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Reservoir Surface Area from Landsat Imagery

Four methods for estimating area were compared by employing imagery covering six New Mexico reservoirs.

Abstract: *Various areal measuring techniques, used for estimating reservoir surface areas from Landsat imagery, were compared for accuracy. Water volume and surface area data obtained from reservoir management agencies for six New Mexico reservoirs were used as test data. Acreage estimates obtained from a dot grid, an electronic planimeter, a 32-level color density slicer, and a 16-level black-and-white density slicer, were compared to the field data. Surface area measurements were taken from Landsat infrared images by these devices at scales of 1:1,000,000, 1:500,000, and 1:250,000. The acreage estimates were obtained for four seasons during 1973. Results of the study show that, although the dot grid at a scale of 1:250,000 and the planimeter at a scale of 1:500,000 and 1:250,000 provided acreage estimates which approached the actual field data, none was able to measure all of the reservoirs with consistent accuracy.*

Introduction

Inadequate water supplies and poor water quality are two major problems facing an expanding population in the southwest. With the advent of the energy crisis, New Mexico and its neighboring states have become centers of accelerated industrial activity.

In a region such as this with few available water resources, natural and man-made water impoundments represent a major potential for development of urban and agricultural water supplies. A critical need exists for accurately mapping these areas on a regular basis in order to determine their location and quality as sources of potable water.

Our ability to map the spatial distribution of standing surface water by using remote sensing techniques is a reality (Brown *et al.*, 1975; Work and Gilmer, 1976); however, the feasibility of determining the *quantity* of standing surface water in a region on a timely basis has been the focus of limited research. This paper is concerned with the development of a technique whereby the surface areas of these impoundments can be measured from satellite imagery with enough *consistent accuracy* that water volume estimates can be made.

Landsat imagery has proven useful for making regional inventories of standing surface water (Stoertz and Carter, 1973; Salomonson and Rango, 1973; Brown *et al.*, 1975). The use of Landsat data for investigating seasonal lake level fluctuations has been moderately successful, (Burgy 1973; Lind, 1973; Reeves, 1973). With these demonstrated applications of Landsat data, one of the next fronts for research lies in the accurate determination of reservoir volume through the measurement of reservoir surface areas. By relating surface area measurements to U.S. Geological Survey (USGS) published stage-area tables, it should be possible to estimate the volume of water available in a surveyed reservoir. Few published reports address this aspect of water resources management. Colcord (1975) and Inglis (1975) have both looked into measuring reservoir surface areas from Landsat imagery as an aid in estimating their volume. Results indicate good potential, but neither report provides sufficient data to assess their techniques. This paper addresses the methodology and results of a project to measure reservoir surface areas from Landsat imagery for accurately determining reservoir volume.

The objective of this project was to examine a variety of measurement techniques for determining reservoir surface areas and to compare their accuracy with field data. Questions related to the objective of the study included (a) which area measuring techniques best provide surface area measurements which meet the USGS and U.S. Army Corps of Engineers required degree of accuracy?; (b) which image scale(s) provide the most accurate area measurement?; and (c) to what extent does reservoir basin morphology affect the accuracy of area measurements?

To provide answers to these questions, six New Mexico reservoirs were selected, each having a different basin configuration. The reservoirs studied were Navajo, Heron, Abiquiu, Conchas, Elephant Butte, and Caballo. The heterogeneity of these reservoirs allowed comparison to be made between the accuracies achieved from measuring simple versus complex shorelines and steep versus gently sloping reservoir basin profiles.

The relationship between reservoir basin morphology and water surface area has been referred to by Lind (1973), Burgy (1973), and Reeves (1973). Each of these authors noted that the steepness of the basin profile directly affects the area of exposed surface water with respect to depth and, therefore, the detectability of temporal surface area changes. Figure 1 shows the geometric configurations and the basin gradients for each of the six reservoirs. Where possible, Landsat band 7 near-infrared images (0.8 to 1.1 μm) were obtained for each reservoir for each season.

Methodology

Three image scales, 1:1,000,000, 1:500,000, and 1:250,000, were used to evaluate the affect of image scale on the accuracy of different measuring techniques. Table 1 gives the dates, scene identification numbers, and quality of the imagery used. Intuitively, one would expect more accurate measures to be obtained from 1:250,000 scale imagery than from either 1:500,000 or 1:1,000,000 scale imagery. Likewise, measurements at 1:500,000 should be better than those obtained from 1:1,000,000 scale imagery.

Four measuring techniques were used to measure acreages from the Landsat images. They range in complexity from (1) a dot grid with 64 dots per square inch requiring total user decision of water surface area to (2) an electronic 16-level black-and-white analog density slicer linked to a mini-computer preprogrammed to count scaled acreages and requiring a minimum of user decision. Other measuring instruments were (3) an electronic digital planimeter with a plotting accuracy of 0.01 inches and (4) a 32-level analog density slicing processor. According to two data collection and report agencies (USGS and U.S. Army Corps of Engineers), published daily data for any reservoir are thought to be accurate to within ± 10 percent. This range is related to an unknown degree of reservoir sedimentation occurring since the last hypsographic survey and from possible water stage-recorder inaccuracies.

Evaluation of the measuring techniques was done by comparing the mean percentage error of the experimental data to the field data. This statistic was derived by the following procedure:

$$\frac{E - FD}{FD} = \% \text{ error}$$

$$\frac{\Sigma \% \text{ error}}{n} = \text{mean percentage error}$$

where

E = surface area estimate obtained from image measurement,
FD = field data, and
n = number of field data surface area measurements (n = 22).

To be considered acceptable, a technique had to produce measurements with an overall mean percentage error within ± 10 percent. Furthermore, each datum value had to be within this range and the mean and standard deviation of the surface area measurements had to be approximately those found for the field data. If achievable, these criteria would assure that a given technique pro-

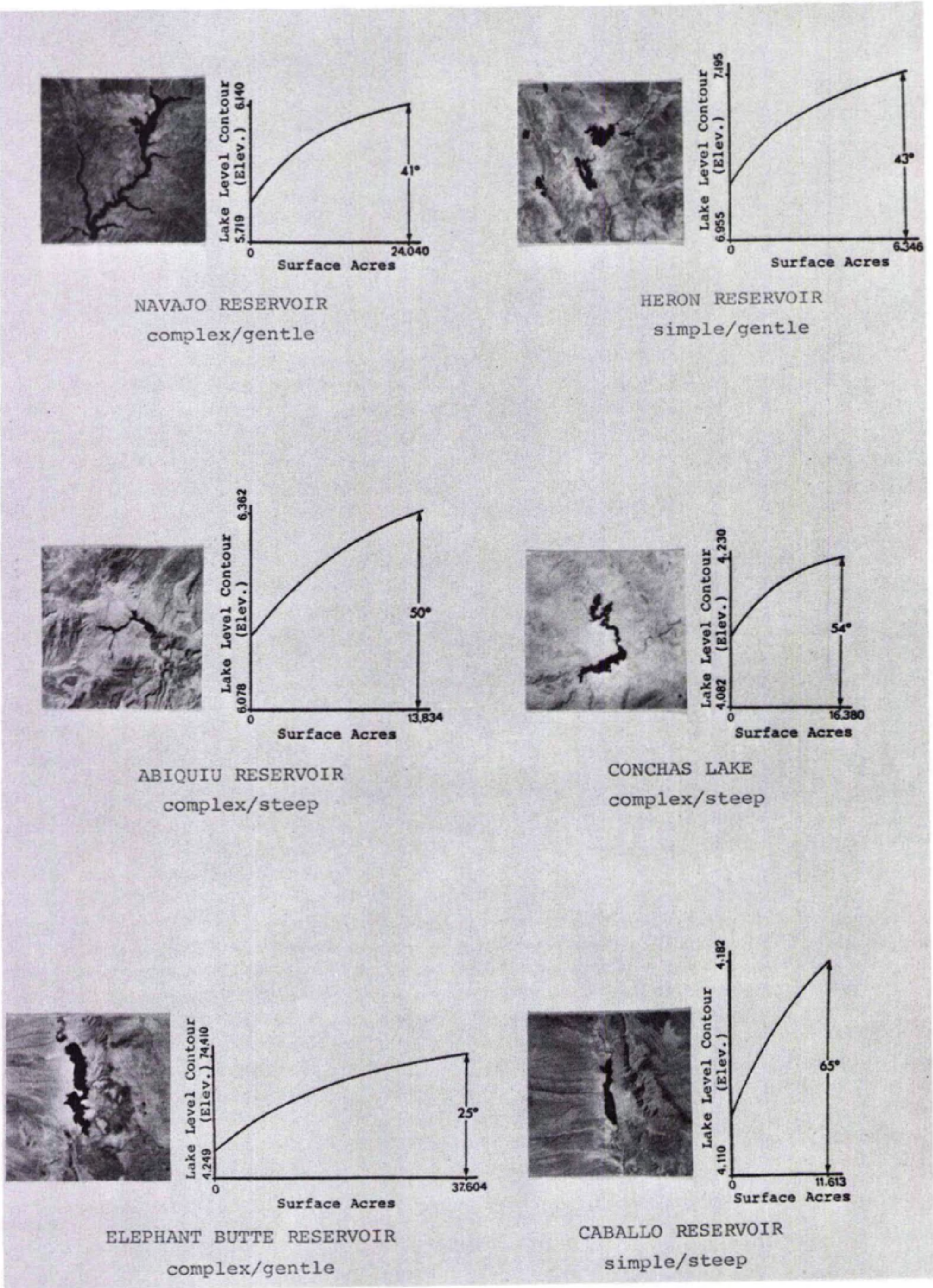

FIG. 1. Shoreline configurations and basin gradients of reservoirs studied.

TABLE 1. LANDSAT-1 IMAGERY USED IN THIS STORY

Reservoir	Scene Identification Number	Date 1973	Scene Cloud Cover	Scene Quality
Navajo	1191-17204	30 Jan	0%	Good
	1299-17205	18 May	5%	Good
	1371-17200	29 July	30%	Fair
	1461-17181	27 Oct	0%	Good
Heron	No Useable Imagery	—	—	—
	1298-17153	17 May	15%	Fair
	1388-17143	15 Aug	15%	Fair
	1461-17181	27 Oct	0%	Good
Abiquiu	No Useable Imagery	—	—	—
	1298-17153	17 May	15%	Fair
	1388-17143	15 Aug	15%	Fair
	1460-17125	26 Oct	15%	Good
Conchas Lake	1224-17042	04 Mar	30%	Poor
	1278-17044	27 Apr	0%	Good
	1386-17030	13 Aug	8%	Good
	1440-17015	06 Oct	0%	Good
Elephant Butte	1226-17163	06 Mar	20%	Fair
	1298-17162	17 May	15%	Good
	1388-17152	15 Aug	15%	Fair
	1460-17134	26 Oct	0%	Good
Caballo	1226-17163	06 Mar	20%	Fair
	1298-17162	17 May	15%	Good
	1388-17152	15 Aug	15%	Fair
	1460-17134	26 Oct	0%	Good

vided accurate and reproducible estimates for all reservoirs regardless of basin form or shoreline configuration.

RESULTS

Table 2 presents the overall mean percentage error for the machine/scale combinations studied. Table 3 provides the mean percentage error statistic for each machine/reservoir/scale combination. Table 4 provides the standard deviations and Table 5 contains the statistical means for the experimental measurements and the field data.

A review of these tables shows that only three of the twelve machine/scale combinations evaluated produced data with an overall mean percentage error within the ± 10 percent range. They are—

(1) the dot grid at a scale of 1:250,000 (8.2 percent),
(2) the planimeter at the 1:500,000 scale (7.3 percent) and,
(3) the planimeter at a scale of 1:250,000 (9.6 percent).

The more sophisticated measuring techniques such as the analog density slicers failed to satisfy the criteria. Intuitively one might expect the accuracy of the data produced by these devices to exceed that of the data obtained from devices requiring large

TABLE 2. OVERALL MEAN PERCENTAGE ERRORS FOR MACHINE/SCALE ACREAGE ESTIMATES. NEGATIVE PERCENTAGES INDICATE UNDERESTIMATIONS. POSITIVE PERCENTAGES INDICATE OVERESTIMATIONS.

Scale	Dot Grid	Planimeter	32-Level Color Density Slicer	16-Level Black-and-White Density Slicer
1:1,000,000	78.3%	12.0%	−34.6%	28.5%
1:500,000	−13%	7.3%	−35.2%	−78.0%
1:250,000	8.2%	9.6%	−57.6%	59.6%

TABLE 3. MEAN PERCENTAGE ERRORS FOR ACREAGE ESTIMATES DERIVED FROM EACH MEASURING DEVICE/IMAGE SCALE/SEASON/RESERVOIR COMBINATION INVESTIGATED.

Reservoir	Dot Grid	Planimeter	32-Level Color Density Slicer	16-Level Black-and-white Density Slicer	Scale
Navajo	107%	27%	−46%	61%	1:1,000,000
A.G.	−13%	10%	−35%	−76%	1:500,000
	36%	29%	−46%	122%	1:250,000
Heron	97%	7%	−26%	18%	1:1,000,000
R.G.	−2%	8%	−26%	−78%	1:500,000
	4%	6%	−58%	43%	1:250,000
Abiquiu	171%	27%	−35%	44%	1:1,000,000
A.S.	−19%	66%	−45%	−74%	1:500,000
	9%	15%	−66%	107%	1:250,000
Conchas	50%	17%	−39%	32%	1:1,000,000
A.G.	−11%	9%	−34%	−76%	1:500,000
	12%	8%	−60%	54%	1:250,000
Elephant Butte	14%	−1%	−40%	4%	1:1,000,000
A.S.	−13%	−4%	−36%	−80%	1:500,000
	−9%	−4%	−59%	20%	1:250,000
Caballo	54%	−4%	−16%	9%	1:1,000,000
R.S.	−11%	−1%	−31%	−79%	1:500,000
	2%	2%	−54%	26%	1:250,000

R = Rounded Shoreline S = Steep Basin
A = Angular Shoreline G = Gentle

amounts of operator input. Two other machine/scale combinations approximated the ± 10 percent acceptance range. They were the planimeter (12.0 percent) at 1:1,000,000 scale and the dot grid (−13 percent) at the 1:500,000 scale. As encouraging as the results in Table 2 are, Table 3 shows that none of the measurement techniques investigated, regardless of scale, can estimate the area of every reservoir. No meaningful relationships between accuracy and basin morphology could be identified.

TABLE 4. STANDARD DEVIATIONS IN ACRES FOR EACH SCALE AND MEASURING DEVICE COMPARED TO THE FIELD DATA. (n = 22 measurements).

Scale	Dot Grid	Planimeter	32-Level Color Density Slicer	16-Level Black-&-White Density Slicer	Field Data
1:1,000,000	7535.31	5324.32	2817.74	6663.71	4667.13
1:500,000	4128.82	4950.21	2985.45	1119.30	4667.13
1:250,000	5553.77	5345.83	2354.20	9936.60	4667.13

TABLE 5. DATA MEANS IN ACRES FOR EACH SCALE AND MEASURING DEVICE COMPARED TO THE FIELD DATA. (n = 22 measurements).

Scale	Dot Grid	Planimeter	32-Level Color Density Slicer	16-Level Black-&-White Density Slicer	Field Data
1:1,000,000	12701.18	8747.93	4847.19	10108.79	7831.76
1:500,000	6831.12	8282.34	5070.75	1712.71	7831.76
1:250,000	8575.33	8600.46	3458.81	12760.98	7831.76

Conclusion

The objective of this effort was to evaluate the feasibility of measuring the surface area of open water bodies as registered on Landsat-1 infrared imagery with enough accuracy that lake volume estimates could be made. Four techniques were evaluated for their ability to measure the surface acreage of various reservoir types. Although several of the techniques provided data which approximated the field data, none was able to measure all of the reservoirs with consistent accuracy.

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