the Printed article

# SUPERSONIC METHODS SHORT-CUT RESERVOIR SILT MEASUREMENTS

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The entire economy of the semiarid western United States is dependent upon reservoirs for water storage. Silt-laden rivers carry sediment in amazing quantities--two billion tons have been deposited in Mead Lake behind Hoover Dam since 1935--and this sediment slowly but permanently impairs reservoir storage capacity. Studies of the location and extent of deposits, and the movement of silt-carrying density currents within them surely will extend the useful life of storage reservoirs. High-frequency echo-sounding equipment is standard for depth measurements, and several electronic instruments are being tried out for coordinating quickly the horizontal location of the soundings. After describing conventional silt-survey equipment and procedures before the Hydraulic Division session in Oklahoma City, Mr. Thomas challenged engineers to develop supersonic sounding equipment further to measure depths of silt directly as well as explore the behavior of density curvents.

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Economic life of any water conservation or utilization project, whether such project be for irrigation, flood control, navigation, power, domestic water supply, or other use, is directly dependent upon the length of time that the reservoir continues to fulfill the purpose for which it was built--namely, the storage of water. Reservoir sedimentation must be studied extensively in order to plan the proper location and operation of outlets through the dam and for the reduction of sediment accumulation.

The Bureau of Reclamation has constructed approximately 80 storage reservoirs since its inception as a Federal service. Operation of the reservoirs is complicated because they must serve multiple purposes by storing water for irrigation and power and making available additional capacity for flood control.

After construction of a dam, changes occur in the stream channel for a considerable distance both upstream and downstream from the structure. These changes may be caused by the departure from virgin conditions in quantities of water released into the same channel, by a similar change in the sediment content of the water released, by changes of velocities, by combination of these factors, or by deposition in backwater areas. The results of these changes may be to increase drainage difficulties, increase the head on pumping plants, cause excessive scour around existing structures, excessive deposition around river developments, or other effects due to changes in stream regimen.

## HALF OF SILT IN UPPER HALF OF RESERVOIR

A study of the reservoir surveys conducted to date has permitted the determination of the location of the sediment deposits within reservoirs. This is important from many standpoints, particularly with regard to planning aspects. It has been found that 60 percent of the sediment in Guernsey Reservoir, Wyoming, is deposited in the upper 35 percent of the reservoir depth, calculated from spillway level. This reservoir is operated so that the reservoir pool is held nearly constant during the irrigation season. In Roosevelt Reservoir, Arizona, which operates over wide variations in pool elevation, only 30 percent of the sediment is deposited in the upper 35 percent of the depth. In contrast to these two reservoirs is the deposit in Elephant Butte Reservoir, New Mexico, where approximately 50 percent of the sediments are found in the upper 25 percent of the reservoir depth. This reservoir also has considerable variation in the operating levels.

The most important conclusion to be drawn from these studies is that in all cases so far studied in the West, over 50 percent of the sediment deposits lie in the upper half of the reservoir. Inasmuch as allocations for sediment storage in reservoirs have normally been placed at the bottom of the reservoirs, it seems advisable to question continuation of the practice of allowing relatively large amounts of dead storage that will not be filled with sediment for many years.

Conversely, it has usually been considered that the upper levels of reservoirs, usually allocated to flood control in multipurpose projects, would be free from sediment deposits. Data so far collected show that

in some cases this section of the reservoir may be subject to the greatest amount of sediment deposition. These facts should alter our planning of reservoirs, particularly those intended for multiple-purpose operation.

Surveys of sediment deposits must be adequately planned in order that they may furnish a maximum of information from which to calculate the length of time required for the sediment to accumulate to the extent of impairing or ending the useful life of the reservoir. The exact location of the sediment with regard to the dam thus becomes important.

For that portion of the survey lying above the water surface existing at the time, the survey procedure is similar to that followed in the conduct of ordinary topographic determinations. Some modification in methods and equipment used is necessary to penetrate shore-line vegetation and to negotiate mud flats.

That portion of the reservoir below the existing water surface is not readily accessible. The usual procedure in this case is to employ hydrographic survey methods. Hydrographic surveys are three dimensional. A sounding represents a vertical dimension downward from the water surface to the bottom of the reservoir. This sounding must be located in the horizontal plane by two coordinates. Hence, in addition to the sounding, there must also be horizontal control of the survey.

In large reservoirs soundings are made along predetermined sedimentation "ranges" or reservoir cross-section lines. Where practicable, these ranges are located normal to the stream flow and the valley, and spaced so that the average end areas of adjacent ranges are representative of

the section between them. Ranges are located across the mouths of all principal arms of the reservoir, and the range network should extend up these tributaries in a manner similar to that on the main stream. The ends of each range are permanently marked, and all ranges should be tied together by an active triangulation network expanded from a chained and checked base-line. In small reservoirs these ranges may be spaced sufficiently close so that bottom contours can be drawn. In some reservoirs when it is desired to develop bottom contours, ranges might be dispensed with and independent sounding surveys made.

One of the two major factors involved in the hydrographic survey is obtaining the soundings. These are made in shallow water depth by means of a sounding pole with a baseplate. The general practice for measuring greater depths has been, until the past few years, to make soundings by conventional lead-line methods, or by some mechanical device. A rope, lead line, held in the hand, or a piano wire on a sounding wheel have been used, and can still be used to advantage under certain circumstances. However, the more modern supersonic echo-sounding equipment is now more generally utilized.

Horizontal control of reservoir sedimentation surveys may be accomplished by utilizing two general classes of equipment: (1) planimetric survey and navigation instruments and (2) electronic equipment. The first method is now used almost exclusively, while the latter method has been used in coastal and land surveys and could be adapted to reservoirs. The possibility of using photogrammetry has been considered, but, to date, no practical application has been made.

When range lines are used, the problem resolves itself into locating the survey craft as it progresses along them. Coordinating position and depth determinations is facilitated by the fix button, which is an integral part of the echo-sounding equipment. Each time this button is depressed, a permanent mark is made on the sounding chart. These fix marks are identified by numbers. The craft is kept on the range line by the operator, who lines up objects on shore, or by a transitman stationed at one end of the range line who signals the helmsman when deviations from course occur.

## CONVENTIONAL SURVEY METHODS SLOWER

The following methods employing optical and mechanical equipment have been used successfully to accomplish the horizontal control, but are dependent upon visibility from shore to survey craft:

One or more transits are set up on shore, at suitably situated and accurately located triangulation stations, and the angles from known geographic locations to the survey craft are read at the instrument or instruments. The angle or angles are read periodically, and a voice, radio, or flag signal is transmitted to the survey craft at the exact instant that the measurement is made so the fix may be recorded on the sounder chart. This method gives quite accurate results but necessitates trained instrumentmen and some means of boat-to-shore communication. Notes must be kept both on the craft and on shore and these must be coordinated frequently.

Another method of using intersection to determine the position of the survey craft on the range line is to make use of the alidade

and planetable. One or more planetables are located on shore at carefully located points, and the angle between a known point on shore and the survey craft is determined graphically. This method gives results slightly less accurate than the use of transits.

A method of resection is used to determine the position of the craft on the range line by reading the angle between two points on shore with a sextant located on the survey craft. The monuments, or points on shore, must be accurately located. This is a simple, accurate method and does not necessitate communication between the boat and the shore except to keep the survey boat on the range line. Since the angles are read at or near the sounder, notes may be made directly on the recording. One man on the boat can operate a sextant with a small amount of special training.

Piano wire on a calibrated reel is used to measure the distance from the boat to a known point on land as the boat proceeds along the range line across the reservoir. This method, which requires only a calibrated reel for the wire, has the advantage of being used and read on the craft. The silt range monument and the shore anchor for the wire must be accurately located. The boat is kept on the silt range line by range markers or by instrumentmen. Floats attached to the wire at intervals keep it on the water surface and hence in a horizontal position. Distances up to one mile may be measured in this manner without appreciable error.

A calibrated Price-type current meter is used to measure distance along the range line. The meter is suspended in the water and the

revolutions of the bucket wheel counted electrically as the boat proceeds. From data read on the calibration curves for the meter, the distance traveled may be calculated.

Where it is desired to study the deposition of material brought in by tributaries and deposited as a delta, or to determine accurate bottom contours, a piano wire is fastened to an anchor on shore and the boat is moved in arcs about this point as a hub. Arcs of 25 or 50 feet in radius are ordinarily used. The location of the boat on the arc is determined by the transit or alidade and planetable.

## ELECTRONIC DEVICES LOCATE SOUNDINGS

There are a number of methods of horizontal control that employ electronic equipment. Some of this equipment has been used in making hydrographic surveys, and there is other equipment that may be applicable to hydrographic surveys or reservoir sedimentation surveys. A brief description of the equipment and the method of operation of a few of these electronic devices follows:

The Shoran method was developed for precision control of air-borne aircraft on bombing missions during the war. Two land stations could control a number of air-borne stations aboard the bombers. The Coast and Geodetic Survey has successfully used this equipment in conducting off-shore surveys in both the Atlantic and the Pacific Oceans. Two accurately located shore stations and one station on the craft are needed. The station on the craft radiates pulses in alternate groups at two different carrier frequencies of very short wave length.

One of the shore stations is tuned to one carrier frequency and the other station to the remaining frequency.

Reception of the pulse from the aircraft causes a ground station to act as a transponder and relay a pulse on a different frequency back to the craft where it is received and displayed and the distance to the station recorded. The equipment consists of very compact and well-built components, and the accuracy is very good for long distances, but the percentage of error is greater for short distances. This is due to equipment errors. Estimated probable error with unmodified Shoran equipment is ±50 feet regardless of the distance.

The Corps of Engineer, Department of the Army, has experimented with the use of SCR-584 radar system in Galveston harbor. Positioning of soundings in this harbor had been accomplished, previously, by means of two sextant angles read aboard the survey boat between prominent landmarks on the shore. An effort to speed up this method by means of a sextant angle grid was a definite improvement, but the fact that the work could be delayed by bad weather and poor visibility was another difficulty that had to be overcome. The mobile radar unit SCR-584 consists of a large truck-mounted steel van with all equipment and controls inside. The antenna, located on the roof of the van, will automatically position on a ship and track it. Readings for range and azimuth are obtained from dials. A small telescope is mounted on the antenna and may be used to assist in the initial orientation of the unit. The operating power is furnished by a portable generator.

For the Galveston surveys a responder was mounted on the survey craft to assist the antenna in tracking the survey boat. Ship-to-shore radio contact was maintained for supervision of the work. The results of the experiment showed that a greater error existed in the data from the measurement of the angle than in the distance measurement. The distance measurements were obtained with an error of $\pm 6$ feet for the best results.

A system known as Raydist, developed by the Hastings Instrument Company, Hampton, Virginia, for wartime use, has since undergone intensive development as a means of surveying over water or rough terrain and as a precise navigation and tracking system. In these applications the Raydist system results in high accuracy with the use of light and simple apparatus. Raydist is a continuous wave system and depends on the relative phase relationship between continuous wave radio transmitters.

Probably the best application of this equipment for sedimentation surveys is to use it as a pure range system. Only two instruments are required, and a continuous indication of the distance between the two sets is obtained. If one instrument were located at the end of the range line and a recording instrument carried in the survey craft, continuous indication of distance along the line could be had. Equipment of this type built for the Navy has been put in operation, and consistently repeated measurements within 2 feet on the indicators and 5 feet on the recorders have been obtained. These errors were obtained in distances of approximately 6 miles. The equipment may be completely housed in

suitcase-type cabinets, the heaviest single unit weighing approximately 32 pounds. Equipment necessary for the horizontal control of a sedimentation survey would probably cost in the neighborhood of $20,000 at the present time, but this amount should be somewhat reduced after exact needs are known and production of the equipment increases.

Lorac, or "long-range accuracy," developed by the Seismograph Service Corporation, is another radio surveying system operating on medium frequencies and medium wave lengths. The use of medium frequencies and low voltages causes the equipment to be less susceptible to common electrical problems that give trouble in high-frequency, high-voltage systems and does not confine its use to line-of-sight operation. In this system three shore stations and one boat installation are required. The boat installation is quite small, and the major portion may be mounted in an out-of-the-way position.

The three land stations are bulky and presently used equipment is not easily moved. This characteristic would be a disadvantage in sedimentation surveys in that when the survey moved from one portion of a large lake to another, it would probably be necessary to move the shore equipment. The average repeatability error in distances up to 9-1/2 miles has been found to be about 2-1/2 to 3 feet.

## EQUIPMENT FOR NORMAL SILT-SURVEY PARTY

The equipment now employed by the Bureau of Reclamation is designed to provide complete mobility, since the reservoirs are separated geographically. This separation distance may be a few miles or several hundred miles. The prime mover consists of a 1-1/2-ton, 4-wheel drive, Dodge

power wagon equipped with racks and hitches for carrying the survey equipment and towing the survey boat and trailer. This vehicle has adequate power to traverse rough terrain and will develop satisfactory speed for moving from one lake to another without undue delay. A station wagon is also employed to carry instruments and personnel and to serve as a utility vehicle on the job.

An 18-foot boat with a 6-foot 8-inch beam is used for the underwater survey. This craft is of the open type, has a plywood hull, and is powered by a 52-horsepower inboard gasoline engine. The boat has ample space for a five-man crew. One set of oscillators for the supersonic echo-sounding equipment is permanently installed in the hull of the craft, and brackets are provided for outboard mounting of a separate pair of oscillators. A small boat equipped with an outboard motor is used for obtaining the soundings in shallow water.

A two-wheel trailer capable of carrying the boat at reasonable speed on the highway is provided. This trailer is backed into the water for loading and unloading.

The supersonic echo-sounding equipment being used is a Submarine Signal Company Model 808-J. As previously mentioned, both inboard and outboard oscillators have been provided with this sounding equipment. Experience has shown that the outboard oscillators give a better-defined record than the oscillators installed in the hull of the boat. This may be due to the fact that the hull is not of model dimensions. The sounding equipment is of the portable type and is not installed permanently in

the survey craft. An NK-2 model sounder manufactured by Bloodworth Marine Company is maintained in the laboratory in working order as standby equipment.

A very useful piece of equipment for the party has proved to be walky-talky radios. This means of communication enables the boat party and the instrumentmen on shore to maintain conversational contact with one another, thereby reducing hand signals and misunderstanding. The equipment used is former Army Signal Corps radio receivers and transmitters and is operated on the frequencies assigned to the Bureau of Reclamation. These radios are used to supplement the signals sent and received between the boat and shore parties and to check the data as taken.

The hydrographic party for the sedimentation investigations consists of from three to five men specially trained for their duties in this particular kind of work. Since the boat crew also does the above-water surveys, it is necessary in most instances to supplement the crew with personnel obtained locally or borrowed from nearby projects. It is desirable for the recorder operator, or some other man in the party, to have some knowledge of radio and electronic circuits in order to maintain the supersonic echo-sounding equipment, the radios, and other electrical devices used by the party.

In a number of the surveys the water surface of the lake varied considerably during the time the surveys were being made. In these instances it was necessary to supplement the sounding charts at each end of the ranges by land surveying. This surveying was done in the conventional

method by using transit, rod, and level, or alidade and rod. No significant differences were noted between the profiles obtained by the conventional methods and those obtained by the use of the echo sounder where they overlapped. In many instances profiles were intentionally overlapped to provide a check. Since the lake stage usually fluctuates during the period in which the survey is in progress, numerous check readings may be made using both methods on the same portion of the reservoir cross-sections.

## NAVY COOPERATES IN LAKE MEAD SURVEY

A silt survey is now being conducted on Lake Mead above Hoover Dam. This survey is being carried out under a cooperative agreement by the Navy, the Bureau of Reclamation, and the Geological Survey. Preliminary reports indicate that in the 13 years since completion of Hoover Dam, sedimentation deposits ranging in depth from as little as 4 feet in the Virgin River arm of the lake to as much as 260 feet in the Colorado River arm have accumulated in the lake. With the rate of Colorado River deposits averaging 400,000 tons per day, a total of about two billion tons have been deposited in the lake to date.

The experiences of the Bureau of Reclamation have shown that echo-sounding equipment provides a rapid and accurate means of conducting the underwater portion of the reservoir sedimentation surveys. Caution must be exercised in the use of the equipment near the faces of dams, against steep cliffs, in swiftly flowing water, and in water containing air in any noticeable quantity. Frequent bar checks of the equipment will insure that the necessary constants have been correctly applied.

## DEVELOP SUPERSONIC EQUIPMENT FURTHER

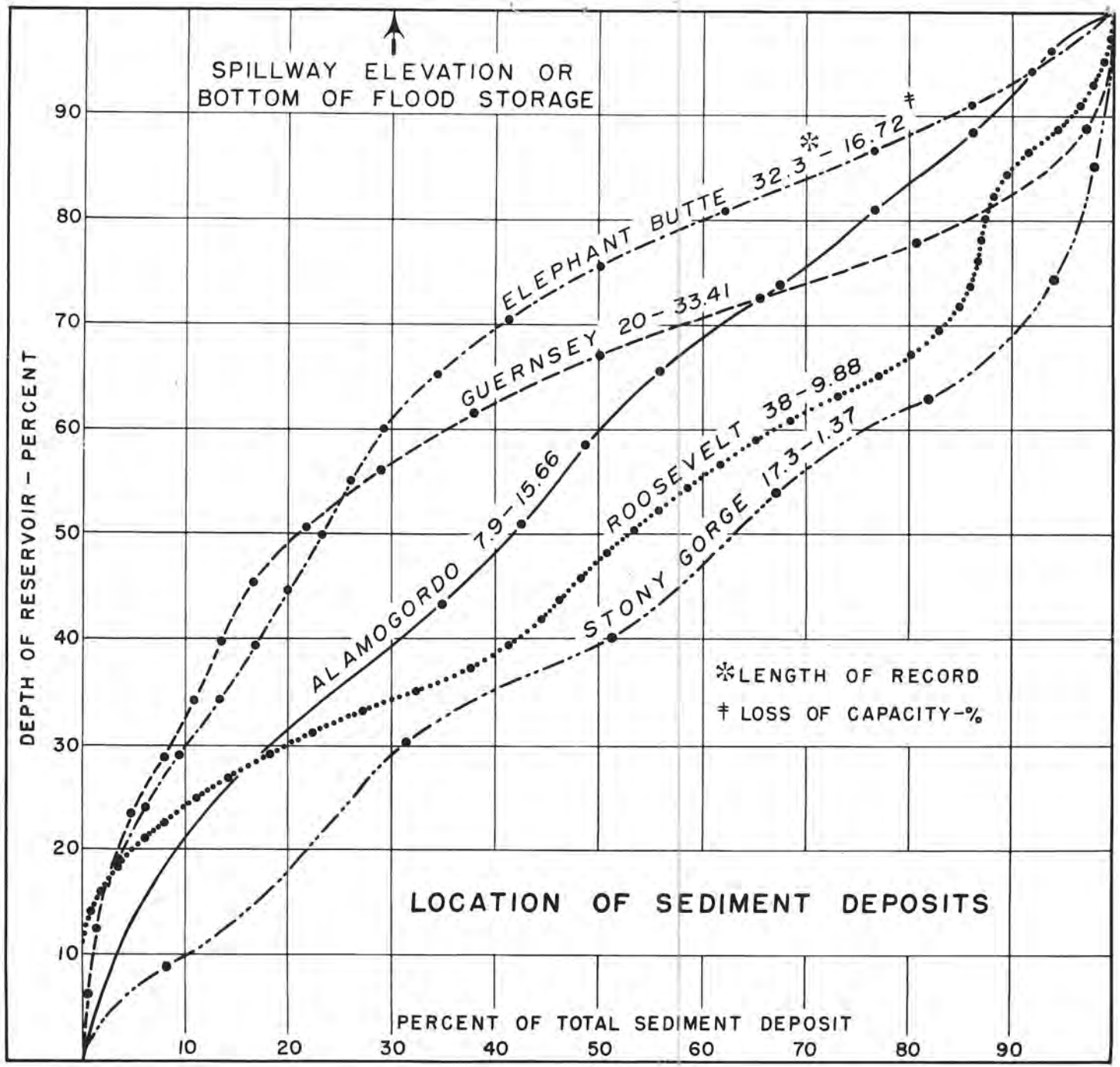
Although the results of the sedimentation surveys conducted to date have been quite satisfactory, engineers should not be satisfied that the ultimate has been reached, but should be always on the alert for possibilities of further advances either by way of electronics or by extended application of the present equipment. Thinking along these lines, it appears possible that the supersonic echo-sounding equipment now used to obtain the top of the sediment deposit in the reservoir may also be used to measure the depth of the deposit in the reservoir directly.

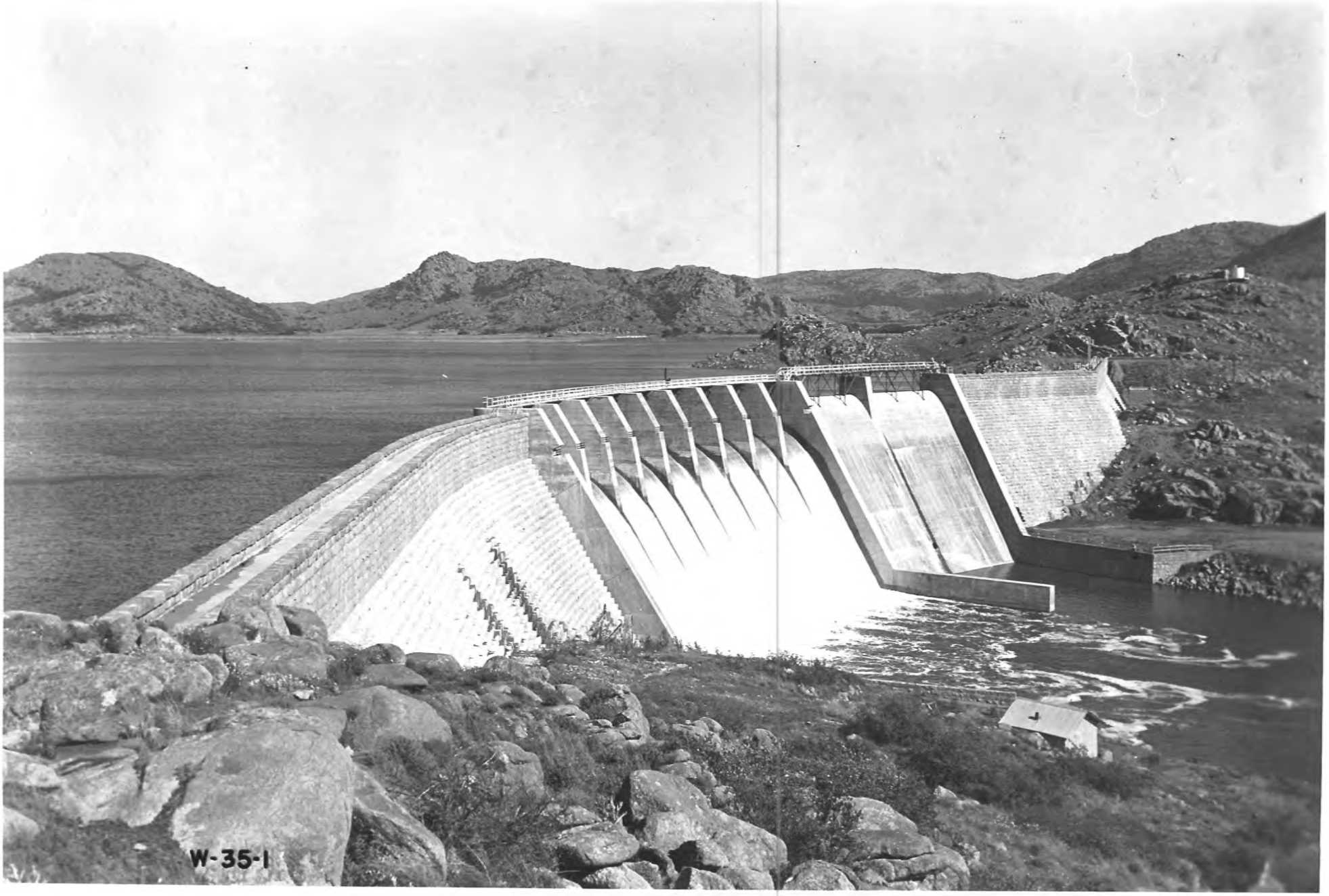
It is also possible that this echo-sounding equipment may be used for detecting and measuring depth and extent of density currents in a reservoir such a Lake Mead. If so, it would provide a rapid and economical means of measuring and plotting these currents. Once the behavior of this phenomenon is understood, selected operation of gates and sluices might permit passage of considerable sediment through the dam. These potential uses of the instrument in question have been considered, and a limited amount of work has been done to determine their adequacy for such surveys.

In Elephant Butte Reservoir a recording was made on one range, and a series of spot tests was made to coordinate the multiple echoes of the echo sounder with the results shown by sampling of the sediment with a spud. The spud is a rod equipped with cups designed for taking samples at different levels in the sediment. The spud used was only 10 feet long and did not penetrate the old bottom in all cases. Inspection of the spud samples showed layers of silt that corresponded to the reflection

surfaces in the recording. However, in one area of the reservoir, only one surface was recorded by the echo sounder, and the spud test showed about 6 feet of sediment above the old original bottom. It was assumed from this that there was no penetration of the sound energy into the sediment. This may have been due to baking of the surface during the low water period in the past. The results of the meager experimentation are not conclusive, but some indications have been found from the small amount of data taken. Evidence from these and associated studies shown that a different frequency of the supersonic wave will have a different penetration into the soil or silt layer. The 808-J Submarine Signal Company echo-sounding equipment operates at approximately 21 kilocycles per second. The NK-2 Bloodworth Marine equipment operates at approximately 14 kilocycles. The Bendix Aviation Corporation is now building equipment that operates at about 40 kilocycles per second. It appears that the higher frequency equipment has a slightly better definition in the study of either silt layers or density currents. It is proposed to use the equipment having the three different frequencies to obtain comparative recordings from which the optimum frequency for probing the sediment deposits might be indicated, or an instrument developed for the purpose whenever a comprehensive study of deposits might be initiated.

The overall magnitude of reservoir sedimentation determinations is such that it merits the concerted cooperative efforts of all concerned, even to the joint purchase and development of equipment. There is a definite need for an accurate, continuous means of position finding as well as a wider adaptation for the use of the present sounding equipment.


SPILLWAY ELEVATION OR
BOTTOM OF FLOOD STORAGE
ELEPHANT BUTTE 32.3* - 16.72‡
GUERNSEY 20 - 33.41
ALAMOGORDO 7.9 - 15.66
ROOSEVELT 38 - 9.88
STONY GORGE 17.3 - 1.37
*LENGTH OF RECORD
‡ LOSS OF CAPACITY - %
LOCATION OF SEDIMENT DEPOSITS
DEPTH OF RESERVOIR - PERCENT
PERCENT OF TOTAL SEDIMENT DEPOSIT
10
20
30
40
50
60
70
80
90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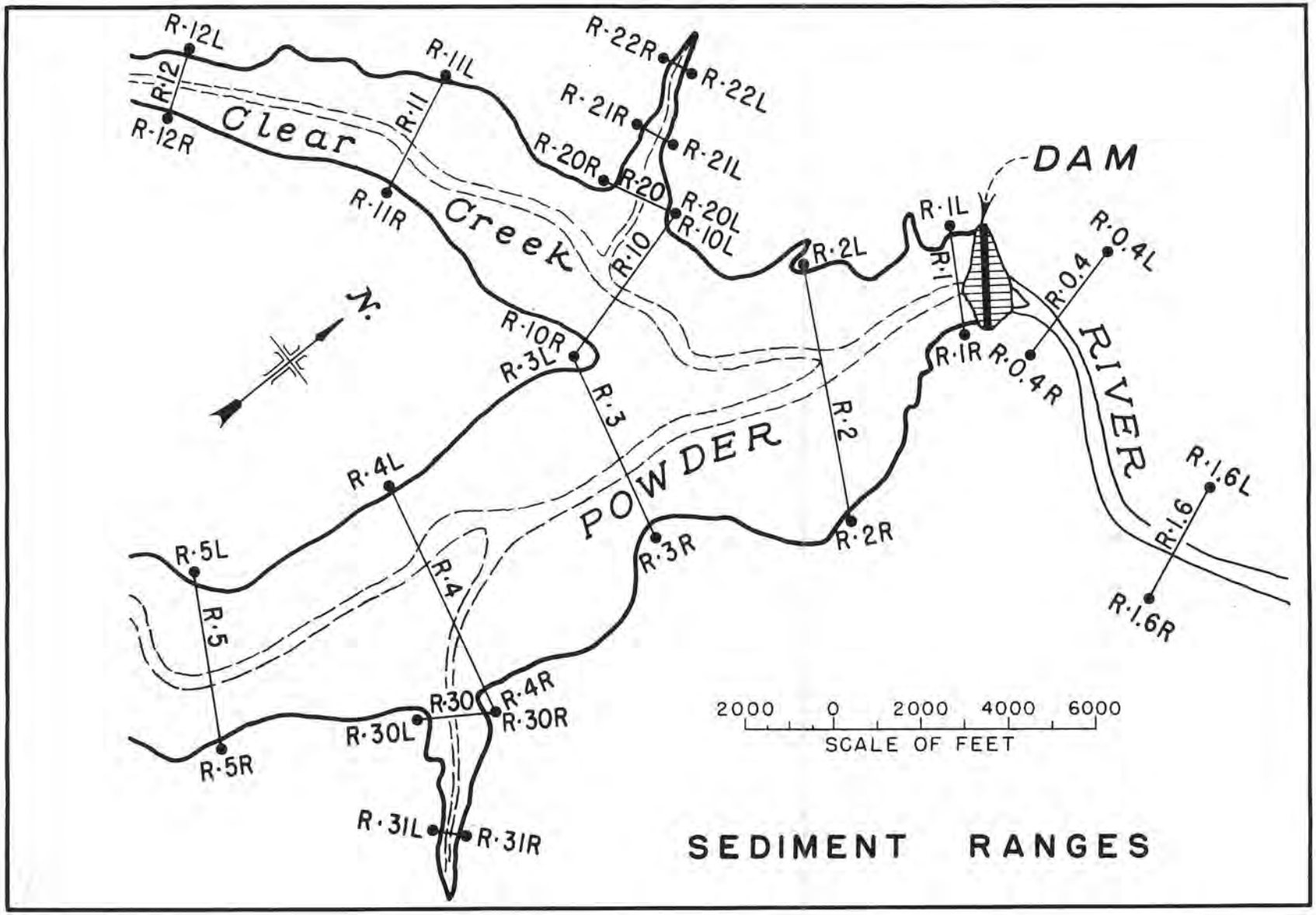
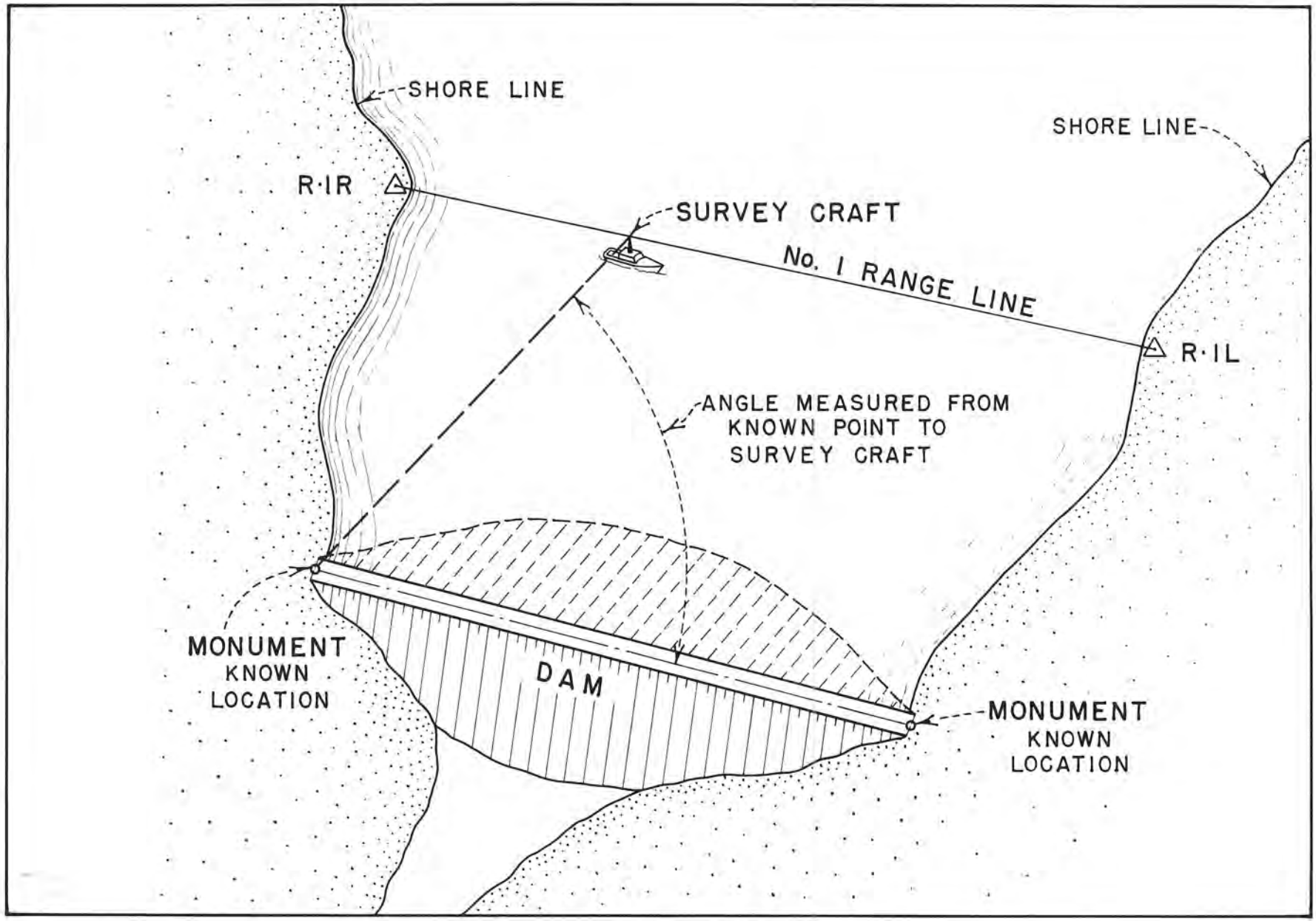
W-13-30

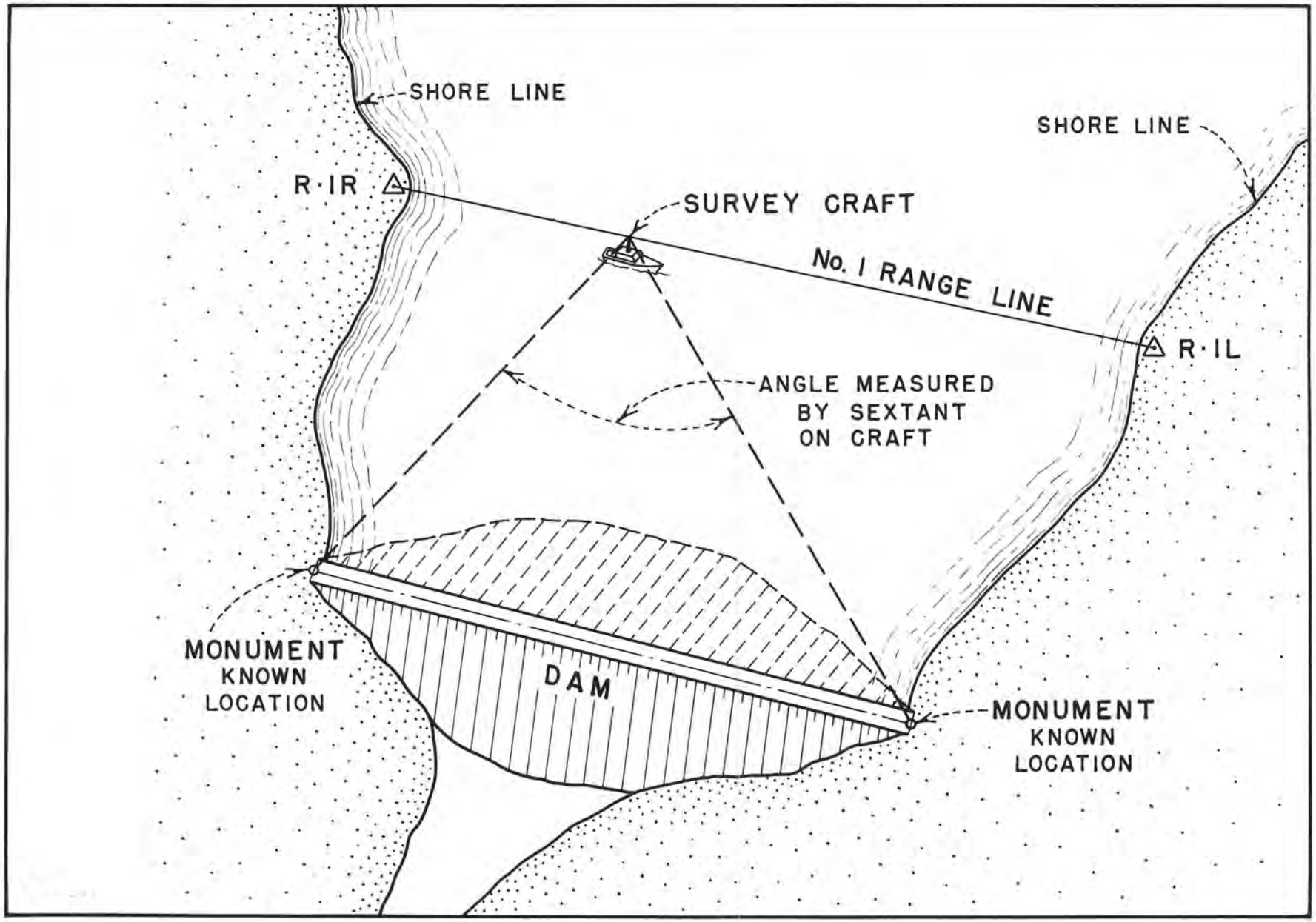

W-13-4




SEDIMENT RANGES

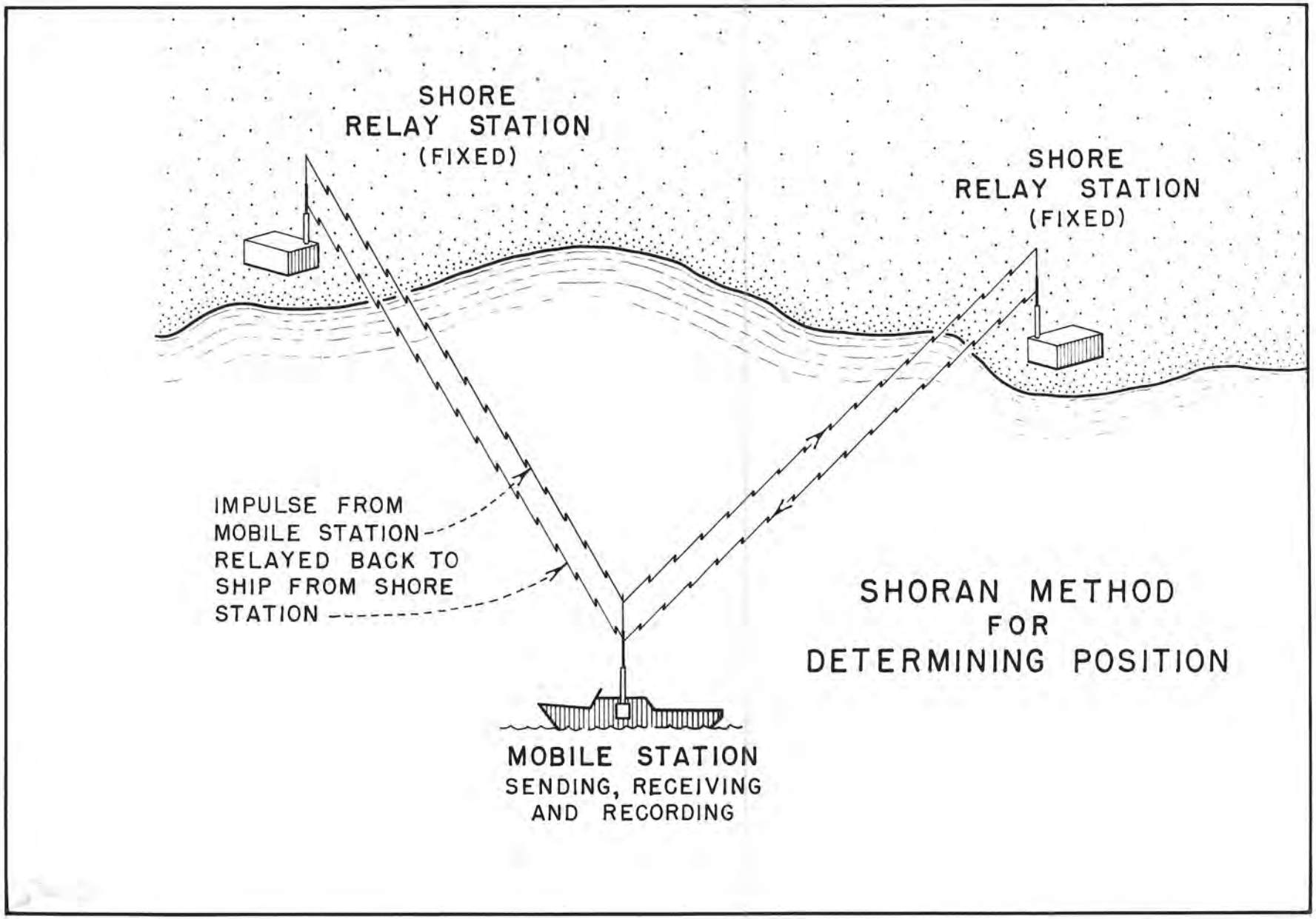

SHORE LINE
SHORE LINE
R·IR
SURVEY CRAFT
No. 1 RANGE LINE
R·IL
ANGLE MEASURED FROM
KNOWN POINT TO
SURVEY CRAFT
MONUMENT
KNOWN
LOCATION
DAM
MONUMENT
KNOWN
LOCATION


W-10-5

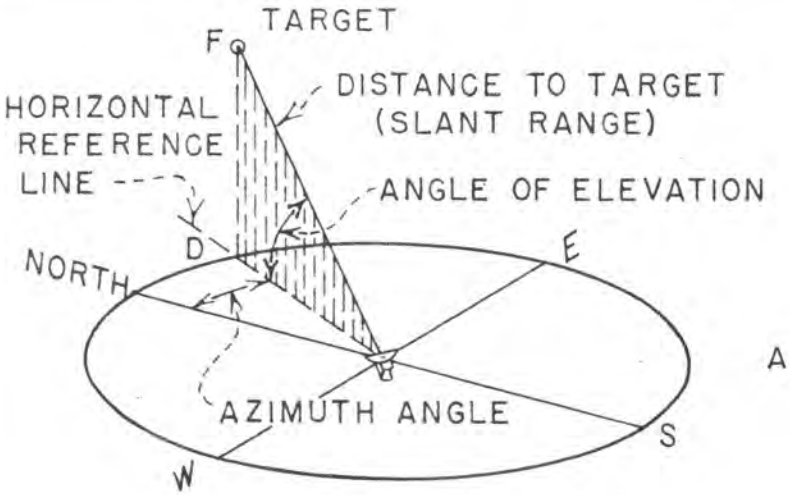

SHORE LINE
SHORE LINE
R·IR
SURVEY CRAFT
No. 1 RANGE LINE
R·IL
ANGLE MEASURED
BY SEXTANT
ON CRAFT
MONUMENT
KNOWN
LOCATION
DAM
MONUMENT
KNOWN
LOCATION


H-807-2

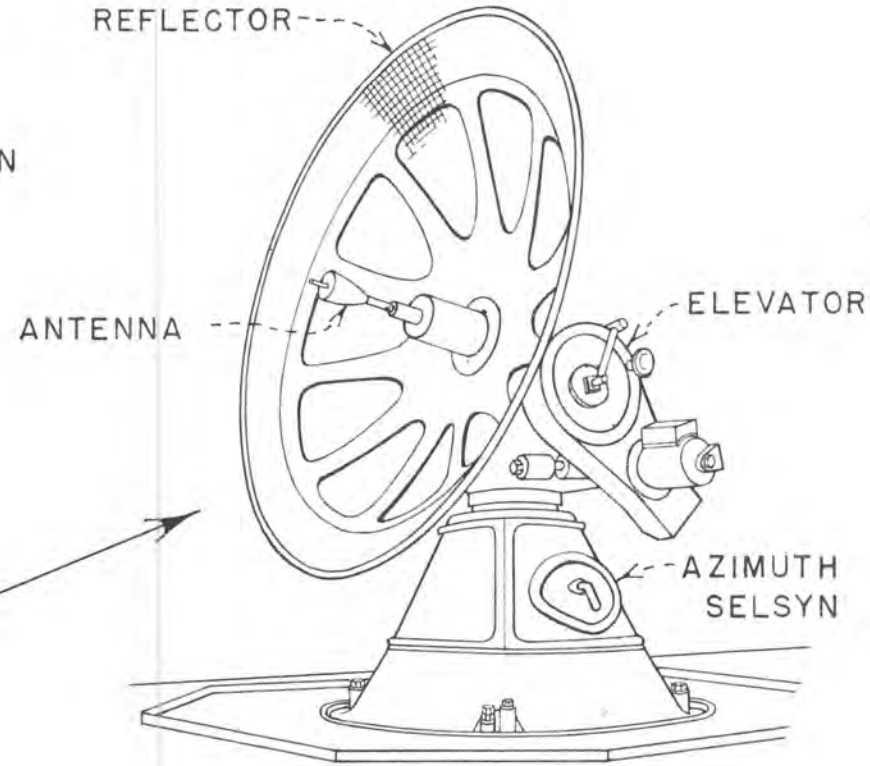

H-807-1



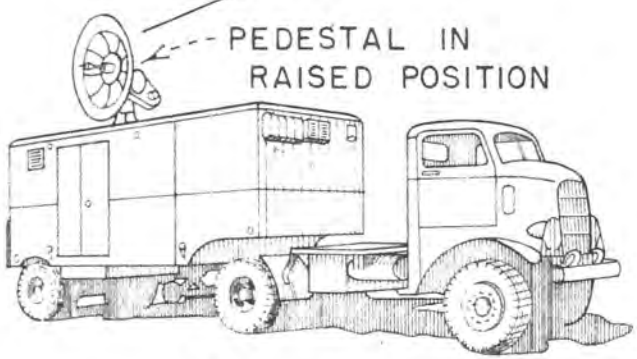

SHORAN METHOD
FOR
DETERMINING POSITION




BASIC PRINCIPLES
OF OPERATION




PEDESTAL




MOBILE UNIT

RADAR 584

FIGURE

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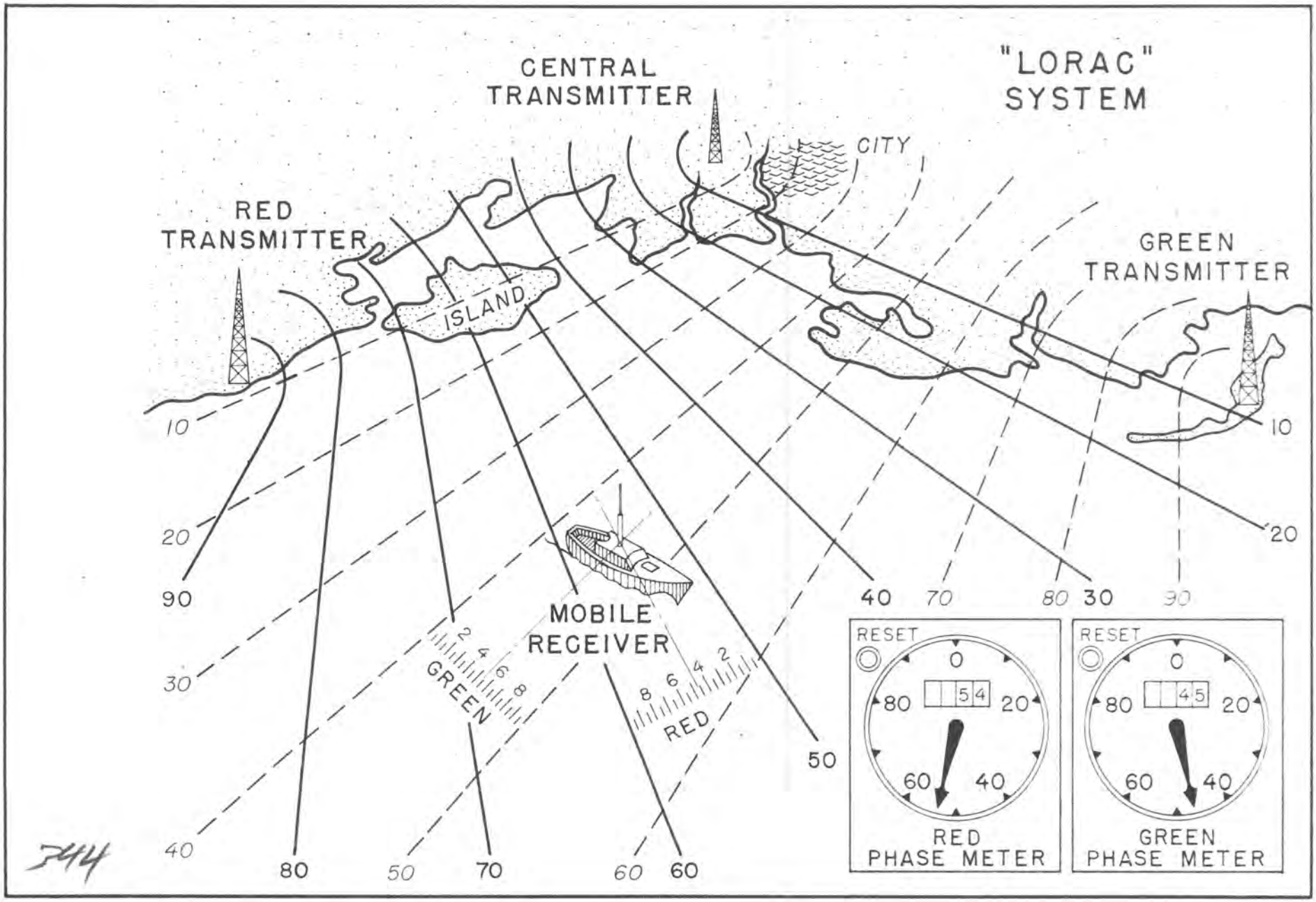
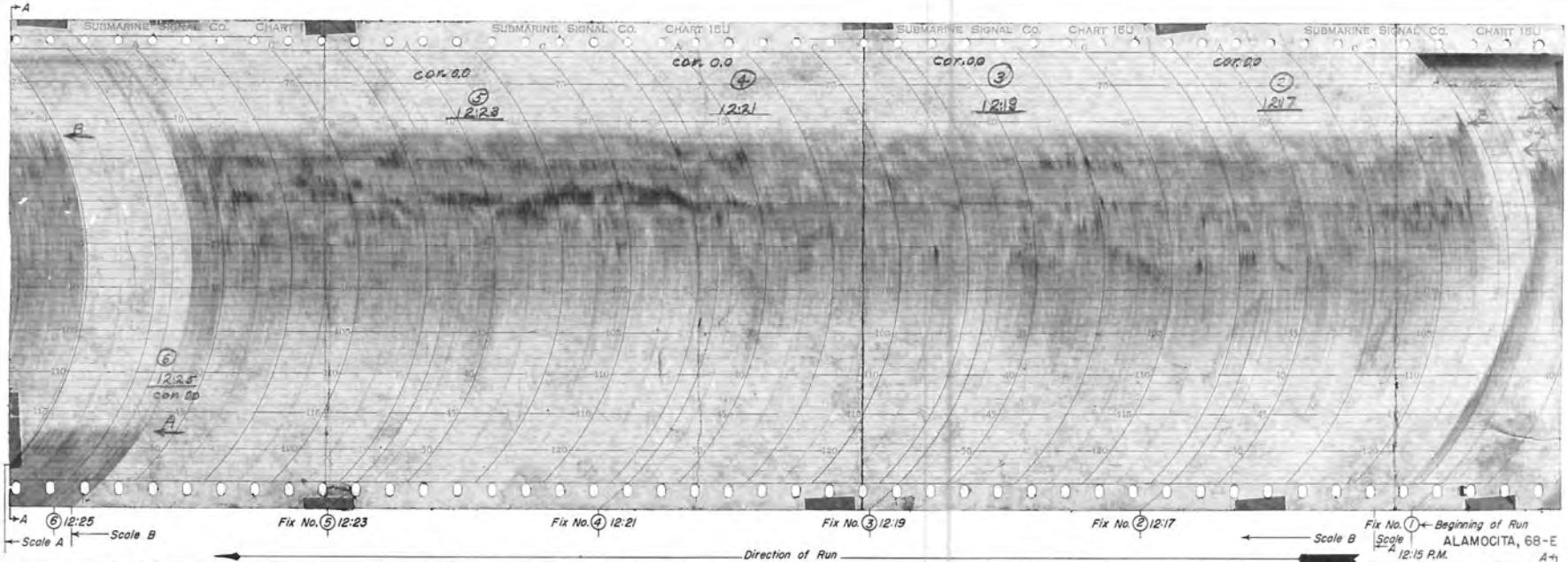

"LORAC" SYSTEM
CENTRAL TRANSMITTER
RED TRANSMITTER
GREEN TRANSMITTER
CITY
ISLAND
MOBILE RECEIVER
GREEN
RED
RESET
RED PHASE METER
GREEN PHASE METER

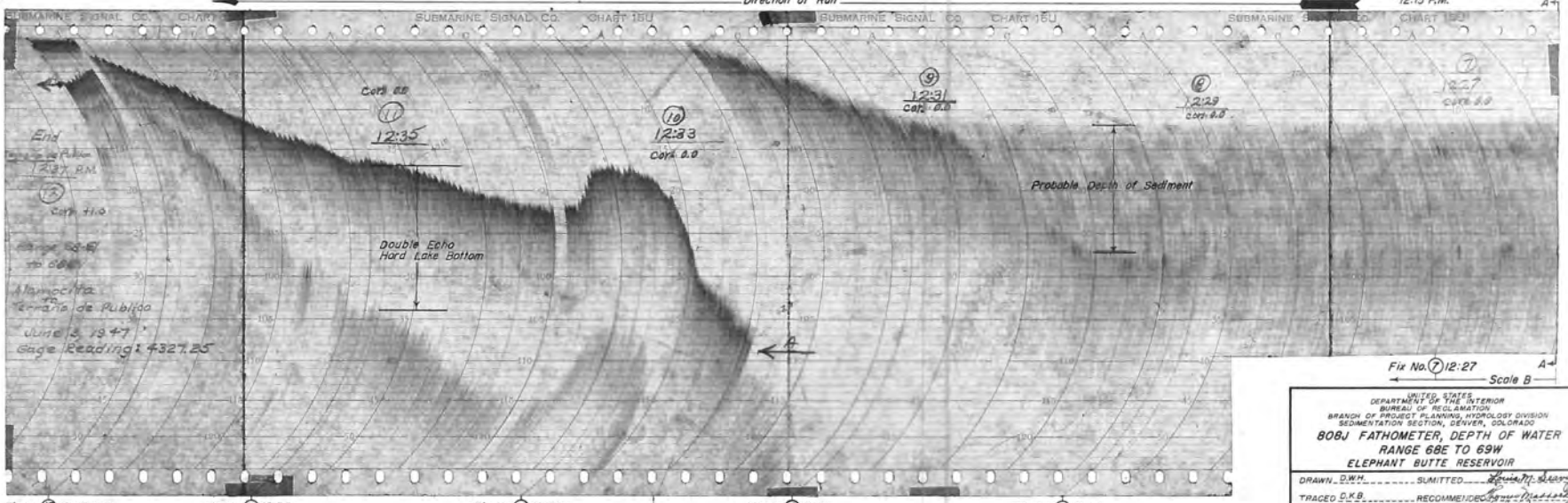
FIGURE

344


W-29-4


W-10-9



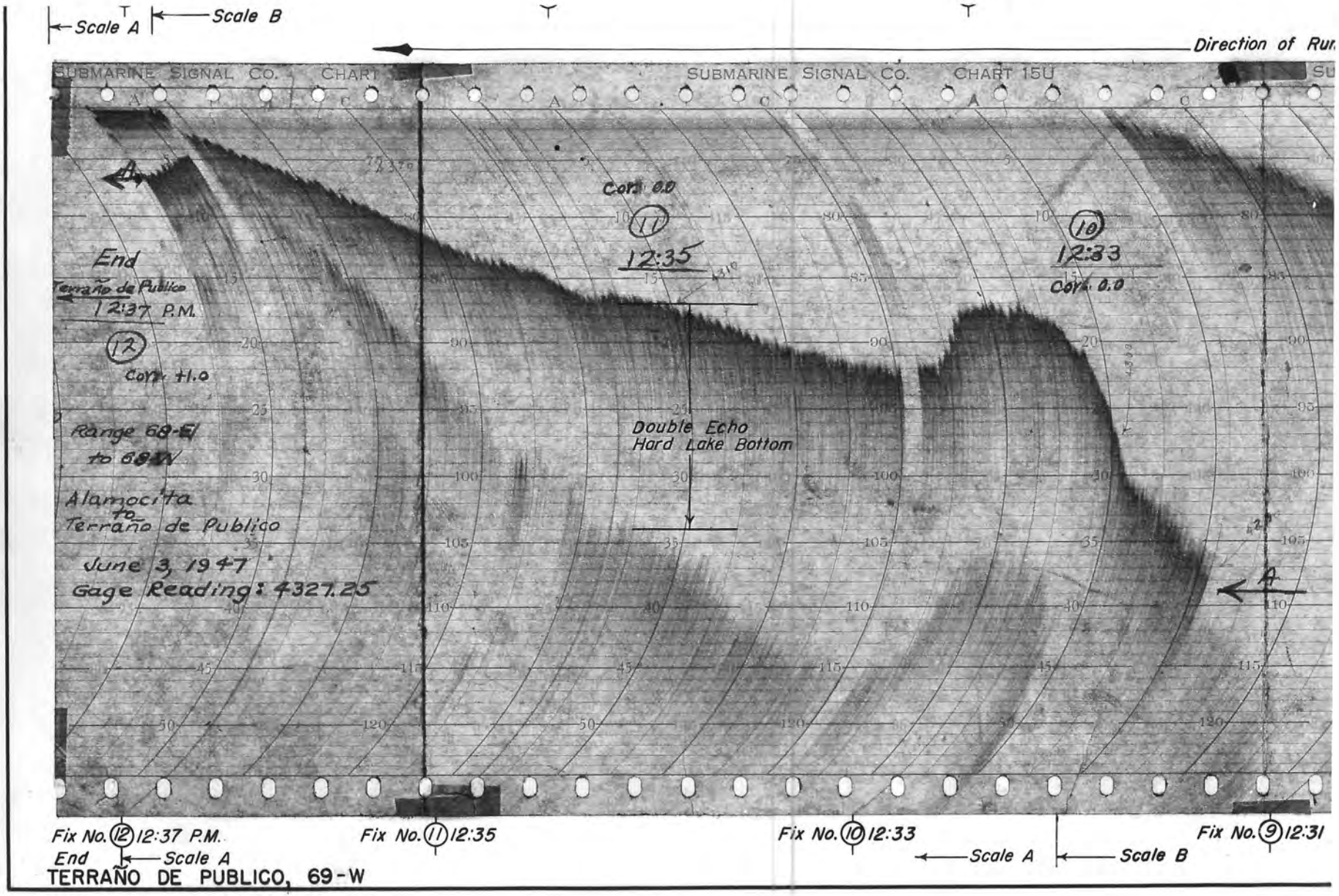




UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BRANCH OF PROJECT PLANNING, HYDROLOGY DIVISION
SEDIMENTATION SECTION, DENVER, COLORADO

**808J FATHOMETER, DEPTH OF WATER**
**RANGE 68E TO 69W**
**ELEPHANT BUTTE RESERVOIR**

DRAWN D.W.H. SUMITTED Louis M. Leary
TRACED D.K.B. RECOMMENDED [illegible]
CHECKED E.A.P. APPROVED [illegible]

DENVER, COLO. 1-17-49

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