elevation versus surface areas.

In some of the earlier Reclamation resurveys new contour maps were drawn from range-line survey data. All of the contours for a new map in an area between range lines were estimated by using the original contour map as a guide or control and estimating the new contour location based on the changes which occurred at each range line. This method was abandoned for the constant factor method by Burrell (1951) which was further modified to the width adjustment method described by Pemberton (1980). The width adjustment method is illustrated on figure 26. In this method the new contour area, A_1, between any two ranges is computed by applying an adjustment factor to the original contour area, A_0, between the two ranges. This adjustment factor is defined as the ratio of the new average width to the original average width for both upstream and downstream ranges at the specified contour. The revised segmented surface areas for each contour are then summed for the whole reservoir.

A guide for computing the new segmental contour areas is given in appendix II. The computation is currently accomplished by hand except for the original and resurvey range widths. The width of the section at each contour is computed using the Reclamation program PSEUDO. Instructions for preparing range coordinate data input sheets for PSEUDO are given in appendix III.

A comparison of the simultaneous plots of original range profiles (fig. 27) against the resurveyed range profiles indicates the lateral distribution



Initial Survey	New Survey
A_o = Contour Area	A_1 = Contour Area (Computed)
W_o' = Downstream Width	W_1' = Downstream Width
W_o'' = Upstream Width	W_1'' = Upstream Width

$$A_1 = A_o\left(\frac{\frac{W_1'+W_1''}{2}}{\frac{W_o'+W_o''}{2}}\right)$$

Figure 26. - Width adjustment method for revising contour areas.

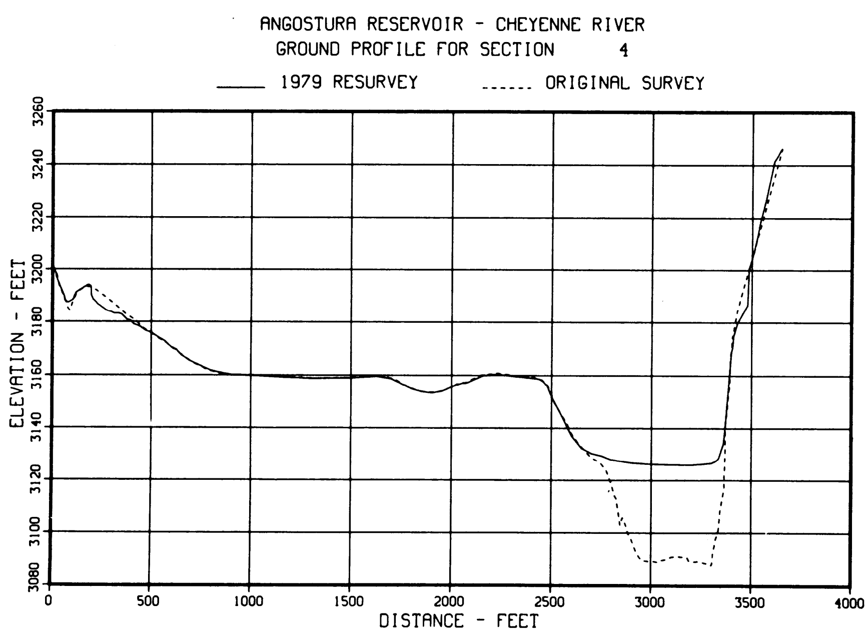


Figure 27. - Example plot of original versus new range profile.

of the sediment at the measured points. Where these plots indicate changes have occurred on the side slopes of the reservoir, a judgment decision may be required to determine whether the change is due to survey inaccuracies or actual deposition or erosion.

A Reclamation computer program is being developed to compute the revised contour areas by means of the width adjustment method. The program addresses the problem in two steps. In step one, the original and new range data files are accessed and used to compute the segmental adjustment factors and revised segmental contour areas. After making judgmental corrections to step one adjustment factors, the revised output from step one becomes input to step two for computing the final segmental and total contour areas based on the new survey.

The elevation versus surface area table becomes the basic input data in an electronic computer computation of revised area and capacity tables. The computer program generally used by Reclamation for this purpose is called ACAP, a program developed by Reclamation providing two alternative computation procedures.

The segmented least square-fit procedure is used most often. In this procedure, area points at specified elevation increments between the basic data contours are derived by linear interpolation. The respective capacities and capacity equations are then obtained by integration of the area equations. The capacity equation over the first interval is tested over the second interval to see whether it fits the range of the second equation within an allowable epsilon or error term. If the fit is within the limits established, the first equation's range is then extended on to the third interval, etc., one interval at a time until it reaches an interval [(n to n + 1), where n is a data point in the data set)] where the equation does not fit the data within the allowable epsilon term. The first equation is then called good for the range 1 to n. The original equation for the range n to n + 1 is then tested over the range n to n + 2 and the whole process is repeated. The resulting capacity curve is a series of splines representing a number of equations, each equation being applicable over a limited range. The final area equations then are obtained by differentiating the capacity equations. Depending on the epsilon term, the number of curves necessary to fit a reservoir is from 1 to N - 1, where N is the total number of data points within the data set. Capacity equations are of the form $y = A_1 + A_2X + A_3X^2$ where y is the capacity and X, the elevation above an elevation base. An example set of equations based on the 1967 resurvey of Altus Reservoir are shown in table 1.

The cubic spline fitting procedure, establishes a new third degree function between each pair of input points. These functions are continuous in the first and second derivatives, thus providing a potentially smoother transition from function to function than the least squares fit would give. The disadvantages of the cubic spline procedure is that the resulting capacity values at low reservoir elevations sometimes oscillate in an insupportable manner. Although the cubic spline procedure is available within the program ACAP, it is not recommended for use in preparing operational area and capacity tables.

Table 1. - Capacity equations from program ACAP

ALTUS RESERVOIR W.C. AUSTIN PROJECT

AREA AND TOTAL CAPACITY TABLES - BASED ON REC-ERC-71-21

EQUATION NUMBER	ELEVATION BASE	CAPACITY BASE	COEFFICIENT A1(INTERCEPT)	COEFFICIENT A2(1ST TERM)	COEFFICIENT A3(2ND TERM)
1	1509.00	0	.0000	-.0000	29.5000
2	1510.00	29	29.5000	59.0000	12.3000
3	1515.00	631	632.0000	182.0000	92.1000
4	1520.00	3844	3844.5000	1103.0000	54.2000
5	1525.00	10714	10714.5000	1645.0000	52.0000
6	1530.00	20239	20239.5000	2165.0000	45.1000
7	1535.00	32191	32192.3032	2615.6894	60.3500
8	1545.00	64384	64384.5000	3823.0000	80.3000
9	1550.00	85506	85506.6388	4626.2943	90.7606
10	1565.00	175321	175322.0000	7349.0000	132.9000

ACTIVE CAPACITY TABLES - BASED ON REC-ERC-71-21

EQUATION NUMBER	ELEVATION BASE	CAPACITY BASE	COEFFICIENT A1(INTERCEPT)	COEFFICIENT A2(1ST TERM)	COEFFICIENT A3(2ND TERM)
1	1517.50	0	-.0000	642.5000	92.1000
2	1520.00	2181	2181.8750	1103.0000	54.2000
3	1525.00	9051	9051.8750	1645.0000	52.0000
4	1530.00	18576	18576.8750	2165.0000	45.1000
5	1535.00	30529	30529.6782	2615.6894	60.3500
6	1545.00	62721	62721.8750	3823.0000	80.3000
7	1550.00	83844	83844.0138	4626.2943	90.7606
8	1565.00	173659	173659.3750	7349.0000	132.9000

Table 2. - Example reservoir area table

ALTUS RESERVOIR W.C. AUSTIN PROJECT

AREA TABLES IN ACRES

ELEVATION INCREMENT IS ONE FOOT

COMPUTED
04/27/81
09.33.41.

ELEV. FEET	0	1	2	3	4	5	6	7	8	9
1500										0
1510	59	84	108	133	157	182	366	550	735	919
1520	1103	1211	1320	1428	1537	1645	1749	1853	1957	2061
1530	2165	2255	2345	2436	2526	2616	2736	2857	2978	3098
1540	3219	3340	3461	3581	3702	3823	3984	4144	4305	4465
1550	4626	4808	4989	5171	5352	5534	5715	5897	6078	6260
1560	6442	6623	6805	6986	7168	7349	7615	7881	8146	8412
1570	8678									

Table 3. - Example reservoir capacity table

ALTUS RESERVOIR W.C. AUSTIN PROJECT

TOTAL CAPACITY TABLES IN ACRE FEET

ELEVATION INCREMENT IS ONE FOOT

COMPUTED
04/27/81
09.33.41.

ELEV. FEET	0	1	2	3	4	5	6	7	8	9
1500										0
1510	29	101	197	317	462	632	906	1364	2007	2834
1520	3844	5002	6267	7641	9124	10714	12411	14212	16117	18126
1530	20239	22450	24750	27140	29621	32192	34868	37665	40583	43621
1540	46779	50059	53459	56980	60622	64384	68288	72352	76576	80961
1550	85507	90224	95122	100202	105464	110907	116532	122338	128326	134495
1560	140846	147378	154092	160987	168064	175322	182804	190552	198565	206844
1570	215389									

The final result of the computer program is a set of area and capacity tables for use by project personnel in allocating storage and operating the reservoir. (See table 2 and 3.) The tables can be produced at 0.01-, 0.1-, and 1.0-foot increments as may be required. The area and capacity data should also be plotted as illustrated on figure 28 to compare the revised data with the original data.

2. Sediment accumulation. - The total volume of sediment deposited in the reservoir generally may be determined as the difference between the original reservoir capacity and the capacity computed from the resurvey. Both capacity computations should be made by the same method. In reservoirs where significant compaction of sediment occurs between subsequent surveys the difference in reservoir storage would not be truly representative of sediment deposition in the intervening time periods, see Heineman and Rausch, (1971). For those reservoirs the rate of sediment accumulation should be computed only for the total storage period based on the difference in capacity between the original capacity and the present capacity.

Some reservoirs will be subject to significant bank erosion or bank collapsing caused by wave action or severe reservoir drawdown. In analyzing the survey data, the increase in contour surface areas at the higher reservoir elevations in areas where bank line changes have taken place will offset some of the loss of surface area in the delta areas. In cases where the range method is used for monitoring sediment, the increases in surface area of higher elevations will usually not be totally compensated for by a decrease in surface areas at lower elevations. The difference may be due either to compaction of the sediment, movement of some of the sediment downstream of the surveyed range line, or transport of the fine sediment through the dam. If sediment inflow and outflow records are obtained during the period between surveys, it may be possible to roughly differentiate between the sediment accumulation due to inflow and that due to bank changes. If the bank changes are very localized, not continuous through a segment of the reservoir, and the volume of material involved is relatively small, the bank changes may be voided in the analyses. Otherwise, the change in contour surface areas due to bank change should be permitted. The sediment yield rate developed for the drainage basin above a reservoir where significant bank changes are occuring will usually include the bank materials and should be thus explained.

The trap efficiency of the reservoir may be determined when sediment inflow and outflow records are available for the period between surveys. These data usually are not available on Reclamation reservoirs. When the records are available, the trap efficiency for the period between surveys should be computed and compared with Reclamation predictive methods described by Strand and Pemberton (1982).

The distribution of sediment throughout the reservoir can be described in several ways. A plot of percent sediment deposits versus percent reservoir depth is useful in comparing the deposition pattern with other reservoirs and checking on the reservoir predicted pattern. An example is shown on figure 29 for Lake Mead, Harry Strunk Lake, Guernsey, and John Martin Reservoirs. This relationship has been used to derive design curves which are used in planning studies for predicting sediment distribution.

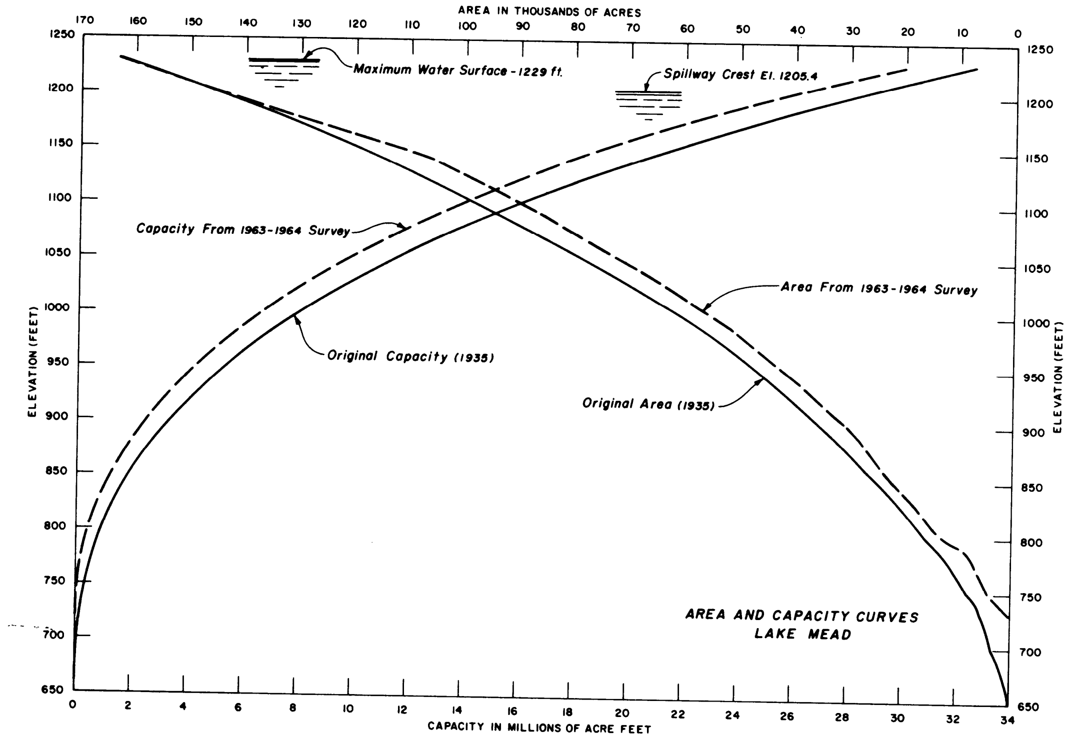


Figure 28. - Example area and capacity curves.

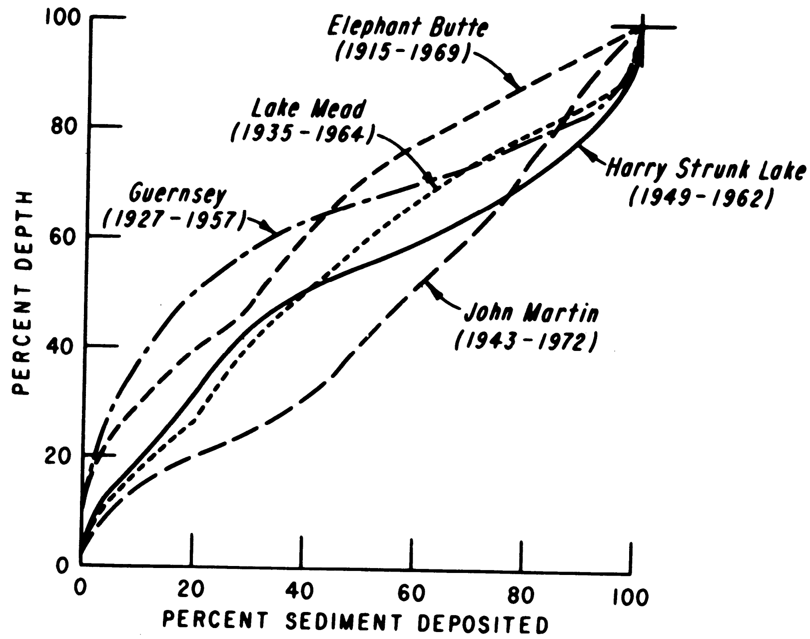


Figure 29. - Sediment distribution from reservoir surveys.

Another useful and more common plot is the sediment deposition profile extending the full length of the reservoir. Figure 30 shows the profile plot based on the original 1948 resurvey, and the 1964 resurvey of Lake Mead. The deposition profile is useful in displaying delta growth and depth of sediment near the dam.

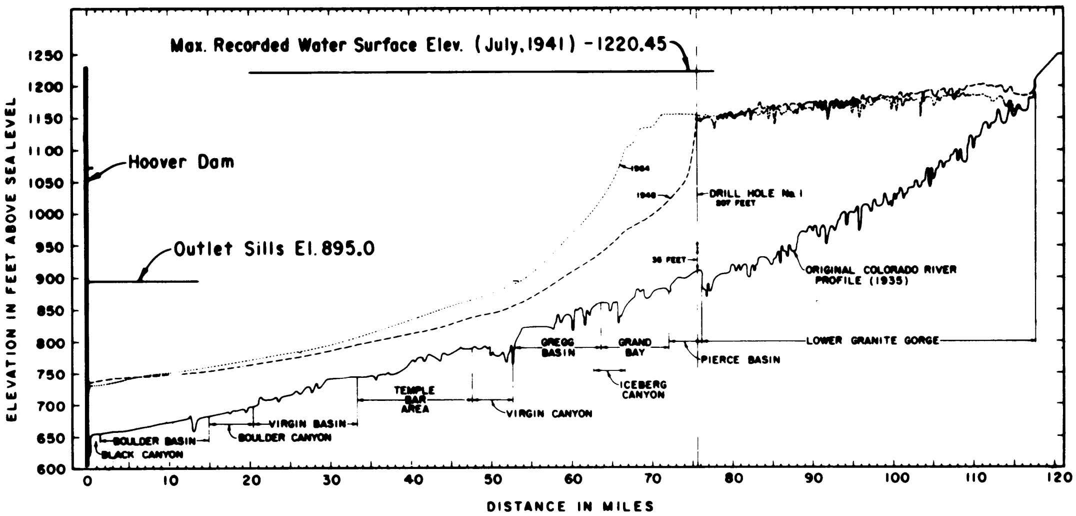


Figure 30. - Colorado River profiles through Lake Mead.

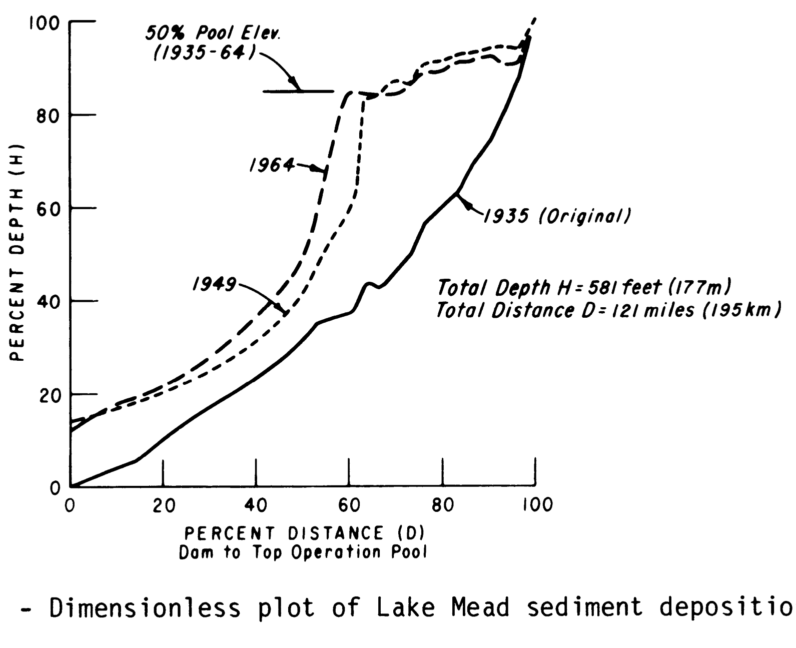


Figure 31. - Dimensionless plot of Lake Mead sediment deposition profile.

The longitudinal profile may also be displayed in a dimensionless plot of percent distance from the dam versus percent reservoir depth as is shown on figure 31 for Lake Mead. This plot permits the comparison of reservoir deposition profiles without scale interference.

If a sampling program is conducted as part of the resurvey, an analysis of the particle size and density distribution also should be made. A weighted overall size gradation and density for the deposited sediments may be obtained by use of a weighting technique which utilizes segmented sediment volumes and attaches a weight to the measured sample gradation and density based on that portion of the total volume of sediment contained in the segment where the sample was taken. Because the density is based on samples from the surface to depths of 2 to 5 feet the density usually should be considered as an initial density. For more information on initial density, see Strand and Pemberton (1982).

I. Report of Results

An important feature of any reservoir survey is the report of results so that others may benefit from the time and effort expended in the investigation. The information gathered during a detailed survey helps define the sedimentation characteristics of the contributing drainage basin as well as the reservoir. A prepared report serves the interest of the Federal Government and other engineers and scientists not involved in the investigation.

The report should be as inclusive as necessary to document the survey and provide the information useful in future surveys. The items included in individual reports may vary according to the problems and circumstances encountered. Some of the important items which may be included in a report are:

1. General information on the dam, reservoir, and drainage basin.

2. Information on all surveys, past and present, which have been conducted on the reservoir.

3. Description of the survey and sampling techniques for the present survey and the special equipment used.

4. A reservoir map showing the location of all range lines. In many cases the original range survey map is sufficient.

5. A description of all major survey controls together with a table listing horizontal and vertical control information.

6. A graph showing the reservoir stage fluctuation or stage duration curve.

7. Profiles of all reservoir and degradation ranges showing the latest survey superimposed on the original profile, and, in some instances, plots from other surveys.

8. Graphs of sediment distribution in a longitudinal profile, a percent depth versus percent sediment volume, and a percent depth versus percent distance from dam.

9. Data in tabular and graphic form describing sediment densities and particle sizes.

10. Revised area and capacity tables and curves resulting from the new survey.

11. Any data on sediment inflow and outflow which may be available for estimating trap efficiency.

12. A completed reservoir sedimentation data summary sheet on the form provided by the Subcommittee on Sedimentation, Interagency Advisory Committee on Water Data. Instructions for filling out the form are given in appendix IV. Information contained on these forms are used to compile a summary of reservoir data published by the U.S. Department of Agriculture (1978).

Although a formal report is not essential for development of new area and capacity tables and curves it does provide an excellent document for future surveys and for other reservoir sediment investigations. Reclamation offices involved in reservoir surveys should schedule preparation of a report in the advanced planning for a survey.

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APPENDIX I

ESTIMATING COST FOR SURVEY

A. Work item checklist
   1. Planning
      a. Locate original base data
      b. Hold planning meeting
      c. Complete preparation of base data for use in the resurvey analyses
      d. Secure funding
      e. Arrange for survey crew and equipment
      f. Make all arrangements with landowners, reservoir operations staff, and other affected parties
   2. Preliminary field work
      a. Locate all range monuments
      b. Replace missing range monuments
      c. Flag monuments
      d. Profile range ends from monument to shoreline as required
      e. Flag shoreline points on range lines
      f. Profile all range lines which are above water as required
      g. Determine horizontal grid-coordinates for all monuments not previously determined
      h. Convert field data to useable form
      i. Maintain all equipment necessary to the work
   3. Hydrographic survey
      a. Transport equipment to and from reservoir
      b. Survey underwater portion of all range lines
      c. Sample deposited materials
      d. Maintain all equipment necessary to the work
   4. Data Analyses
      a. Convert chart and digital data to profile form
      b. Prepare comparative plots of original versus new range profile
      c. Compute new contour surface areas
      d. Compute revised area capacity table
      e. Analyze core samples
      f. Prepare area-capacity tables
      g. Prepare final report for publication

B. Cost item checklist
   1. Labor for all participants
      a. Hourly wages
      b. Overtime
      c. Leave
   2. Per diem for all traveling participants
   3. Travel
      a. Planning meetings
      b. Conducting survey
   4. Special equipment procurement
   5. Fuel, supplies, etc.
   6. Data processing
   7. Printing
   8. Any contracted work items

APPENDIX II

GUIDE FOR PREPARING CONTOUR-AREA TABLES

1. On the full scale base topography, finalize location of all reservoir sediment ranges, including locations of range-end monuments.

2. Divide reservoir into storage segments defined either by adjacent range lines and/or by terminal ends of the reservoir, such as the dam or upstream ends of surface area contours. Segments should be numbered from I to N on the main stem proceeding from downstream to upstream and the numbering of tributaries segments should follow in sequence from downstream to upstream. Each segment number should be entered on a copy of the attached form, figure II-1.

3. By planimetering or digitizing, determine the original segmental contour surface areas between boundaries for each contour from maximum water surface to the lowest contour. Enter the contour elevation and corresponding contour area in columns (1) and (2) of figure II-1. A space should be left between each entry for notes or corrections. Areas should be given to the nearest acre unless otherwise specified.

4. Compute the original contour width for all contours for each sediment range and enter the width to the nearest foot in columns (3) or (4) of figure II-1.

5. Compute the original average width for each contour of a segment and enter in column (5). For the segment adjacent to the dam, the contour width for range 1 usually can be considered an average width for that segment. For the upstream terminal segments, the average width would be one-half the terminal range contour width. When tributaries enter the reservoir in a segment, it may be necessary to alter the table to include tributary range widths.

6. From finalized new survey range data, repeat items 4 and 5 and enter the computed contour widths and average width in columns (6), (7), and (8), respectively.

7. Compute adjustment factors by dividing the new survey average width, column (8), by the original survey average width, column (5). Enter the results in column (9).

8. Compute new segmental contour areas by multiplying the original contour area, column (2), by the adjustment factor, column (9). Enter the results in column (10).

9. Prepare a summary table of contour elevations versus new surface areas for use in the area-capacity computations.

TABLE____

____ CONTOUR AREA COMPUTATION

________ RESERVOIR

SEGMENT____

ELEVATION FEET	____ AREA ACRES	____ RANGE WIDTH			____ RANGE WIDTH			ADJUSTMENT FACTOR	____ AREA ACRES
		RANGE____ FT.	RANGE____ FT.	AVERAGE FT.	RANGE____ FT.	RANGE____ FT.	AVERAGE FT.	$\frac{(8)}{(5)} = \frac{\_\_\_\_ \text{ WIDTH}}{\_\_\_\_ \text{ WIDTH}}$	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

Figure II-1. - Contour area computation.

APPENDIX III

GUIDE FOR PREPARING SEDIMENT RANGE

COORDINATE DATA FORM 7-1902H

1. Station. - The index numbers used to identify sediment ranges should be used in place of stationing, that is, for range 1, place a 1 in column (10) for each line of x-y coodinates. (Figure III-1 is a copy of the form.)

2. x-coordinates. - Cross section station 0+00 should be set at the range monument on either left or right bank looking downstream on the main stem or tributary (preferably left bank). Each section station 0+00 should be set on the same bank, whichever is chosen, and the stationing should proceed positively toward the opposite range monument. The x-coordinate should be entered on the computer data sheets in the designated five-column field to the nearest foot, that is 10,000.4 feet should be entered 10000. For reservoir ranges, ignore the decimal location shown on the sheets.

3. y-coordinates. - For corresponding x-coordinates, the y-coordinates in mean-sea-level elevation should be entered to the nearest tenth of a foot, that is, elevation 1410.5 should be entered 14105. The Reclamation computer program will place the decimal between the 0 and the 5.

4. For ease in entering the data on the computer, skip one line between each line of coordinates and three lines between each range.

5. Check prepared data sheets for any obvious errors.

7-1902H (6-69)
Bureau of Reclamation

COORDINATE DATA

☐ Use blue stripe colored cards
☐ Use color of cards as designated under "comments"

PROBLEM WATER SURFACE PROFILE COMPUTATIONS
DETAIL FORMAT FOR COORDINATE CARDS
FEATURE X AND Y COORDINATES PROJECT

Job No.
Machine Proc. No.
Return to (ENGR., ROOM NO., PHONE, ETC.)

	STATION	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y		
1 2 3 4	5 6 7 8 9 10	11 12 13 14 15	16 17 18 19 20	21 22 23 24 25	26 27 28 29 30	31 32 33 34 35	36 37 38 39 40	41 42 43 44 45	46 47 48 49 50	51 52 53 54 55	56 57 58 59 60	61 62 63 64 65	66 67 68 69 70	71 72 73 74 75 76 77 78 79 80	COMMENTS

NOTE: Dots between columns indicate implied decimal points

BY
DATE:
CHECKED:
Sheet ____ of ____

GPO 852-986

Figure III-1. - Coordinate data.

APPENDIX IV

SUBCOMMITTEE ON SEDIMENTATION (ICWR)

INSTRUCTIONS FOR COMPILING THE RESERVOIR SEDIMENT DATA SUMMARY FORM

Prepared by the following agencies represented on the
Subcommittee on Sedimentation
Inter-Agency Committee on Water Resources

DEPARTMENT OF AGRICULTURE
- Agricultural Research Service
- Forest Service
- Soil Conservation Service

DEPARTMENT OF COMMERCE
- Bureau of Public Roads
- Environmental Science Services Administration

DEPARTMENT OF DEFENSE
- Corps of Engineers
- Naval Oceanographic Office

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
- Water Pollution Control Administration

DEPARTMENT OF THE INTERIOR
- Bureau of Mines
- Bureau of Reclamation
- Geological Survey

FEDERAL POWER COMMISSION

TENNESSEE VALLEY AUTHORITY

Foreward

(REVISED MARCH 1966)

The following instructions were prepared by members of the subcommittee as a guide for use in the completion of Reservoir Sediment Data Summary forms. The purpose of the summary form is to provide for the uniform compilation and dissemination of pertinent basic data obtained from reservoir sedimentation surveys. A summary is desired for each reservoir on which one or more sedimentation surveys have been made. New summaries should be prepared when additional sedimentation surveys are made and should carry forward the results of previous surveys, as indicated in the instructions. A typed copy of each new summary in condition suitable for offset printing should be furnished for publication. After a summary is prepared it will be reproduced by the subcommittee in sufficient numbers to meet the needs of each agency represented on the subcommittee. This will permit each agency to maintain a file of basic data prepared in a uniform manner suitable for analysis and interpretation. The subcommittee recognizes that all items of data provided for on the summary will not be readily available for every reservoir. The early compilation and dissemination of available data is preferable to postponement until all items can be completed. However, it is important that every item be filled out for which data are obtainable. The following instructions are based on the instructions issued by the Subcommittee on Sedimentation in 1961 but are revised to apply to the new summary form.

General Notes

A. In all cases where data are estimated or assumed, insert an asterisk, and show an asterisk with the word "assumed" at the bottom of the front page of the form.

B. Where other information is presented that needs clarification, footnotes should be used and shown by numbers, as 1/, 2/, etc. All footnotes are to be explained in the space provided under item 47.

C. All data should be shown to at least three significant figures, if available, and if accuracy of the survey warrants. However, it is common practice and permissible to show all items of data to the nearest whole number, even though the accuracy of the survey may not give significance to the last one or two whole numbers. For example, for item 14: 167,624, 16,762, 1,676, 168, 16.8, 1.68.

D. Items 31, 32, 33, 37, 38, 40, and 41. Where the sedimentation survey of a multiple-purpose reservoir has covered only the pool level or levels used for storage most of the year (as irrigation, power, inactive) and has not covered the flood-control pool above such levels, the data should be shown for the pool levels surveyed. However, any data obtained concerning sedimentation in the controllable flood-control pool (not including surcharge storage) should be shown under the above items with a footnote reference of explanation under item 47.

E. Use continuation sheets when all data cannot be placed on one sheet.

Specific Items

Name of Reservoir: Give the official or most commonly used name. If the dam has another name give it in parentheses, i.e., Lake Mead (Hoover Dam).

Data Sheet No.: The Data Sheet Number is composed of two parts, the first being the river basin map number as shown in the hydrologic atlas compiled under the auspices of the subcommittee on Hydrology, ICWR, and the second is the sheet reference number supplied by the subcommittee on Sedimentation periodically when data are compiled for publication. If the map number for the river basin in which the reservoir is located is available, it should be shown here. The data sheet reference number will be supplied later by the Subcommittee on Sedimentation.

Item

1 The name of the person or the organization that owns or operates the structure. If a Federal or State Government, give both the department and agency having supervision or control over the operation of the dam. (Abbreviate as necessary.)

2 If the reservoir is located on a small stream, the name of which is not known, list as a tributary of the next largest stream. For example: "Trib. of Rock R."

Item

3 If the dam lies in two states, both states should be given, the first state being that in which the headquarters for operation of the dam are located.

4 Give the location of the dam by section, township, and range.

5 Give the name of the nearest post office. If space permits, adding the distance in miles and direction of the dam from the nearest post office helps to pinpoint the location of the dam, as Tulsa 2 SE.

6 Give the county in which the dam is located. If the dam is in two counties, the first-named county should be the one in which headquarters for operation of the dam are located, followed by a hyphen and the name of the second county.

7 Give the latitude and longitude of the dam in degrees and minutes (seconds, if known).

In items 8, 9, and 21, if no actual sea level datum elevation is available, an assumed elevation or local datum plane should be given for these items wherever possible, so that the height of the dam and the spillway above the streambed can be determined. (Observe A under General Notes, page 2.)

8 The elevation of the top of the dam which is equal to the highest spillway elevation (item 9) plus freeboard.

9 This is the elevation of the highest spillway. If the spillway is topped by movable gates, give the elevation of the top of the gates in closed position, with an explanatory footnote in item 47 (REMARKS AND REFERENCES). (See B under General Notes, page IV-2.)

10-14 All data corresponding to storage allocations 10a through g refer to original storages in the reservoir, if these data are available, or otherwise, to the first accurate capacities determined after the beginning of storage. Show revisions of the initial storages if recent surveys yield more accurate data than the early surveys.

10a-b These items designate the purpose of storage space allocation. Multiple use storage space (item 10b) refers to that which is purposely varied, seasonally or alternately, as required to serve two or more purposes. Use a footnote to explain the specific uses in item 47.

10c This item ordinarily refers to storage for hydroelectric or direct power development. However, storage developed or allocated specifically for cooling purposes in steam powerplant operation should be listed under this item with a footnote explanation in item 47.

10d This item refers to water supply for municipal, industrial, domestic, or livestock use and fire protection.

Item

10e This item refers to storage space allocated specifically for water used to irrigate agricultural land.

10f This item refers to storage allocated for regulation of low water flow of streams, navigation pools, recharge of ground water, recreation, fish and wildlife, etc. Specify by footnote.

10g This refers to storage below the lowest outlet in the dam which cannot be withdrawn for any consumptive or beneficial use and is not generally considered to be of significant value for any purposes listed under item 10f, (CONSERVATION). This pool elevation in small reservoirs generally is considered by the Department of Agriculture to be the sediment pool elevation. It is the level below which sediment is generally continually submerged and above which the sediment deposits tend to be more compacted due to periodic exposure to the air.

11a-g These elevations should correspond to the top of pools listed under item 10, in terms of mean sea level, if known. Otherwise, an assumed elevation or local datum should be given, as relative elevation to the streambed level, the top of the dam, or the spillway crest. If regulation schedules provide for variation (seasonal or otherwise) in the top-of-pool levels, the maximum elevation should be shown with a reference to the footnote explanation of the other pertinent pool levels.

12a-g Give the original surface area in acres at the elevation at the top of each pool shown in item 11.

13a-g Give the original storage capacity in acre-feet in each allocation.

14a-g Give the total original accumulated storage in acre-feet from the bottom of the reservoir to the top of each pool elevation indicated. Thus, the uppermost item recorded should be the original capacity of the reservoir below the spillway crest elevation shown in item 9.

15 Give the date when water was first impounded (month, day, and year, if possible).

16 Give the date (month, day, and year, if possible) that the initial operation for any function started.

17 Give the length of the reservoir, from the dam to the head of the backwater of the contributing stream. If the reservoir is composed of two or more principal arms, give the sum of the lengths and specify the length of each main arm in a footnote in item 47. Give the average width by dividing the surface area by the summation of the lengths.

18 Give the entire flow-contributing drainage area above the dam.

Item

19 Give the drainage area exclusive of the surface area of the reservoir at the spillway crest elevation (item 9) and exclusive of the upstream non-contributing basins or the watersheds above the larger reservoirs that are effective sediment traps.

20 Give the length of the total drainage area along the centerline of the main stream valley. The average width is the area in item 18 divided by the length in item 20.

21 The maximum elevation would be the highest point of the watershed boundary. The minimum elevation of the watershed should be the lowest original streambed elevation at the axis of the dam. This elevation is used to determine the height of the dam.

22-24 Give the longest available recorded mean value. If known, include in parentheses the number of years of record.

22 Give the average annual precipitation value for the total drainage area. If the mean annual precipitation varies widely for different parts of the watershed, record the range of values, for example: "18-35."

23 Mean annual runoff in inches may be obtained from direct measurement; from published reports such as USGS Water Supply Papers, by transposing known data from similar adjacent watersheds, or from average annual runoff maps such as USGS Circular 52. The source of data may be shown by footnote with explanation under item 47.

24 The mean annual runoff in acre-feet may be obtained by multiplying item 23, mean annual runoff in inches, by item 18, total drainage area in square miles, times the conversion factor 53.33.

25 The mean annual temperature and the average annual range in temperatures should be given in degrees Fahrenheit.

26 Give the date of the beginning of storage, if used to compute sedimentation, or the average date (month, day, and year) of the first reservoir survey, and of all succeeding surveys used in computing sedimentation. The original data from which the sedimentation record begins and the subsequent data should be given under items 26, 29, 30, 31, 32, and 33, but the original data should not be repeated under item 26 below or in parallel boxes from item 34 through item 42, inclusive.

27 Give the elapsed period between the beginning of storage or the first survey used to compute sedimentation (whichever is the more recent date) and between the average dates of each succeeding sedimentation survey. Compute to the nearest 0.1 year. If computations have been carried out to the nearest 0.01 year, two decimal places may be shown.

Item

28 Give the accumulative period from the beginning of storage or the first survey used to compute the sedimentation (whichever is the more recent date) to each suceeding sedimentation survey. Compute to the nearest 0.01 year, two decimal places may be shown.

29 Indicate "Range" or "Contour" and "Detailed" or "Reconnaissance" as applicable. Detailed may be shown by the symboled (D); Reconnaissance by (R). A detailed range survey is defined as one in which instrumental control of all sounding and spudding positions in the lake was maintained. Where this was not done, the survey should be labeled as (R). In a few cases, where instrumental control was not maintained, but the number of ranges and observations per range were substantially the same as those made on a detailed survey, the designation "Semi-detailed" may be used. The symbol for this should be (S). A contour survey to be labeled (D) should conform with at least standards of third order accuracy for topographic mapping(1 in 5000). If the contouring was of a sketchy or very generalized nature, designation should be (R). All contouring done with Kelsh Plotters and similar equipment shall be considered (D), but sketching of contours with portable stereoscope shall be considered (R).

30 Give the number of ranges or the contour interval. If a reconnaissance survey, give the number of individual measurements. The letter (M) should follow to indicate that they are meaurements and not ranges. Where a combination range and contour survey is made the symbol (R) should follow the number of ranges and (CI) should follow the contour interval.

31 The surface area at the spillway crest elevation (use the elevation of item 9 to obtain the first entry). If the areas of different allocated storages have been deterimined each should be referenced with a footnote to be shown in item 47.

32 The first figure entered should be the original capacity (below the spillway crest elevation, item 9). If the capacities for different allocated storages have been determined these should be shown and each referenced with a footnote in item 47. If the original capacity was not determined, give the first accurate capacity determined after the beginning of storage and note the date.

33 Capacity-inflow ratio. C/I = item 32 ÷ item 24. Use the maximum capacity for the date (item 32) for which the C/I ratio is being calculated and divide by the mean annual runoff in acre-feet (item 24). This ratio should be adjusted if there are one or more upstream reservoirs that have a significant trap efficiency and control a substantial part of the drainage area (usually more than 25 percent).

34 Give the mean annual precipitation over the drainage area for each period of years given in item 27. If there is a substantial variation in precipitation for different parts of the drainage area, give the range as: "10-23."

Item

35 In 35a give the average annual water inflow to the reservoir, in acre-feet, for each period of years given in item 27. The highest annual for each period, in acre-feet, is to be given in item 35b, and the total for each period is given in item 35c.

36 Give the water inflow, in acre-feet, to the reservoir for the accumulated periods of years given in item 28.

37 In item 37a, give the volume of capacity loss below crest (item 9) for the periods of years given in item 27. Item 37b is obtained by dividing the volume given in item 37a by the corresponding period of years shown in item 27. Item 37c is obtained by dividing the value in item 37b by the net sediment contributing area shown in item 19.

38 In item 38a give the accumulative total sediment deposits below crest for the period or periods of years given in item 28. Item 38b is obtained by dividing the value of item 38a by the corresponding accumulative years shown in item 28. Item 38C is determined by dividing item 38b by the net sediment contributing area shown in item 19. If the above crest deposits exist and are measured, add their volume to the below crest deposits in items 38a, 38b, and 38c, and also give these total values just under the other values. Where above crest deposits are included, they should be referenced with a footnote and explained in item 47 (REMARKS AND REFERENCES) (see notes C and D).

39 Weighted average dry weight in pounds per cubic foot of sediment in place in the reservoir. Since the dry weight of deposits tends to increase with time due to compaction, an average dry weight for the total deposit should be measured or estimated at the time of each survey. If assumed values are used, indicate by asterisk (see note A).

40 Compute the values as follows:

Item 40a = for first survey, item 38c x item 39 x 21.78
Item 40a = for subsequent surveys:

$$\frac{\left[\left(\begin{matrix}\text{Item 38a for}\\ \text{latest survey}\end{matrix} \times \begin{matrix}\text{Item 39 for}\\ \text{latest survey}\end{matrix}\right) - \left(\begin{matrix}\text{Item 38a for}\\ \text{preceding survey}\end{matrix} \times \begin{matrix}\text{Item 39 for}\\ \text{preceding survey}\end{matrix}\right)\right] 21.78}{(\text{Item 27 for latest period}) \times (\text{Item 19})}$$

It is imperative that samples of the sediment representative of the entire period of sediment accumulation be obtained at the time of each survey.

Item 40B = item 38c x item 39 x 21.78.

41 Compute the values as follows:

$$\text{Item 41a} = \frac{\text{Item 38b}}{\text{Item 14 (Maximum value in item)}} \times 100$$

Item

Item 41b = $\frac{\text{Item 38a}}{\text{Item 14}} \times 100$ (Maximum value in item)

42 Compute as follows:

Item 42a = $\frac{\text{Item 40a x Item 27 X Item 19 x } 10^6}{\text{Item 35c x 1,359}}$ = p/m by weight

Item 42b = $\frac{\text{Item 38a x Item 39 x 1,000,000}}{\text{Item 36b x 62.4}}$ = p/m by weight

43 If elevation capacity curves are developed, select the appropriate intervals in feet below and above the crest. Give the percentage of the total sediment deposits located within each depth designation (elevation zone). For example:

$\frac{\text{(depth range)}}{\text{(\% of sed't.)}} = \frac{122\text{-}100}{4} \quad \frac{100\text{-}85}{5} \quad \frac{85\text{-}70}{6} \quad \frac{70\text{-}60}{7} \quad \frac{60\text{-}50}{7} \quad \frac{50\text{-}40}{9} \quad \frac{40\text{-}30}{10}$

$\frac{30\text{-}20}{12} \quad \frac{20\text{-}10}{15} \quad \frac{10\text{-Crest}}{18} \quad \frac{\text{Crest - +15}}{5} \quad \frac{\text{+15 - +25}}{2}$

44 The sediment distribution in percent according to distance from the dam. The reach designation is the percent of the distance from the dam to the maximum upstream extent of the spillway-crest contour at the elevation given in item 9 at the date of the beginning of storage. Thus, 20 percent would be 1/5 of the distance from the dam to the head of backwater at the original crest stage.

45 List the maximum and minimum water elevations and the total inflow in acre-feet for each water year of record.

46 Give data from the elevation-capacity curve for the latest survey shown on item 26. Be sure to label each survey date on the form. If space permits, give data from the elevation-capacity curve for the original survey.

47 List here all published and unpublished reports on sedimentation surveys of this reservoir. All footnote explanations are to be shown in this space. Also note and give any pertinent data, including dates of abnormal operational occurrences, such as reservoir evacuation; sluicing out sediment; releasing density currents; extreme floods and droughts; changes in spillway-crest elevation; use of flash boards; and the installation of upstream control structures. Briefly describe the sediment and any available textural analyses. If needed, use continuation sheets.

48 Give the department, agency, and division, branch, or field office responsible for each survey.

49 Give the agency and department reporting the data.

50 Give the date this form was prepared by the office listed in item 49.

RESERVOIR SEDIMENT
DATA SUMMARY

NAME OF RESERVOIR

DATA SHEET NO.

DAM	1. OWNER	2. STREAM	3. STATE
	4. SEC. TWP. RANGE	5. NEAREST P. O.	6. COUNTY
	7. LAT. ° ' " LONG. ° ' "	8. TOP OF DAM ELEVATION	9. SPILLWAY CREST ELEV.

	10. STORAGE ALLOCATION	11. ELEVATION TOP OF POOL	12. ORIGINAL SURFACE AREA, ACRES	13. ORIGINAL CAPACITY, ACRE-FEET	14. GROSS STORAGE, ACRE-FEET	15. DATE STORAGE BEGAN
RESERVOIR	a. FLOOD CONTROL					
	b. MULTIPLE USE					
	c. POWER					
	d. WATER SUPPLY					16. DATE NORMAL OPER. BEGAN
	e. IRRIGATION					
	f. CONSERVATION					
	g. INACTIVE					
	17. LENGTH OF RESERVOIR MILES		AV. WIDTH OF RESERVOIR MILES			

WATERSHED	18. TOTAL DRAINAGE AREA SQ. MI.		22. MEAN ANNUAL PRECIPITATION INCHES
	19. NET SEDIMENT CONTRIBUTING AREA SQ. MI.		23. MEAN ANNUAL RUNOFF INCHES
	20. LENGTH MILES	AV. WIDTH MILES	24. MEAN ANNUAL RUNOFF AC.-F T.
	21. MAX. ELEV.	MIN. ELEV.	25. ANNUAL TEMP. MEAN RANGE

SURVEY DATA

26. DATE OF SURVEY	27. PERIOD YEARS	28. ACCL. YEARS	29. TYPE OF SURVEY	30. NO. OF RANGES OR CONTOUR INT.	31. SURFACE AREA, ACRES	32. CAPACITY, ACRE-FEET	33. C/I. RATIO, AC.-FT. PER AC.-FT.

26. DATE OF SURVEY	34. PERIOD ANNUAL PRECIPITATION	35. PERIOD WATER INFLOW, ACRE-FEET			36. WATER INFL. TO DATE, AC.-FT.	
		a. MEAN ANNUAL	b. MAX. ANNUAL	c. PERIOD TOTAL	a. MEAN ANNUAL	b. TOTAL TO DATE

26. DATE OF SURVEY	37. PERIOD CAPACITY LOSS, ACRE-FEET			38. TOTAL SED. DEPOSITS TO DATE, ACRE-FEET		
	a. PERIOD TOTAL	b. AV. ANNUAL	c. PER SQ. MI.-YEAR	a. TOTAL TO DATE	b. AV. ANNUAL	c. PER SQ. MI.-YEAR

26. DATE OF SURVEY	39. AV. DRY WGT., LBS. PER CU. FT.	40. SED. DEP., TONS PER SQ. MI.-YR.		41. STORAGE LOSS, PCT.		42. SED. INFLOW, PPM	
		a. PERIOD	b. TOTAL TO DATE	a. AV. ANN.	b. TOT. TO DATE	a. PERIOD	b. TOT. TO DATE

Figure IV-1. - Reservoir sediment data summary.

26. DATE OF SURVEY	43. DEPTH DESIGNATION RANGE IN FEET BELOW, AND ABOVE, CREST ELEVATION											
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN DEPTH DESIGNATION											

26. DATE OF SURVEY	44. REACH DESIGNATION PERCENT OF TOTAL ORIGINAL LENGTH OF RESERVOIR														
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	-105	-110	-115	-120	-125
	PERCENT OF TOTAL SEDIMENT LOCATED WITHIN REACH DESIGNATION														

45. RANGE IN RESERVOIR OPERATION							
WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.	WATER YEAR	MAX. ELEV.	MIN. ELEV.	INFLOW, AC.-FT.

46. ELEVATION-AREA-CAPACITY DATA								
ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY	ELEVATION	AREA	CAPACITY

47. REMARKS AND REFERENCES

48. AGENCY MAKING SURVEY

49. AGENCY SUPPLYING DATA

50. DATE ____________________

April 1966
GPO 839-245

Figure IV-1. - Reservoir sediment data summary - continued.