AERIAL PHOTO TECHNIQUES

FOR A RECREATION INVENTORY OF MOUNTAIN LAKES AND STREAMS

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AERIAL PHOTO TECHNIQUES FOR A RECREATION INVENTORY OF MOUNTAIN LAKES AND STREAMS

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THE WATER RESOURCE INVENTORY IN RECREATIONAL PLANNING

The importance of water in comprehensive resource planning is clear to all. The management and development of the water resource is a difficult and complex task which must be carried out according to the multiple use concept of public land management.

In planning for recreational water use, a complete inventory of lakes and streams in a given area is a necessity. Such an inventory ideally provides information about the location and size of the water body; about water volume fluctuations and water characteristics such as clarity, temperature, and pH; and about insect life and the presence of plankton and underwater vegetation.

To date, any attempts at making such inventories have been confined to the larger lakes and streams. There are many obstacles to the collection of water resource information, particularly in mountainous areas, which are of major interest for recreation. The field season for exploration is often short. Roads may be few, and even trails may be lacking to many of the smaller lakes and streams. Travel on the ground is blocked by snow and ice during much of the year and is strenuous at any time. Also, great fluctuations in water volume leave only a short time in late summer when comparative measurements can be made. The roaring spring torrent may dwindle to a trickle by fall.

Thus, a field survey of the smaller lakes and streams is generally too time consuming and costly to be practical. Other possibilities, such as individual air surveys using planes or helicopters, are both expensive and hazardous in rugged mountains.

A survey made from maps alone is unsatisfactory. The scale of the aerial photography from which maps are usually made is not large enough to allow for identification of some of the smaller water bodies, and much desired detail is not normally included on maps. Meadows are sometimes mislabeled as lakes, and dry ravines are not consistently distinguished from year-round watercourses.

A step toward the solution of the problem is the use of aerial photographs of 1:20,000 scale. Photogrammetric techniques may be used to make rapid and reasonably accurate inventories of mountain lakes and streams. By this means, existing maps may be corrected and supplemented, and additional information useful for recreational planning may be gathered.

A TEST OF PHOTOGRAPHIC SURVEY TECHNIQUES

To test the procedures in a photographic survey, a study was conducted on the North Slope of the Uinta Mountains in northeastern Utah (fig. 1). An attempt was made to collect as much information as possible from the photographs, for use in an initial reconnaissance inventory of recreational water resources. The data gained from interpretation of photos was checked for accuracy by ground surveys. The test showed that although some of the information desirable for such a survey can be collected only in the field, a substantial amount of general descriptive detail can be obtained rapidly and at reasonable cost from aerial photographs.

The study area was fairly typical of mountainous areas offering recreational possibilities. Several hundred miles of streams and several hundred lakes lie within the 677,000 acres studied, most of which is administered by the U.S. Forest Service, although scattered tracts are privately owned. The mountains are composed primarily of quartzites and other sedimentary rocks and have been heavily glaciated, although no glaciers are now present. Elevations range from about 6,200 to over 13,000 feet, and much of the area is above timberline (11,000 feet). The predominant tree cover is lodgepole pine and there are lesser amounts of Engelmann spruce, Douglas-fir, and subalpine fir. Many aspen stands grow among these coniferous forests. Alpine meadows are numerous and give way to tundra above timberline. Low willows are common in the meadows and along streams. At lower elevations, ponderosa pine, pinyon pine, juniper, and sagebrush are found.

Few roads currently penetrate the North Slope. A much enlarged road network is planned outside the roadless High Uintas Primitive Area. Thus many remote streams and lakes may suddenly become accessible to large numbers of people, creating a need for an inventory of available recreation resources and plans for their development.

This paper describes the techniques used in the test survey and makes general recommendations. Wherever possible, evaluations of accuracy of--and estimates of time consumed by--the various operations are given.

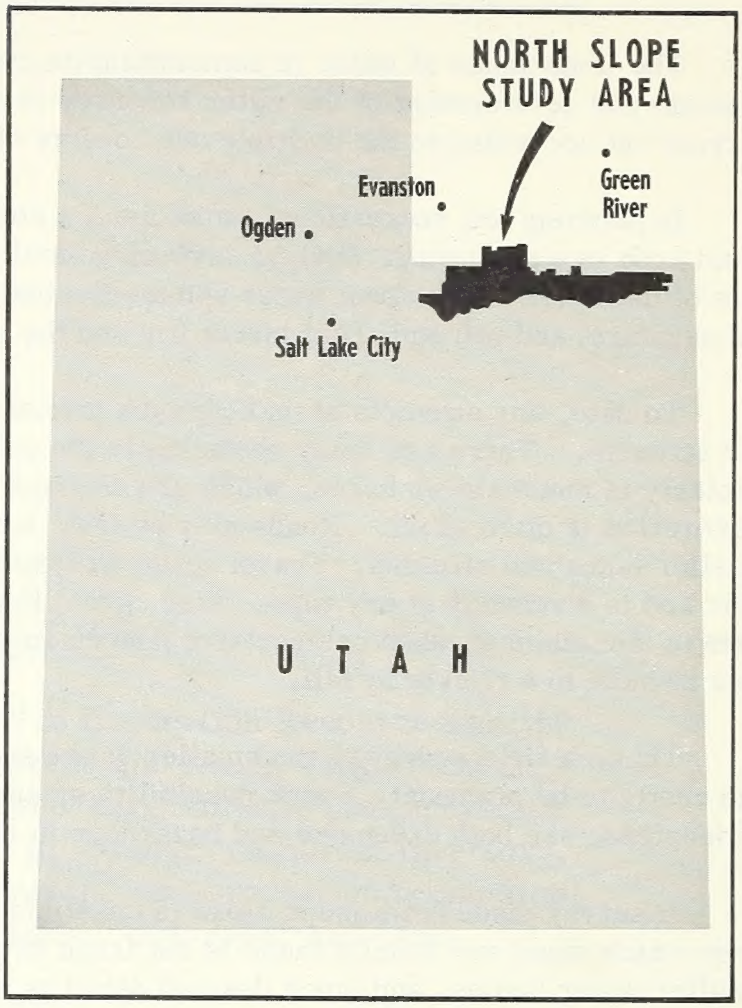

Figure 1.--Location of study area.

PRELIMINARY PROCEDURES

To be successful, a water resource inventory using aerial photographs must be planned and organized to make the best use of available funds and manpower. The amount and kind of detail to be collected must be decided upon. Selection and training of the photo interpreter require a varying amount of advance preparation, depending on the level of intensity of the study.

THE DRAINAGE BASIN UNIT

The drainage patterns of mountains greatly influence the development of timber and other resources, as well as water. Water resource data are most useful to administrators when mapped and presented by units that correspond to drainage basins. The acreage included in any particular drainage unit is not of great importance, but the unit boundaries should coincide as nearly as possible with the boundaries of working units established for timber, forage, and other resources. This organization allows comparison of resource values common to a specific area. Fishery biologists, foresters, water engineers, highway planners, and land managers can adjust their specific development plans to avoid damaging other resources.

Ridgelines, divides, and saddles form the natural separation between drainage units and are logical choices for boundaries. They have the advantage that they can be easily identified without costly surveying on maps and photos as well as in the field. The boundaries of drainage units should be marked on a map of adequate scale; one-fourth inch to the mile is usually sufficient. The same boundaries should be marked on a series of maps of larger scale, such as 1 to 2 inches per mile. These are used to show the position of lakes and streams as the inventory progresses.

On both the large and small scale maps, the drainage basin units should be systematically numbered for identification and reference of inventory data.

PURCHASE AND PREPARATION OF AERIAL PHOTOS

When the boundaries of the area to be studied have been determined, the photos may be ordered. Median scale (1:20,000) aerial photographs are readily available at moderate cost and cover most of the United States. Such photos are usually taken with panchromatic film and a filter to remove blue light, permitting moderate penetration of haze. They can be purchased from the U.S. Agricultural Stabilization and Conservation Service or from the U.S. Forest Service. Index sheets show the photographic coverage available over any specific area, and the required prints should be ordered from these sheets by individual photo number.

In aerial photography, images of all terrain features visible on one photo are duplicated on one or more adjacent photos; that is, there is a large amount of overlap between adjacent photos. Therefore, it is particularly important that the effective area of each photo be marked before the inventory is begun, so that no water areas are either omitted or inventoried more than once. The effective area is an approximately rectangular area in the central portion of each photo. Procedures for delineating effective area are given in appendix A.

Because the scale on an aerial photo varies with the height of the camera above ground level, it not only changes from one photo to another, but from one portion of a photo to another, even within the effective area. Changes in scale are particularly great in mountainous regions where ground elevation changes abruptly and where conditions require frequent changes in flying height. Unless the photo interpreter recognizes scale variations, he will get erroneous impressions or measurements. For this reason, care must be taken to determine the scale of each aerial photo to be used in the inventory. This is not necessarily a difficult or time-consuming procedure, as convenient tables may be worked out to simplify the calculation. Detailed discussion of procedures for scale determination may be found in "Manual of Photographic Interpretation."[1] In general, scale determination requires the use of accurate contour maps from which the elevation above sea level can be read for specific points on a given photo.

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[1] American Society of Photogrammetry. Manual of photographic interpretation. 868 pp., Washington, D.C., 1960. See chapter 3, Fundamentals of photo interpretation.

QUALIFICATIONS AND TRAINING OF THE PHOTO INTERPRETER

The efficient use of aerial photography for a water resource inventory requires that persons assigned the duty of interpretation have some technical knowledge of photogrammetry and some training and experience in actual interpretation. In any practical situation, the success of the inventory will depend largely on the skill of the interpreter. Every effort should be made to secure a qualified person or to give adequate training to those who are assigned to the work. Those without general aerial photogrammetric training may refer to the publications on this subject by Moessner[2] and Moessner and Choate.[3] Most colleges and universities offer courses in photogrammetric techniques.

A primary requisite for the photo interpreter is the ability to use the stereoscope. Normal vision in both eyes is therefore required. Almost all the work with the photographs is done with the three-dimensional image provided by stereoscopic viewing. In this, as in all skills, experience is valuable in that it allows the user to produce results faster and more accurately. Time spent in practice with the stereoscope is a necessary part of training.

In addition to specific training and experience with the photos themselves, the interpreter should have field experience. He should have the opportunity to make a few comparative ground measurements of features typical of those he will be expected to recognize or measure on photos. He should travel through the inventory area with the aerial photos and make direct comparisons between the photo image and the ground situation. In a water inventory, for example, he would want to study the ground situation in terms of lake depth, stream width, slope of bank, vegetation type, and similar features.

INVENTORY OF LAKES

The inventory of lakes has two aspects: (1) the determination of the total number of lakes and their location, and (2) the physical description of each lake. Because this information is valuable even for small lakes and streams, it is desirable that the inventory be as complete as possible.

RECOGNITION OF LAKES ON PHOTOS

For the most part, lakes are easily recognized on aerial photos. The smooth texture of the lake surface is generally so different from the surrounding vegetation or ground surface that the interpreter can instantly pick out the lake images. However, photo images of lakes vary considerably in tone from deep black to light gray. When light is reflected from a lake surface, suspended sediment, light-colored vegetation, or lake bottom material, the image on panchromatic photos appears light gray. But when light is absorbed by deep water, dark materials in the water, or the lake bottom, the resultant tone of the photo image is dark.

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[2] Moessner, Karl E. A simple test for stereoscopic perception. U.S. Forest Serv., Central States Forest Exp. Sta. Tech. Pap. 144, 14 pp., illus. 1954.

[3] Moessner, Karl E., and Grover A. Choate. Estimating slope percent for land management from aerial photos. U.S. Forest Serv. Res. Note INT-26, 8 pp., illus. 1964.

Lake images that are light gray or white seem to blend with the image tones of adjacent rock slopes, and may easily be overlooked (fig. 2). Stereoscopic examination reveals them, however, and field investigation shows that such lakes are almost always heavily silted; their water is opaque, and all underwater detail is obscured.

Occasionally alpine meadows and dry lakebeds have photographic tones similar to those of opaque lakes. Stereoscopic study of the photo images, however, reveals textural differences between the water surface of a lake and the vegetation of a meadow. When meadows surround marshlike lakes, the exact position of the shoreline is difficult to delineate on photos. In such cases, ground inspection often shows that the area is subject to spring flooding followed by a lowering of water that exposes meadows during the late summer. Dry lakebeds, on the other hand, can be recognized by their basinlike conformation.

RECORDING THE LAKES BY DRAINAGE UNITS

The photo interpreter can quickly identify and count all the lakes within each drainage unit. Any convenient method may be used to identify them if they are not already named. It was helpful in this study to number each lake initially by both drainage unit and the number of the aerial photo on which it appears. For example, lake 3-10-EBW-9-198 would be the third lake in drainage unit 10 on photo EBW-9-198. The center of each lake was pinpricked on the photo and the lake number was written on the back of the photo next to the pinprick. All the lakes in one drainage unit were later numbered consecutively on the map and cross-referenced to the photo numbers for rapid retrieval of the photo on which a particular lake was shown. These numbers were used on the drainage unit map to show the location of the lake. When large numbers of small lakes less than an acre each are clustered on the photo, it may be unnecessary or difficult to indicate the precise position of each on the map. In such instances, the total number of lakes less than 1 acre and of a single type can be simply recorded for each drainage unit, and no specific locations need be shown.

Figure 2.--An opaque lake image, compared with a clear lake image. Lakes that appear cloudy on the ground may produce light images on panchromatic photographs; such images may blend with the tones of rock slopes. (Enlarged X2)

DESCRIBING LAKE CHARACTERISTICS

By measurements made entirely on aerial photos, lakes can be described in terms of (1) type, (2) size, (3) elevation, (4) depth, (5) clarity of water, and (6) shore cover. Description of bottom material, water temperature, forms of aquatic vegetation, and fish life is not possible from aerial photographs.

The extent to which lakes are studied and classified depends primarily on the intensity of the survey to be made. In this study, lakes larger than 1 acre warrant description according to type, acreage, depth, clarity, and shore cover. Smaller lakes usually require type and size classification only.

Lake Type

Five lake types were recognized in the study area. In other geographic regions, additional or different lake types may be appropriate. The following type classes were used:

1. Cirque lakes--those in the cirque basins formed at the head of former glaciers.

2. Moraine lakes--those formed behind the terminal or lateral moraines left by former glaciers.

3. Reservoirs--lakes formed or altered in level by human activity. Reservoirs can be recognized by the amount of shoreline exposed by fluctuating water levels.

4. Beaver ponds--small impoundments created when watercourses are dammed by beaver.

5. Potholes--small depressions formed by disintegrating glaciers and retaining less than 1 acre of water.

The last two lake types are the most difficult to identify because they are frequently similar in size. However, it is desirable to distinguish between them, because beaver ponds are not so permanent as other lakes (spring runoff frequently breaks beaver dams), and because they have different recreational values. Beaver ponds provide fishpools, and the higher water temperatures in the ponds usually allow fish to multiply more rapidly than they generally do in the cold mountain streams. On the other hand, potholes may not support game fish, but they occur in significant numbers and often serve as reflection pools, thus helping to create attractive surroundings for hiking and camping. Some pothole lakes are occupied by beaver, and beaver houses may be visible on photos. Because such impoundments are not created by beaver, they should be classified as potholes rather than beaver ponds.

In general, beaver-formed ponds are associated with flowing water of small streams (fig. 3). They tend to photograph in medium or light tones of gray, and can generally be recognized by the characteristic fan-shaped pool behind the dam. A ripple of "white water" flowing over the crest of the dam is sometimes visible on the photo. Recognizable beaver houses may provide an additional clue. In contrast to beaver ponds, potholes usually occur in groups in the glacial dumps of terminal and lateral moraines or in glacier-scarred basins. These depressions often contain substantial amounts of organic matter, and the ponds thus tend to photograph in darker tones than do beaver ponds.

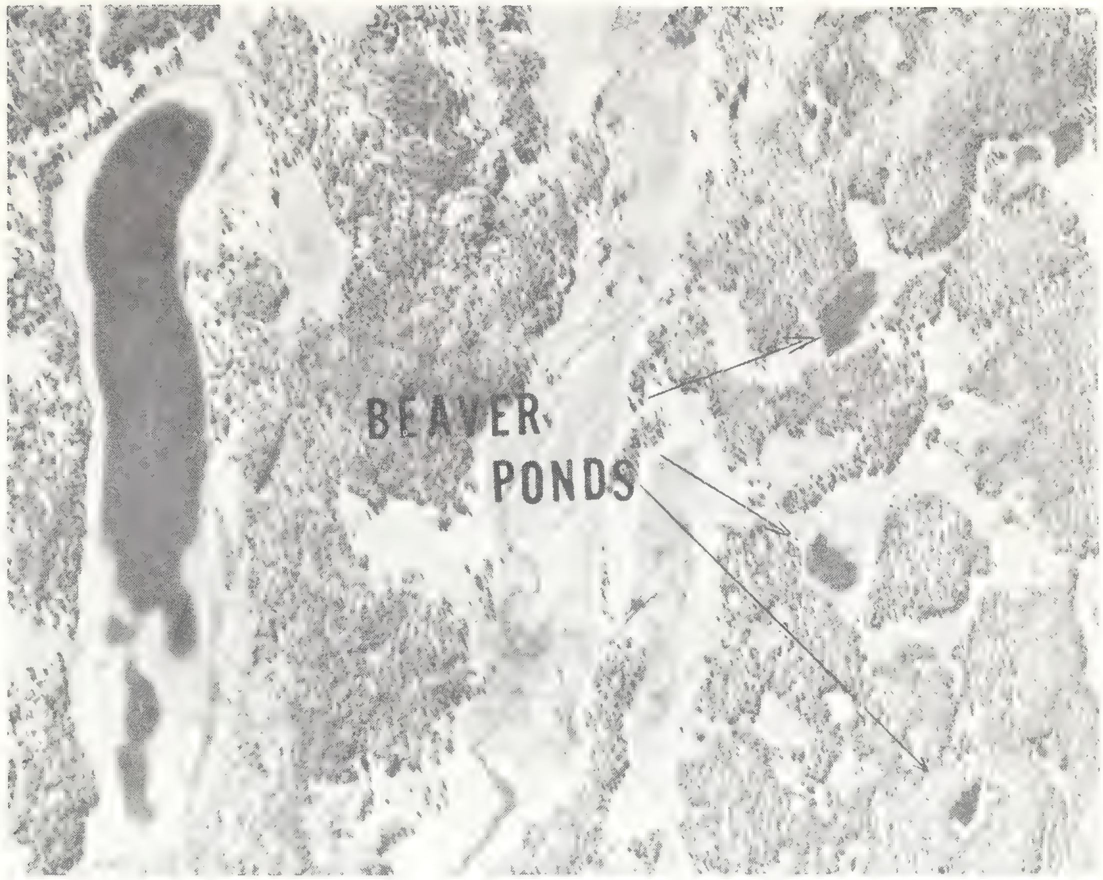

Figure 3.--Beaver ponds on aerial photo. White in upper pond is a beaver house.

Lake Size

Description by class.--Lakes of different sizes have different possibilities for recreational use. Therefore classification according to surface area is recommended. The following five classes have been found useful for mountain lakes:

Class 1--less than 1 acre
Class 2--1.00 to 4.99 acres
Class 3--5.00 to 9.99 acres
Class 4--10.00 to 19.99 acres
Class 5--20 acres or more

The size class of a lake can be estimated directly on a photo by means of a lake size guide, a transparent overlay printed with concentric circles that correspond to the lake size classes at the average scale of the photos being examined. By placing the guide over a lake image on a photo, the interpreter can rapidly select the size class most nearly matching the lake surface area. It should be remembered that division of lakes into general size classes with the guide is merely an approximation of acreage. The acreage of a long, narrow lake, for example, cannot be accurately measured with a circular guide, but a reasonable estimate can be quickly made.

Description by acreage.--When it is deemed necessary to describe lake size more precisely than by classes, each lake image can be measured with a dot grid. This grid is a transparent overlay covered with equally spaced dots, each of which represents the center of a small square. For most lake measurements, a dot grid having 256 dots per square inch is adequate. Where added precision is desired, a microdot grid having 1,024 dots per square inch can be used.

The photo interpreter can rapidly compute the lake area by the following procedures:

Step 1.--Determine the exact scale of the photo at the lake surface elevation.

Step 2.--Determine the acreage per dot. For example, 1 square inch of photo surface at a scale of 1:19,000 is:

$$19{,}000 \times 19{,}000 = 361{,}000{,}000 \text{ square inches}$$
$$= 361{,}000{,}000 \div 144 = 2{,}506{,}944 \text{ square feet}$$
$$= 2{,}506{,}944 \div 43{,}560 = 57.55 \text{ acres}$$

Consequently, for a dot grid with 256 dots per square inch, the acreage per dot for a scale of 1:19,000 is $57.55 \div 256 = 0.225$ acre.

Step 3.--Count the dots superimposed on the photo image of the lake. This should be done while the photos are being viewed stereoscopically.

Step 4.--Multiply the number of dots counted times the acreage per dot.

Lake Elevation

The approximate elevation of a lake can be determined once the lake position is indicated on the contour map. Elevation is critical in estimating the approximate number of snow- and ice-free days that may be expected during the year, an important influence on general recreational use. The duration of the ice-free period also influences the amount of biological activity (such as fish growth) in the lake.

Depth

In this study, determination of maximum lake depth from photos could not be done accurately. Instead, photo interpretation was used to determine whether lakes were less or more than 15 feet deep, and if more, to estimate the percentage of each lake area that was under 15 feet deep. The procedures used were essentially those reported by Moessner.[4]

Any appropriate depth contour may be used. The 15-foot depth contour was judged to be a significant lake measurement in the study area for three reasons: (1) It is about the minimum depth that allows fish in high mountain lakes to escape suffocation and mortality during severe winters; (2) it approximately defines the "littoral zone" in which light penetration and water temperature permit the production of food for fish; and (3) it is the maximum depth at which light penetration allows recognition of underwater detail on panchromatic photographs of clear lakes.

The techniques used for estimating depth on aerial photos are based on the assumption that the immediate bank slope surrounding a lake continues more or less unchanged for some distance under water. Thus, lakes with steep banks on all sides are considered more likely to be deep than are lakes with nearly level banks.

Estimations of lake depth may be based mainly on the interpreter's judgment of steepness of bank slope or may be calculated from bank slope measurements on the photo. Measurement is, of course, more accurate, and it allows the interpreter to predict depth at specific distances from shore.

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[4] Moessner, Karl E. Estimating depth of small mountain lakes by photo measurement techniques. Photogram. Eng. XXIX(4): 580-588, illus. 1963.

Depth classification without measurement.--In this method, the photos are examined stereoscopically and a judgment is made on unmeasured estimates of bank slopes. Other clues to the slope of the lake bottom are considered, including the general configuration of the lake, the expected characteristics of lakes of known origin, images of underwater detail, such as vegetation or rocks, and the lighter or darker tones of different parts of the lake.

In the test study, two experienced interpreters worked independently to estimate the position of the 15-foot depth line for each lake and to draw it on the photo. Their estimates were inaccurate for the shallower lakes. None of the four lakes determined from field measurements to be less than 15 feet deep was correctly classified by either interpreter. Only one lake was judged to be less than 15 feet deep, and field measurements showed this lake to be actually deeper than 15 feet. Although depth judgments were often wrong, lakes with steep banks were seldom misclassified. Training of photo interpreters should include practice in comparing estimates of bank slopes with parallax measurements of the same slopes.

Depth classification using parallax measurement.--In this method, selected bank slopes around each lake image are measured, using parallax wedges, as described by Moessner and Choate.[5] Accuracy may be improved if the banks most likely to characterize lake depth are chosen according to indications such as the clues mentioned above. For example, if underwater vegetation is evident near a steeply sloping bank, that bank is probably not a good choice for parallax measurement.

The underwater extension of each measured bank is calculated, and the distance from shore at which a water depth of 15 feet would be expected is calculated. The resulting points are then plotted on the photo. For example, a 20-percent bank slope (20/100) would result in a 15-foot lake depth at 75 feet from shore if it continued under water without change:

$$\frac{\text{15 feet}}{\text{Distance from shore}} = \frac{20}{100}$$

$$\text{Distance from shore} = \frac{15(100)}{20}$$

$$= \text{75 feet}$$

In the test study, three trained interpreters measured bank slopes of 21 lakes on the photos. Their measurements gave dependable depth information for steep-sided lakes. The 17 lakes that were deeper than 15 feet, as determined from depth measurements made from a boat, were all correctly identified by parallax measurements. However, this procedure proved undependable for lakes with the shallowest water and the gentlest bank slopes. Of the 12 depth estimates made for the four lakes found to be less than 15 feet deep, only three were correct (25 percent).

Lake size as an indicator of lake depth.--To cut down the time required for depth classification using parallax measurements, the relation of lake size to the steepness of general terrain and lake banks may be used as an indicator of depth. The bank slope of a small lake must be quite steep if the lake depth is to reach 15 feet or more. Conversely, large lakes are likely to be 15 feet deep even when their bank slopes are relatively gentle. This general relation between lake size and minimum average bank slopes may be tabulated for convenience, using general estimates taken from the photos and based on field experience. For lakes on the North Slope, the relationships between size and slope were as follows:

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[5]See footnote 3.

Lake size (Acres)	Slope[1] (Percent)
Less than 5	28
5-10	25
10-15	22
15-20	19
20-40	15
More than 40	10

[1]Average of the two steepest measured slopes.

Such a table may be used to classify lakes into two groups as more or less than 15 feet deep, on the basis of average bank slope measurement, without actual plotting of the 15-foot depth contour. Eliminating the plotting of the underwater contour considerably reduces the work time required per lake. Although the time saving does result in somewhat reduced accuracy, 80 percent of the lakes in the study were classified correctly by this method. Lakes that fail to meet these minimum criteria of slope and lake size must be measured with additional slope readings and the 15-foot depth contour must be plotted.

Estimating Shallow Area of Lakes

In a recreation inventory, it is often desirable to know what proportion of a deep lake is relatively shallow. As mentioned earlier, fish are not likely to survive over winter in lakes less than 15 feet deep but are largely dependent on food produced in the shallow zone of less than this depth.

Two methods can be used to determine the proportion of shallow zone area. The first, contour plotting, requires that slopes be measured on photos, and that the 15-foot depth line be plotted. The shallow area is then determined by the dot-counting technique described earlier. The second method, formula computation, still requires bank slope measurements but eliminates the plotting and dot-counting chore by using a formula to compute the proportion of shallow area. The proportion can easily be converted into acreage if a dot count of the total lake area has been made.

Shallow area estimation by plotting contour.--Once the 15-foot depth line has been drawn on a photo, either from unmeasured estimates or from projection of 5 to 10 measured bank slopes per lake, it is easy to obtain the shallow zone area of each lake by the dot-count procedures described earlier.

Contour plotting with parallax measurements was found to be the most accurate of the two methods when results were compared with field measurements. Without parallax measurements, only 47 percent (16 out of 34) of the photo estimates of the shallow zone area were within ±25 percent of field measurements. However, estimates based on parallax measurements and projections of bank slopes were within ±25 percent of field measurements 80 percent of the time (41 out of 51).

Formula computation of shallow area.--The formula method of estimating shallow zone area uses 5 to 10 bank slope measurements and projections. The equation is as follows:

$$\text{Proportion of lake in shallow zone} = \frac{2\bar{D}(L + W - 2\bar{D})}{LW}$$

where

$\bar{D}$ = the average distance from shore to the 15-foot depth line as projected from measured bank slopes

L = length of lake

W = width of lake.

The formula is derived on the assumption that each lake is a perfect ellipse.[6] Formula estimates of shallow zone area were within ±25 percent of field measurements 69 percent of the time (35 out of 51, table 1, page 21).

Formula-derived estimates of shallow area averaged somewhat less than field estimates. An adjustment factor may be used to improve accuracy if field measurements are available for a few sample lakes. The factor is the result of dividing the average field-measured proportion of total lake area to shallow area by the average formula-estimated proportion. Each formula estimate is then multiplied by this factor to obtain an adjusted formula estimate. In the test study, an average factor for the three interpreters was used (1.16). The adjusted estimates were within ±25 percent of field measurements 75 percent of the time (38 out of 51). Because estimates tend to differ from one photo interpreter to another, slightly better accuracy can be obtained by using a separate adjustment factor for each photo interpreter.

The accuracy of the four methods may be summarized according to percent of estimates coming within ±25 percent of values based on field measurements as follows: (1) 80 percent accurate (41/51)--plotting of 15-foot depth contour with parallax measurements; (2) 75 percent accurate (38/51)--adjusted formula estimation; (3) 69 percent accurate (35/51)--unadjusted formula estimation; and (4) 47 percent accurate (16/34)--contour plotting without parallax measurement. (The estimates on which these percentages are based are given in table 1, page 21.)

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[6] If the lake is an ellipse, then the shallow zone area equals the total lake area minus the deep zone area. Thus,

$$\text{Total lake area} = \frac{\pi LW}{4}$$

$$\text{Deep area} = \frac{\pi(L - 2\bar{D})(W - 2\bar{D})}{4}$$

$$\text{Shallow area} = \text{total area} - \text{deep area}$$

$$= \frac{\pi LW}{4} - \frac{\pi(L - 2\bar{D})(W - 2\bar{D})}{4}$$

which reduces to

$$= \frac{2\pi\bar{D}(L + W - 2\bar{D})}{4}$$

This must be divided by the total area of the lake to convert it to the proportion of lake in shallow zone.

$$\text{Shallow area} = \frac{2\pi\bar{D}(L + W - 2\bar{D})/4}{\pi LW/4} - \frac{2\bar{D}(L + W - 2\bar{D})}{LW}$$

NOTE: In order to convert a proportion obtained by the formula method to acreage of shallow area, when no dot count of total lake area has been made, the total area can be calculated by the formula $\pi LW/4$.

Clarity of Lake Water

The relative clarity of the water contained in lakes can be judged on the basis of the color tone of the photo image. Lakes which appear light gray or white (opaque) on panchromatic photos generally contain suspended solids. It is more difficult to predict the water clarity of a lake which appears dark on the photo. The water may be clear or may contain varying amounts of suspended material.

Shore Cover

The type of vegetation surrounding a lake influences its recreational utility. Wood for campfires is difficult to obtain at lakes without tree cover. Dense brush cover may require construction of trails. Boggy or marshy areas surrounding a lake make access difficult. For these and other reasons, it is desirable to indicate the approximate percentage of the lakeshore that falls in the following cover classes:

1. Forest--stands of trees averaging 20 feet or more in height.

2. Brush--woody vegetation less than 20 feet in height.

3. Bog--wet areas of grasses and sedges that usually appear in dark tones on photos.

4. Meadow--areas of grasses and sedges that are drier than bog and usually appear in lighter tones on photos.

5. Barren--no vegetation present.

INVENTORY OF STREAMS

Aerial photographs provide far less information for streams than for lakes. Streams less than 20 feet wide can be easily obscured by tree or brush cover, so that any measurement is difficult. Depth measurements such as those made on lakes are impossible, even when the stream is plainly visible. Nonwater features are often mistaken for streams on photos. Live streams that are not hidden by overtopping vegetation appear as thin and meandering dark lines (fig. 4). Shadows of steep drainage banks, as well as the outcrops of dark rock strata, can appear as similar lines.

In spite of these problems, photo interpretation and measurement can be used to obtain estimates of stream length, width, and gradient, and a general description of streambank cover. The principal value of the photos in a stream inventory is to correct and supplement the information given on available maps of the area. In addition, photos are a logical tool for field location of sample points if on-the-ground measurement of additional stream characteristics is planned.

If no field measurements are to be taken, aerial photos should be used to improve the basic description of streams given on the best maps of the area. Most modern maps are made from aerial photos and show the location of streams fairly accurately. However, because in general these maps are based on small-scale photos, much detail visible on 1:20,000 scale photos is not apparent to the mapmakers.

Figure 4.--A typical live stream appears on panchromatic photography as a meandering, thin, dark line.

RECOGNITION OF STREAMS ON AERIAL PHOTOS

Larger streams, which are easily recognized on the photos, are usually correctly mapped. Many smaller streams, however, particularly in mountainous areas, cannot be identified from a map alone as flowing, dry, or intermittent. A number of these can be correctly classified from photos, and substantial savings over field inventory costs can be made.

Where live streams are obscured by vegetation, their presence may sometimes be inferred from related photo features. A meandering pattern of dark blotches through a forested area may be made by marshes, springs, seeps, or other riparian vegetation and water. On the other hand, dry drainage channels usually appear on panchromatic photography in light-colored image tones, because the deposits of clay, silt, sand, and rock tend to reflect light. Such indirect evidence as exposed boulders, the absence of riparian vegetation, and lack of springs or marsh areas all suggest that a channel is dry.

Intermittent streams are the most difficult to identify on aerial photos, especially in the upper reaches where flow is strongly influenced by periodic rainfall. A small channel may contain a live stream on the date of photography and be dry immediately thereafter. Similarly, field surveys may find water where none was present at the time of photography. Nevertheless, experience indicates that if the photo interpreter "sees" water in a channel when he is viewing photos stereoscopically, a field check will usually confirm his judgment. This probability is raised by the fact that most resource photos are taken during late summer and autumn, when stream levels are lowest.

When streams are identified, obviously dry channels can be eliminated from the inventory. Any later fieldwork can be concentrated on streams that remain questionable after the photo interpretation has been completed.

RECORDING STREAMS BY DRAINAGE UNITS

Most drainage units contain one main channel and one or more channels tributary to it. Although most of the main stream channels are named, the smaller tributaries are frequently nameless. For convenience in reference, it is desirable to use some system of numerical and alphabetical identification. In this study, the main channel was given the same number as that of the drainage unit in which it was located. Tributary streams were then identified with the letter "T" following the unit designation number. The first tributary was labeled TA, the second TB, and so on, until each flowing tributary was identified. In the example shown in figure 5, the third tributary in drainage unit 10 is identified as 10TC.

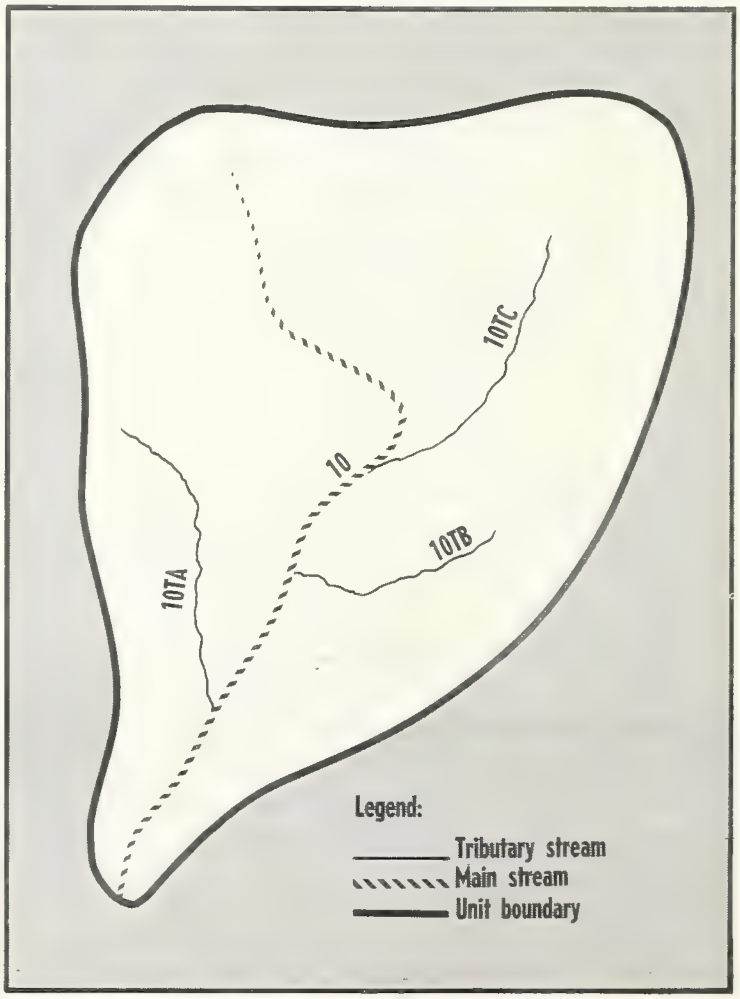

Figure 5.--Typical drainage unit, showing pattern and identification of streams.

DESCRIBING STREAM CHARACTERISTICS

Stream Length

Aerial photos are particularly effective for editing maps for stream length. If available, maps with a scale as large as 1 or 2 inches to the mile are best for use with the photos. End points of each stream should be located first on the photos. The end points are transferred to the map as accurately as possible and the apparent length of the stream and its tributaries can then be measured on the corrected map. The stream's lower end is defined as the point where it flows into another stream. The upper end is defined as the highest point in the drainage that gives evidence of permanent flow of water.[7] Dry or intermittent channels can be eliminated so that only the essential portions of any stream under consideration will be included. Dividers, set to the scale of the map, are used to step off the length at quarter-mile intervals to give the unadjusted length of the entire stream or any portion of the stream. This unadjusted length underestimates actual stream length, because small bends and other deviations in stream direction cannot be accurately mapped. However, the mapped stream length can be multiplied by a "meander factor" to give an adjusted stream length.

The meander factor is the ratio between the meander distance as visible in the photo and the straight-line distance for a given stream segment.

The procedure for determining meander distance on the photo is to rule a thin straight line on a strip of transparent paper and then match this line to short segments of the stream. Two points approximately a quarter of a mile apart in straight-line ground distance are selected on the stream image. The paper is placed over the photo so that one end of the ruled line is over one of the selected points, and a pin is pushed through the paper and into the photo at this point. The paper is then pivoted so that the line lies over a short section of the stream course. A second pin is then placed at the point where the stream image diverges from the ruled line. The first pin is removed and the paper pivoted to coincide with the next section of stream. This process is repeated until the point a quarter of a mile away is reached. The amount of line used is then measured, and the meander factor is calculated:

$$\text{Meander factor} = \frac{\text{Photo meander distance}}{\text{Photo straight-line distance}}$$

Because the value sought is a ratio, any units of measurement can be used on the photo; conversion to ground distances is not required. Several measurements may be made at different points along the stream photo image and an average meander factor established. Thus a stream with an average meander factor of 1.470 and an unadjusted mapped length of 8.6 miles would have an adjusted length of 8.6 X 1.470 = 12.64 miles.

In some instances, a general average meander factor for a particular drainage basin may be used for all streams in the basin. This saves time without any considerable loss of accuracy.

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[7] If work on photos is followed by on-the-ground sampling, the upper end of the stream may be redefined by other criteria. During the fieldwork on the North Slope study the upper end of each stream was arbitrarily defined as the point where stream width dwindled to 4 feet.

Stream Width

Stream width is difficult to measure accurately from photos. Perhaps the most practical course is to group the stream segments on photos into width classes. This method produces reliable estimates. Appropriate class limits for small mountain streams are:

1-20 feet
21-50 feet
51-100 feet
101-200 feet

Limits can be established as needed, depending on conditions in the area under study. However, for evaluation of recreational possibilities of streams, the above classification is generally adequate. If estimates of stream surface area are needed, the adjusted stream length and the midpoint value for the width class can be multiplied together. Length of segments may be determined in any convenient manner, depending on the general amount of variation in stream width.

Stream Gradient

Gradient can be determined most easily directly from contour maps. If contour maps are not available, elevation differences may be determined by parallax wedge measurements on aerial photos. Once the adjusted length for the entire stream has been determined, the gradient, in percent, can be found by dividing the elevation difference between two points by the adjusted stream length between these points and multiplying the result by 100.

Streambank Cover

Streambank cover can be recognized by an experienced photo interpreter and can be classified for stream segments as:

1. Forest--stands of trees averaging 20 feet or more in height.

2. Brush--woody vegetation up to 20 feet in height.

3. Open--no shrub or tree cover recognizable on photos.

If vegetation cover maps have been prepared for other purposes, they may provide adequate cover information without further photo work.

LEVELS OF INTENSITY OF AN INVENTORY

The procedures in a water resource inventory may be combined in several ways to make up inventories of varying degrees of intensity.

LAKE INVENTORY

In the early planning stage of the inventory, some decision will probably be made as to the amount of information desired; however, in the course of the study, it may become advisable to step up or step down in intensity. Particularly promising lake areas discovered in the course of a low-intensity study may warrant closer examination and measurement. In a high-intensity study, a group of lakes of similar nature may require only sampling.

As a guide in the choice of level, information is needed on the time required for each procedure. In the present study the following evaluation has been made:

Procedure	Approximate time required per lake
Lake size determination:	
By class, with lake size guide	1 minute
By area, dot count	$\frac{1}{2}$ hour
Determination of elevation, type, clarity, shore cover	5 minutes
Depth determination:	
By plotting without measurement	5 minutes
By plotting with parallax measurement	$\frac{1}{2}$ hour
Determination of shallow area:	
By plotting without measurement, including dot count	$\frac{1}{2}$ hour
By plotting with parallax measurement, including dot count	$1\frac{1}{2}$ hours
By use of formula	$\frac{1}{2}$ hour or less

Three possible combinations of procedures, with time approximations for photo interpretation, are as follows:

1. Low-intensity photo inventory (average of 10 minutes per lake).

a. Inventory all lakes and ponds within each drainage basin unit by lake type, size class, elevation, water clarity, and shore cover.

b. Use unmeasured estimates of bank slope, the lake size guide, and a table of minimum bank slopes to classify all lakes larger than 1 acre as either "probably deep" (more than 15 feet deep) or "probably shallow" (less than 15 feet deep).

2. Medium-intensity photo inventory (average of 45 minutes per lake).

a. Inventory all lakes and ponds within each drainage basin unit by lake type, size class, elevation, water clarity, and shore cover.

b. Use a combination of unmeasured and measured estimates of bank slopes, the lake size guide, and the table of minimum bank slopes to classify all lakes larger than 1 acre as either "deep" or "shallow." Lakes having bank slopes that are judged to exceed the minimum required by the table need not be checked with parallax measurements and may be classified as "deep." For all other lakes, take parallax measurements of the one or two bank slopes considered most indicative of lake depth. Classify lakes as "deep" if slopes equal or exceed minimum values in table, "shallow" if slopes are less than these table values.

c. Use parallax measurements and the formula for calculating shallow area of lakes that seem to justify further evaluation because of size, location, or depth.

3. Full-intensity photo inventory (1 hour and 30 minutes per lake).

a. Inventory all lakes and ponds within each drainage basin by lake type, size class, elevation, water clarity, and shore cover. Measure area of all lakes over 1 acre in size by dot-count procedures.

b. Classify all lakes over 1 acre in size as "deep," or "shallow." Classify as "deep" if measured bank slopes exceed the table values, "shallow" if they do not.

c. For all lakes classified as "deep," plot the 15-foot depth line from 5 to 10 measured bank slopes and compute the shallow zone area by dot-count procedures.

Any further details unobtainable by a full-intensity inventory must be gathered on the ground. In the Uinta Mountains, field measurements cost approximately seven times as much per lake as full-intensity photo measurements. However, they may often be justified after photo techniques have been used to identify the lakes most likely to offer outstanding opportunities for recreation.

STREAM INVENTORY

The primary objective of a stream inventory from aerial photos is to evaluate the stream resource of each drainage unit in terms that allow comparison with the stream resource in other units. If a higher intensity inventory is desired, however, the same techniques can be used to describe individual segments of a stream, so as to allow comparison of different parts of the same stream. For example, streams can be described in 1-mile segments, permitting the identification of unique or separate sections of a given stream.

The time requirements for stream inventories cannot be estimated as easily as those for lake inventories, because streams vary greatly in length. However, as a rough guide, most streams can be adequately classified in 4 hours. The description of a particular segment of a stream will take between 2 and 3 hours.

APPENDIX A

DETERMINATION OF EFFECTIVE AREAS ON AERIAL PHOTOS

Delineation of effective areas on aerial photos requires marking off the boundaries of the area on each photo that appears on that photo alone. Overlap occurs perpendicular to the flight line and between lines of flight. The procedure is as follows:

Marking boundaries perpendicular to the flight line--endlap.

Step 1.--Taking the first two photos in a flight line, place photo 1 over photo 2 so that images common to the two photos are approximately superimposed. Then, rule a straight line (in ink or crayon pencil) on photo 1 so it approximately bisects the area of endlap and is approximately perpendicular to the line of flight. This line should pass through two easily recognized image points, several inches apart on the photos, and representing the highest points of topography in a position suitable for the ruled line.

Step 2.--Duplicate this ruled line on photo 2 by drawing it through the images of the same points on this second photo. This duplication is simpler if the photos are examined in stereovision. If both lines pass through image points representing high points in the topography, then no photo detail will be excluded. Some detail at low elevations may be duplicated within the effective area of the two photos, but if ruled lines pass through high points, effective areas can easily be separated and adjustments made under stereovision.

Step 3.--Repeat this procedure for all photos in a single flight line, pairing photo 2 with photo 3, 3 with 4, etc.

Marking boundaries between lines of flight--sidelap.

Step 1.--Place the first photo in one flight line over the first photo in an adjacent flight line so that images common to the two photos are approximately superimposed. Then, rule a straight line on the top photo so it is approximately parallel to the flight line and approximately bisects the area of sidelap. If possible, this line should pass through two prominent image points. Draw this sidelap boundary only until it meets the endlap boundaries drawn previously.

Step 2.--Duplicate this ruled line on the bottom photo. Since stereovision of images from adjacent flight lines is difficult or impossible, duplication of the ruled line must be guided by location of image points crossed by the line on the top photo. It is convenient to hold the two photos on a desk top in overlapped position with one hand. The other hand can be used to pull up one edge of the top photo so that images common to the two photos can be identified and marked.

Step 3.--Repeat the procedure for all other sidelapping photo pairs. The boundaries ruled for each endlap and sidelap area will define the effective area on each photo.

APPENDIX B

The guide is prepared by drafting concentric circles to represent areas of 1, 5, 10, and 20 acres at the average scale of the photos being used. Radii for the circles are easily calculated from (1) the formula for the area of a circle ($A = \pi r^2$), and (2) the average photo scale. For example, the radius of a 1-acre circle is calculated thus:

$$A = \pi r^2 = 43,560 \text{ square feet}$$

$$r^2 = 43,560 \div 3.1416 = 13,866 \text{ square feet}$$

$$r = 118 \text{ feet}$$

This can be converted to distance on the photo itself by the relationship:

$$\frac{\text{Radius on photo}}{\text{Radius on ground}} = \text{Photo scale}$$

For a 1-acre circle at a photo scale of 1:20,000 this becomes

$$\frac{\text{Radius on photo}}{118 \text{ feet}} = \frac{1}{20,000}$$

$$\text{Radius on photo} = 118 \text{ feet} \div 20,000 = .0059 \text{ foot}$$

Radii for a lake size guide applicable to 1:20,000-scale photos are as follows:

Area	Radius on photo
1 acre	0.0059 foot
5 acres	.0132 foot
10 acres	.0186 foot
20 acres	.0264 foot

A simple method of putting the circles on transparent material is to photograph them and prepare a positive transparency.

APPENDIX C

Evaluations of the accuracy of the photo interpreters' conclusions as to depth and shallow area have been referred to in the text. Table 1 gives detailed data from which the percentages were drawn, covering the estimation of shallow area by four different methods. Note that somewhat consistent variation is evident in the conclusions arrived at by the three interpreters. Any given interpreter may have a tendency to underestimate or overestimate; in preliminary field training this might well be noticed and thus be taken into account in actual survey work. Also, because of their particular characteristics, certain lakes were overestimated or underestimated by all interpreters.

The methods are as follows:

Method A: 15-foot depth contour plotted on basis of visual estimates; shallow area acreage obtained from dot count.

Method B: 15-foot depth contour plotted on basis of parallax measurements of bank slopes; shallow area acreage obtained from dot count.

Method C: Average distance from shore to 15-foot depth contour calculated from parallax measurements; proportion of shallow area computed by ellipse formula; acreage calculated on basis of total lake acreage obtained from dot count.

Method D: Shallow area computed as in method C; result adjusted by correction factor of 1.16.

Table 1.--Estimates of shallow area of lakes made by three photo interpreters, using four methods, as compared with shallow area measured in the field (North Slope, Uinta Mountains)

Lake no. and total acreage[1]	Measured shallow area[2]	Shallow area estimated by: Method A	Method B	Method C	Method D
		Acres			
		INTERPRETER 1			
1. 2.51	1.75	1.17	1.38*	1.56*	1.81*
2. 3.67	1.75	1.78*	2.14*	1.85*	2.15*
3. 4.51	2.83	1.61	3.13*	2.76*	3.20*
4. 6.64	5.16	4.09*	4.80*	3.57	4.14*
5. 7.44	6.04	5.12*	4.83*	4.80*	5.57*
6. 8.78	6.00	3.10	5.18*	5.15*	5.97*
7. 9.83	8.06	6.54*	5.52	5.57	6.46*
8. 17.61	8.98	11.04*	8.51*	9.26*	10.74*
9. 20.30	18.67	16.88*	13.19	11.71	13.58
10. 22.31	6.68	11.00	5.84*	5.69*	6.60*
11. 29.05	20.74	15.19	17.94*	11.59	13.44
12. 32.36	17.74	13.67*	16.70*	13.01	15.09*
13. 32.44	15.63	10.53	16.43*	15.12*	17.54*
14. 40.30	26.81	29.40*	26.44*	18.30	21.23*
15. 40.80	18.89	20.28*	25.56	19.50*	22.62*
16. 41.12	16.29	24.20	17.11*	11.23	13.03*
17. 63.91	16.18	37.91	21.96	18.34*	21.27
		INTERPRETER 2			
1. 2.51	1.75	2.41	1.46*	1.70*	1.97*
2. 3.67	1.75	2.16*	1.81*	1.73*	2.01*
3. 4.51	2.83	4.26	3.10*	3.20*	3.71
4. 6.64	5.16	4.72*	5.28*	5.05*	5.86*
5. 7.44	6.04	6.62*	4.82*	4.62*	5.36*
6. 8.78	6.00	6.52*	7.90	8.56	9.93
7. 9.83	8.06	9.21*	6.29*	6.46*	7.49*
8. 17.61	8.98	12.67	8.81*	10.14*	11.76
9. 20.30	18.67	19.76*	14.57*	15.27*	17.71*
10. 22.31	6.68	17.93	6.42*	6.02*	6.98*
11. 29.05	20.74	23.25*	22.96*	21.32*	24.73*
12. 32.36	17.74	29.13	16.20*	11.20	12.99
13. 32.44	15.63	25.71	13.99*	12.36*	14.34*
14. 40.30	26.81	40.30	29.30*	20.39*	23.65*
15. 40.80	18.89	39.41	19.31*	15.95*	18.50*
16. 41.12	16.29	34.04	17.33*	14.10*	16.36*
17. 63.91	16.18	46.68	22.11	18.53*	21.49
		INTERPRETER 3			
1. 2.51	1.75	[3]--	1.40*	1.22	1.42*
2. 3.67	1.75	--	2.21	2.07*	2.40
3. 4.51	2.83	--	2.70*	2.02	2.34*
4. 6.64	5.16	--	4.91*	3.76	4.36*
5. 7.44	6.04	--	6.69*	4.97*	5.77*
6. 8.78	6.00	--	6.29*	5.64*	6.54*
7. 9.83	8.06	--	6.60*	6.81*	7.90*
8. 17.61	8.98	--	10.56*	9.76*	11.32
9. 20.30	18.67	--	16.28*	13.44	15.59*
10. 22.31	6.68	--	5.35*	6.31*	7.32*
11. 29.05	20.74	--	20.39*	16.18*	18.77*
12. 32.36	17.74	--	16.93*	11.65	13.51*
13. 32.44	15.63	--	19.02*	19.07*	22.12
14. 40.30	26.81	--	27.60*	12.78	14.82
15. 40.80	18.89	--	25.87	16.48*	19.12*
16. 41.12	16.29	--	20.77	16.78*	19.46*
17. 63.91	16.18	--	28.62	22.50	26.10
Total number of estimates (*) falling within ±25 percent of measured shallow area		16/34	41/51	35/51	38/51

[1] Obtained from photos by dot-grid method.
[2] Based on soundings taken in field and dot count.
[3] Method A was used by two interpreters only.

AFPS, Ogden, Utah

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1967. Aerial photo techniques for a recreation inventory of mountain lakes and streams. U.S. Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah. 21 pp., illus. (U.S. Forest Serv. Res. Pap. INT-37)

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Project headquarters are also at:

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Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)


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