Snow Surveying with Aerial Photography

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1. SNOW surveying is an activity that is usually related to a hydrologist, while aerial photography is ordinarily assumed to be in the domain of a photogrammetry engineer. The two sciences may be strange bedfellows to the uninitiated, but as a matter of fact, they have been closely associated for a number of years.

Following is a description of one such association in progress presently for the Puget Sound Power & Light Company.

2. In 1958, Puget initiated a snow survey program in its Baker River Basin. This program is similar to ones in use since the late 1930's in many basins of the mountainous western United States. Eleven snow courses were established, and at eight of the courses, aerial markers were constructed. Before going further, let me briefly outline for you the nature of snow courses, snow surveys and aerial markers.

3. First, a little history. In the early 1900's, Dr. James E. Church, associated with the University of Nevada, began taking snow-depth measurements on Mt. Rose near Reno in connection with other regular weather observations. Dr. Church discovered that snow-depth, and more importantly the water equivalent of the snow, correlated very closely with the levels of Lake Tahoe in the following spring and summer months. He developed equipment for sampling snow and devised procedures to forecast the resultant runoff. His methods and ideas rapidly spread to most areas of the West Coast and even to many parts of the world. Today, there are 600 to 700 courses in Washington, Oregon and California.* Electric utilities, both public and private, irrigation districts, farmer co-operatives, forestry groups and many others all use data from snow surveys to operate more efficiently.

4. A snow course is usually composed of 5 to 15 sampling points over distances of 100 to 1,000 feet. (See Figures 1 and 2.) Periodically, usually once monthly during the winter season, measurements are made on the course. The measurements consist of taking a core sample at each point on the course.

Sampling is done with a set of sectionalized duralumin tubes, each 30 inches long, graduated in inches. Staggered ports are cut in each tube so that the depth of snow and the length of the snow core can be noted. (See Figures 3 and 3A.) A sample is taken by joining the tubes and forcing them through the snow by means of the tube turning and driving wrench. The tubes are withdrawn after refusal and placed horizontally on the scale for weighing. The sensitive spring balance is calibrated directly in inches of water. (See Figure 4.) The measurements at each of the several points are averaged to obtain an average depth and average water content for the course.

5. Usually several courses are located in a basin at various elevations, and the results of the measurements are used in forecasting runoff of the basin. Two types of runoff forecasts are generally made, both of which offer great utility to operating personnel of the Puget Sound Power & Light Co. The first type is a seasonal forecast, usually of the multiple correlation type which predicts the total volume of runoff during the spring and summer months from the previous winter's accumulated snow pack. Use of this type of forecast allows Puget's power specialists to establish rule curves for Baker River reservoirs that will give a maximum of usable energy output, at optimum head, with no waste or spill. The second type of forecast offering substantial benefits to Puget is the short-term runoff forecast, of the hydrograph synthesis type, primarily, based on aerial snow surveys and precipitation forecasts, which will predict the runoff from fall or winter freshets. Usually several of these short duration (3 to 6 days) rises, resulting from warm moisture-laden winds called "chinooks," occur every year. Being apprised of runoff potential in advance, the system power engineer can operate the reservoirs so spill will be minimized, to effect the most flood control under the

* In all the Western States 1600 to 1700—The Author.

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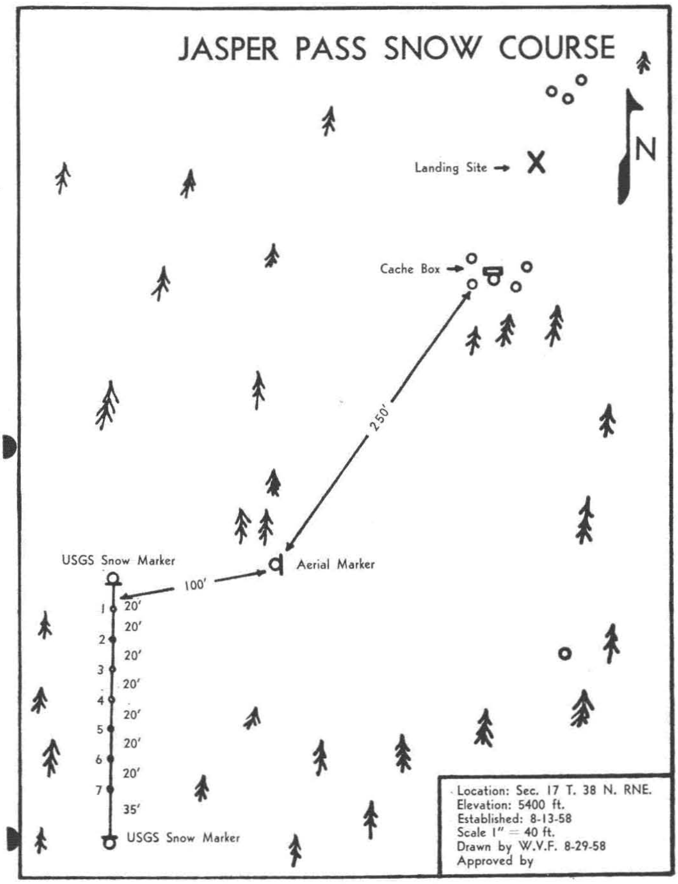

FIG. 1. Jasper Pass Snow Course Layout

This is a sketch showing the Jasper Pass Snow Course area. At upper right is the landing site for the helicopter and adjacent to the landing spot is the cache box location. The cache box is an aluminum container secured high in a tree which holds emergency food, medicine and camping equipment. The aerial marker is just left of center and the course itself is in the left corner. Note the general layout of the course with set distances between sample points.

circumstances, and to maximize the generation of energy.

6. Snow surveys have always been expensive. The courses are invariably located in remote mountain areas inaccessible by ordinary means of transportation. In the early days of snow surveys, several days or a week would be necessary to pack in to one course. Methods have, of course, been streamlined today. In many cases, helicopters are utilized to transport the snow surveyors to and from courses, allowing as many as 10 to 15 courses to be measured in one day. However, helicopters are also expensive tools. So, public agencies and private companies making use of snow surveys have been constantly on the lookout for cheaper and easier means to obtain these important data.

7. With this aim in mind, in the early 1950's, several California utilities began using aerial markers which were simply a ladder-like series of cross-boards (2×6's, 3 feet long) bolted to a tree or to a pipe anchored in concrete. The markers were placed adjacent to a regular snow course where it could be easily seen from a passing plane. Light planes are used to take pictures of the markers throughout the season. Photographs are examined with a magnifying glass and compared to a form drawing of the particular marker (see Figure 5) to obtain snow-depth. Densities are estimated from previous ground measurements. A basin of 8 to 10 courses then can be photographed in a matter of two or three hours counting travel time to and from the basin, or several basins may be covered in one day with resultant savings.

8. Last winter season was the first in which

FIG. 2. Jasper Pass Snow Course and Aerial Marker on January 18, 1961

On the original photo, the line of the course is superimposed on the photograph. The aerial marker in center of picture indicates a snow depth of 134 inches.

Puget attempted to make use of their aerial markers. Jesse Ebert, well-known aerial

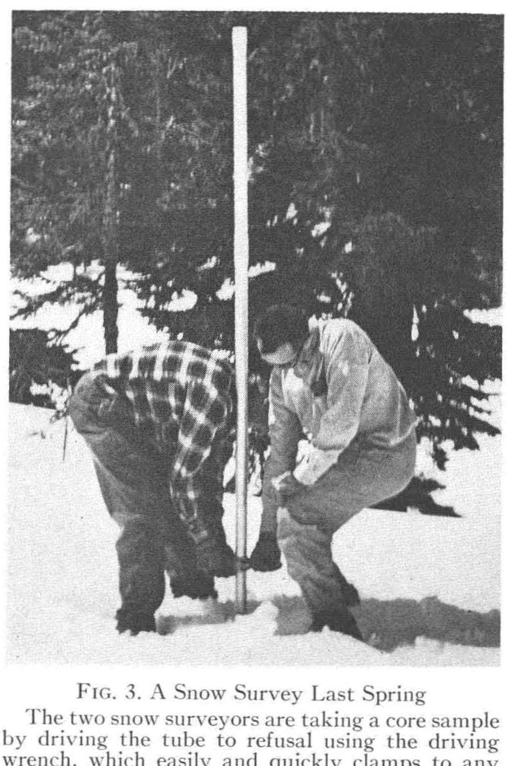

FIG. 3. A Snow Survey Last Spring

The two snow surveyors are taking a core sample by driving the tube to refusal using the driving wrench, which easily and quickly clamps to any portion of the sampling tube.

FIG. 3A. The sampling tube and snow course marker.

photographer in the Seattle area, was contracted to fly the Baker River Basin and photograph the eight aerial markers. Four flights were made with good results. After a brief description of the basin and the power projects, let's accompany Jesse on a typical flight.

9. The Baker River drains 297 square miles of a rugged, heavily-forested region lying partly in Whatcom and partly in Skagit Counties in the northwest sector of Washington. (See Figure 6.) Elevations range from 170 feet at the mouth to over 10,000 feet at the headwaters. Mt. Baker, 10,778 feet, and Mt. Shuksan, 9,127 feet in the upper reaches are, incidentally, two of the most photographed mountains in the United States. Annual precipitation varies from 60–70 inches at the mouth to over 150 inches at upper elevations. Puget began its development of the Baker in 1924 with construction of Lower Baker River Development at the town of Concrete, Washington. In October, 1959, Upper Baker River Development was completed. Upper Baker utilizes 275 feet head in developing approximately 100 MW. The nine

FIG. 4. A Snow Survey Last Spring

After taking the core as in Figure 3, the core and sampling tube are weighed on a spring balance. The balance reads directly in inches of water.

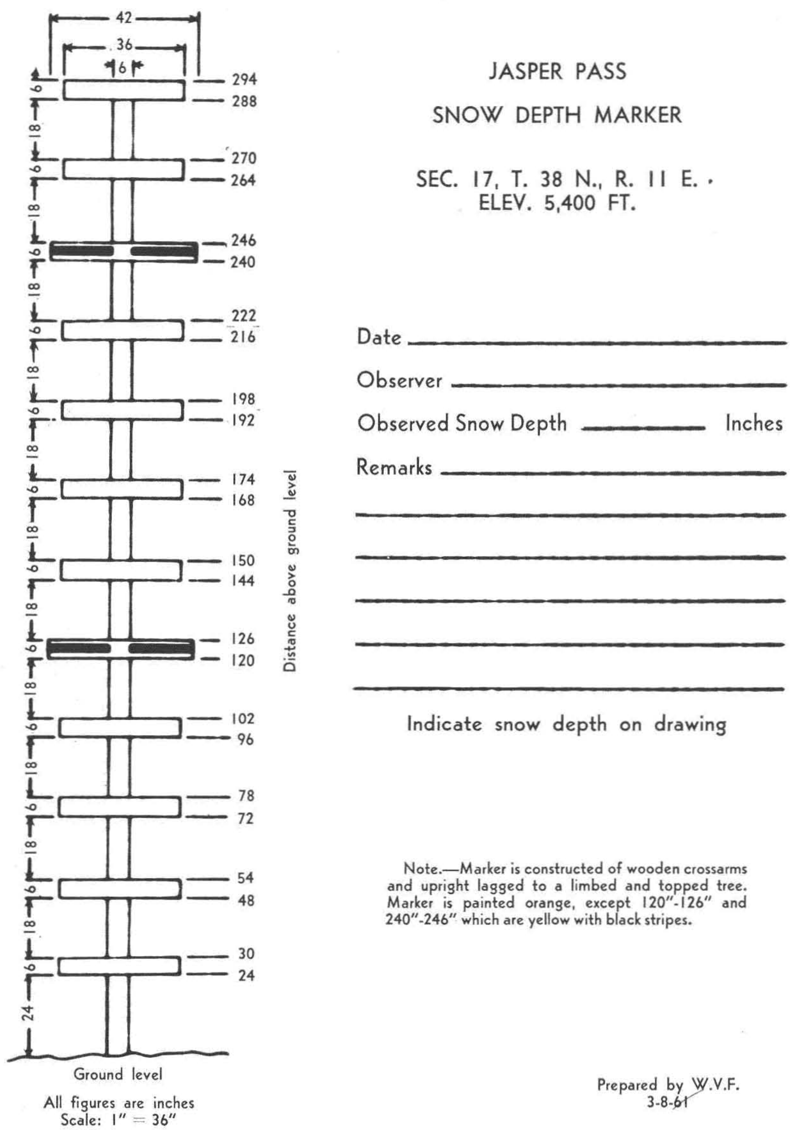

FIG. 5. Form Drawing of Jasper Pass Aerial Marker

Snow depths are determined by comparing photograph of marker with drawing of the particular marker. Depths are then indicated on form and the forms are distributed.

mile reservoir, Baker Lake, contains 185,000 acre-feet of usable storage. Lower Baker develops 110 MW under 240 feet of head. Its reservoir, Lake Shannon, contains 142,000 acre-feet of usable storage. With such amounts of storage and generating capacity, it is essential that water-supply forecasts be as accurate as possible, adding to the project's efficiency and flexibility of operation.

10. The snow courses are situated around the perimeter of the basin at varying elevations. (See Figure 6.) A typical flight might be as follows:

The first station is a low elevation course, *Thunder Creek,* elevation 2,200 feet. This station poses no real problem. Next, a real "toughie," *Watson Lakes* Snow Course, elevation 4,500 feet. This course lies between two beautiful lakes in a tight plateau surrounded on all sides by sheer rock rising almost straight up, 1,000 feet or more. The third course on the flight plan is *Dock Butte,* elevation 3,800 feet. This course is more open than the previous one and doesn't present any particular problem, either photographically or flying. The next "stop" is another low elevation

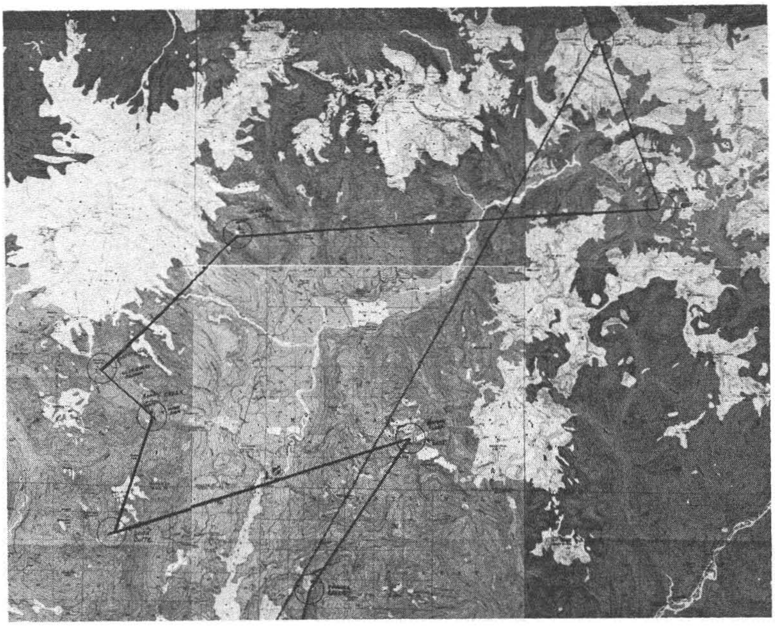

Fig. 6. Baker River Basin Map

This is a series of USGS Topographical Maps showing most of the Baker River Basin. Lake Shannon is at bottom left with Lower Baker Dam just out of the picture. Upper Baker Dam and reservoir (Baker Lake) are not shown on the map, but the new Baker Lake encompasses most of the valley up to and including the portion about two and one-half miles upstream from the old Baker Lake shown on the map. The heavy black line is the usual flight pattern utilized by the photographer. The snow courses are located by the circles. Most of the white area on the map represents permanently snow-covered areas.

course, *Rocky Creek*, elevation 2,100 feet. The aerial marker here was poorly situated; this made photography of it very difficult. The marker was relocated this summer to a more convenient and representative spot. Next is a beautiful clearing at the base of Mt. Baker called *Schreiber's Meadow*, elevation 3,400 feet. This particular station is a key station

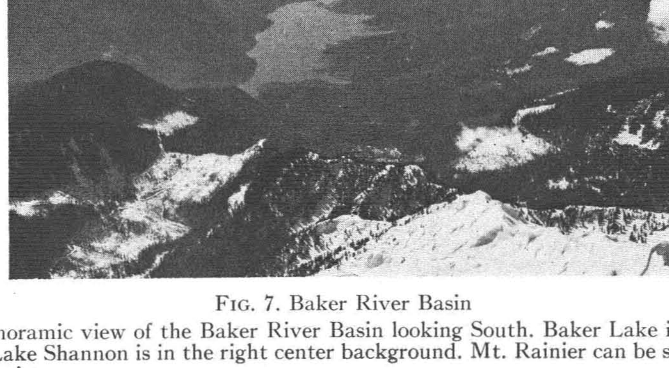

Fig. 7. Baker River Basin

This is a panoramic view of the Baker River Basin looking South. Baker Lake is in the left center foreground and Lake Shannon is in the right center background. Mt. Rainier can be seen in the distance at the top of the picture.

and we'll be seeing more of it later. Another lake is next on the agenda. The course is located on the shores of *Marten Lake*, elevation 3,600 feet. This station was another where the aerial marker had been poorly located, making it very difficult to photograph; this was also relocated this summer. Now we go across the valley to our highest course, *Jasper Pass*, elevation 5,400 feet. The course sits on a high ridge with a 2,000 foot sheer dropoff on three sides; while beautiful to behold, it does present some pretty hazardous flying conditions. But conditions can get worse, and they do, at the last course, *Easy Pass*, elevation 5,200 feet. Here the wind seems to blow continually, and from all directions. To make matters worse, the aerial marker at this station was also partly hidden in the trees. This one was also relocated this summer. Now that the work is done, Jesse Ebert can breathe a sigh of relief and begin to enjoy the wonderful mountain scenery. (See Figure 7.) Now back home to Seattle and to solid ground beneath the feet. The whole trip might take two and one-half to three hours including travel time to and from the basin.

11. Let's examine some of the results of the flights. First, we'll see Jasper Pass for each flight and then Schreiber's Meadow.

Jasper Pass—elevation 5,400 feet

(See Figure 2 for January 18, 1961 flight results)
(See Figure 8 for March 18, 1961 flight results)
(See Figure 9 for April 16, 1961 flight results)
(See Figure 10 for June 13, 1961 flight results)

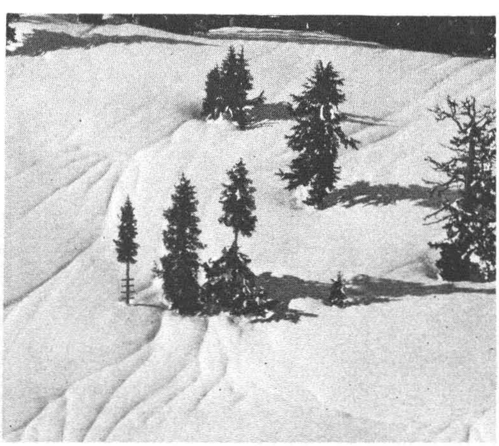

FIG. 8. Jasper Pass Aerial Marker
March 18, 1961
The marker indicates a depth of 200 inches.

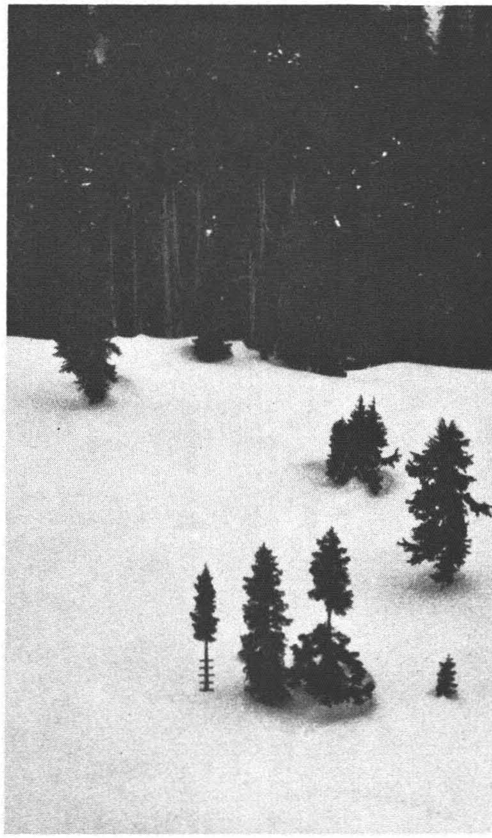

FIG. 9. Jasper Pass Aerial Marker
April 16, 1961
The marker indicates a depth of 192 inches.

Schreiber's Meadow—elevation 3,400 feet

(See Figure 11 for January 18, 1961 flight results)
(See Figure 12 for March 18, 1961 flight results)
(See Figure 13 for April 16, 1961 flight results)
(See Figure 14 for June 13, 1961 flight results)

12. Let's examine some of the problems encountered in this first year of operation and also some of the steps taken in resolving these problems. Three serious difficulties presented themselves during the course of the season, namely:

a) Several markers had been initially constructed at sites that did not lend themselves to the convenient taking of pictures from a passing plane. They were so located as to always be in shadows, or back in a thick growth of trees where the photographer had a difficult time identifying the marker from a safe flying-height.

FIG. 10. Jasper Pass Aerial Marker
June 13, 1961
The marker indicates a depth of 90 inches. Note depression around the base of the marker.

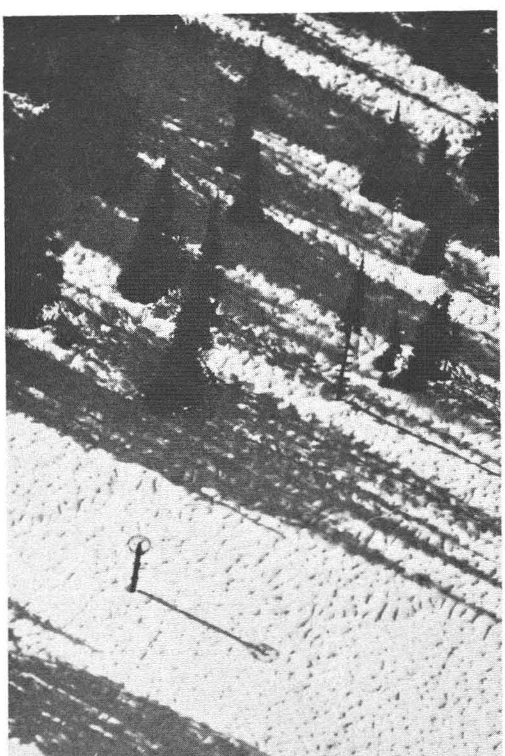

FIG. 12. Schreiber's Meadow Aerial Marker
March 18, 1961
The marker indicates a depth of 128 inches.

b) Large depressions formed around the base of several markers, making depth interpretation from the photographs subject to large error. These were markers that had been bolted to a living tree with considerable foliage still left on top branches to keep the tree from dying. These same branches and those from surrounding trees "intercepted" falling snow and caused the formation of the depressions.

c) It was discovered that in some instances depths indicated by the aerial markers did not coincide with depths measured on the snow course itself. This is the usual problem encountered when comparing a point measurement with one which represents an average of a number of measurements.

In most cases the use of a living tree as the

FIG. 11. Schreiber's Meadow Aerial Marker
January 18, 1961
The marker indicates a depth of 76 inches. The object near the left border is a storage precipitation gage, which catches and stores a full year's precipitation. Annually the gage's contents are weighed out, usually in the late summer.

base of an aerial marker was unsatisfactory; so new markers were made by bolting the crosspieces to a 2 inch heavy-duty steel pipe embedded in concrete and guyed with light wire. Interception losses consequently were greatly minimized. The pipe markers were placed on short offsets from one of the snow course sample points. The sample point which usually represented the average measurement for the course was picked wherever possible. It worked out that these new locations were more photographically accessible, also. Thus, all three problems will have been lessened greatly by these modifications.

13. What is the future of aerial snow surveying? We can look for more and more aerial surveying in the coming years. We can look for a reduction in costly ground measurements and increased aerial coverage as well as increased frequency of measurements. Ground snow surveying will not be replaced entirely, as densities must be known, at least in a few key stations. The services of both the aerial photographer and the hydrologist will continue to be needed. The close alliance of the two will add greatly to man's knowledge of one of his most important resources—water.

SUPPLEMENT BY AUTHOR

EDITOR'S NOTE:

In response to questions and suggestions made by Committee Chairman Rogers in his letter of May 7, Mr. Finnegan, in letter of May 16 wrote as follows:

FIG. 13. Schreiber's Meadow Aerial Marker April 16, 1961

The marker indicates a depth of 134 inches. Note depression which has formed around base of marker.

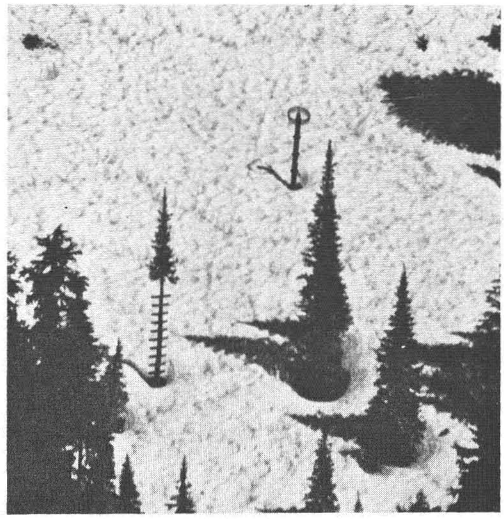

FIG. 14. Schreiber's Meadow Aerial Marker June 13, 1961

The marker indicates a depth of 28 inches. Depression around base of marker now extends to bare ground making depth interpretation subject to error.

"1. At Puget, data from aerial marker observations are used to complement regular ground snow surveys. For the aerial surveys the water content of the snow pack is estimated from densities obtained by previous ground measurements. In addition, a ground survey is taken coincidentally with the aerial surveys at a single snow course just over the north divide in the adjacent basin. By taking into account these measurements, and considering the number and dates of the storms which passed over the basin since the last survey, remarkable accuracy in estimating densities can be obtained. The errors to which I referred in paragraph 12B are not due to reading the markers themselves. The snow markers are not read, only photographed, during the course of an aerial survey. The depths are taken from the finished photographs. Normally, depths can be read from the photographs to within two or three inches of the true depth. However, as I stated in the same paragraph, large depressions formed around the base of several markers, which made depth interpretation of the photographs difficult. . . . At these stations where this problem existed, steel pipe type markers were installed last summer, and I am pleased to report that they have proved very effective in reducing this source of error. All markers are painted a brilliant orange to make them readily visible from a passing plane.

"As to your question concerning a comparison of this system of aerial markers with that of other developments such as electronic and mechanical recordings, this can be said: A great deal of research is being carried out by a number of agencies to improve present snow survey methods. The telemetering of hydrologic data from remote locations as being studied by the University of Idaho Engineering Experiment Station is a case in point. As yet, these methods of obtaining snow data are not sufficiently developed for practical application. Installations and operating costs are much too high to be within the reach of most users. However, there is no doubt that in the future, perhaps only a few years from now, at least one or two stations in a basin will have some type of electronic telemetering equipment.

"2. In my own opinion, reading aerial markers as opposed to utilizing aerial photographs is a waste of time. Any data obtained by an on-the-spot reading would have to be substantiated with a photograph to have any value as a permanent record. Therefore, rather than using an engineer well versed in interpreting snow depths but not experienced in photographic methods, we have decided that the services of a professional photographer who is intent only on taking good photographs which can later be studied for accurate depth readings, is far more effective."

A Photogrammetric Ship-Positioning System

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ABSTRACT: *The possibility of using the photogrammetric flare triangulation technique for positioning a ship at sea for the purpose of accurately locating oceanographic data is considered. Results of tests of a prototype stabilized camera system conducted on a roll and pitch simulator and aboard ship are reported. It is concluded that use of a photogrammetric ship-positioning system, based upon the technique of photographing rocket flares or satellites against a star background from ashore and at sea, is feasible. A properly stabilized camera aboard ship should be capable of providing the same accuracy of position as is possible on land. Weather and sky brightness limit the use of the system to times when these conditions are suitable; but when maximum position accuracy is important, surveys could be scheduled at times when these conditions can be expected to be most favorable.*

INTRODUCTION

THE accurate positioning of features on the earth is a never-ending task that has challenged geodesists and cartographers for centuries. Fortunately, most of the tools and techniques needed for geodetic surveying have been developed. However, once the surveyor strays from shore and begins to map the three-fourths of the world that lies beneath the surface of the sea, his problems mount rapidly. Not only must he probe beneath the ocean's surface to the hidden mountains and valleys below, but once he has identified and mapped these topographic features he must locate them in relation to surrounding shores.

Numerous navigation systems have been devised to guide the mariner throughout the world. The most recent and most sophisticated of these is the Navy's *Transit* system. Developed for the Navy by the Applied Physics Laboratory of the Johns Hopkins University, the *Transit* system makes use of a measurable Doppler shift in signals transmitted from a satellite orbiting hundreds of miles above the earth. In operation, a ship

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