Chow is a darned important item on a snow survey, as you all know. A well stocked cabin is a pleasure to inhabit. When the same surveyors use these cabins from year to year, let them make up their own food list—within the budget, of course. Then be sure that it all gets to the right cabins, and that the packers don't eat all of the goodies before the winter workers arrive. It would be helpful if an inventory sheet for food and supplies could be furnished the last surveyors using a cabin in winter. Then they could list deficiencies and surpluses as well as personal preferences. There is certainly no sense in automatically stocking a cabin season after season with cases of pork and beans if the surveyors don't eat pork and beans.

Some cabins have opened food cartons, glasses, and bottles which have been there for years. These should be periodically cleaned out and replaced. Perhaps a date could be stamped on all food stuffs going into a cabin. The surveyors will tell you that canned potatoes aren't any good when they have been frozen, that canned ham or other similar canned meats are nice to have at any time, and that small cans of fruit juices hit the spot for lunch or at the end of a hot day.

When a field man talks about a snow survey he usually mentions the cabin immediately. He either looks forward to staying in that cabin or else he would like to forget it ever existed. A poor cabin can ruin a survey, particularly if you have to hole-up in it to wait out a storm for several days. A comfortable cabin is a welcome relief at the end of any day of snow surveying.

Here are a few prerequisites for a winter cabin. It should be oriented to reduce the doorway snow shoveling. It should be near water if possible. I'm sure most surveyors would prefer a little extra walking if they could forego melting snow for water. The cabin should be built substantially, low ceiling, wood floor, snow tight, bear-proof. And peopleproof---it seems nowadays that many hunters, fishermen, and campers have no respect for others' property and the safety of winter-cabin occupants. The cabins should have enough room to move around; it should have windows, a good stove, and ratproof containers for bedding and food. If snow melting is necessary, then adequate containers should be provided for the job.

I would like to close by asking a few questions that the uphill skier and snowshoer might like to have answered. What does the future have in store for the snow surveyor? Will over-snow vehicles and helicopters take over and reduce the number of field men needed to cover the mountains? These means of transportation are certainly easy on the legs and perhaps easier on the budget in the long run. What new methods are being developed to improve snow surveying? What's the score on the use of radioactive materials for determining water content of snow? Is any research being done on improving the cutting teeth of the snow sampler; possibly engineers outside of our field would have some novel ideas. Waxes to reduce icing and snow accumulation on the bottom of skis certainly could be improved. The new tube cap for driving through ice layers developed by the San Francisco surveyors is a big help, and other ideas must be floating around in various parts of the snow country that could be used to improve snow surveying. These are just a few of the things your surveyors are thinking about. Answers or improvements certainly will give you an even more satisfied group of snow surveyors.

AN APPLICATION OF SNOW SURVEY DATA TO GLACIER RESEARCH[1/]

By

M. F. Meier[2/] and W. D. Simons[2/]

The Water Resources Division of the Geological Survey is beginning a modest but continuing program of glacier research with two main objectives: first, an understanding of the hydrology of glacier-covered regions, and, second, the use of glaciers as quantitative indicators of climate. Research toward both of these objectives involves the making of snow surveys and the use of conventional snow-depth data. Glaciologists have been making snow surveys for well over a hundred years

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1/ Publication authorized by the Director, U. S. Geological Survey.
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The techniques that have been developed by glaciologists are necessarily somewhat different from techniques used in more conventional snow surveys. The main purposes of this article are to demonstrate that snow-survey data are needed for analyses of glaciers as indicators of climate, how glaciological snow survey techniques differ from conventional procedures, and finally to show that considerable interrelationship exists between glaciology and conventional snow surveying.

A glacier is a gigantic treadmill transporting snow and ice from an area where more snow accumulates than is melted to an area where melting exceeds accumulation. The speed of this treadmill is controlled by the thickness and surface slope of the ice. In an equilibrium situation these factors are delicately adjusted so that the tongue extends into the lower elevations (the wastage or ablation environment) just the right distance so that the annual wastage of ice is equal to the annual accumulation at higher altitudes. If the climate changes so as to increase the accumulation excess, this causes the glacier to thicken and to steepen the slope of its surface. These factors cause a speeding up of the treadmill so that ice is transported further into the ablation environment until a new equilibrium position is reached. Climatic changes therefore produce changes directly in the length, thickness, and surface slope of a glacier.

The profiles of present-day glaciers can be readily determined, and the profiles of glaciers of the past can be reconstructed by a study of moraines and vegetation trimlines. Theoretically, then, if glacier flow were understood completely, it would be possible to reconstruct present or past climatic environments from data on longitudinal profiles of glaciers. Unfortunately many analytical relationships pertinent to glacier flow have not been completely defined and insufficient field data are currently available for testing these relationships. One illustration of the complexity of the problem is that many data suggest that some valley glaciers have an inherent cyclic behavior pattern of advance and retreat which is completely independent of climatic change.

The research program that we have initiated requires three types of essential data. These three elements are: (a) The bedrock configuration, (b) the flow law (the stress-strain rate relation) of ice, and (c) potential accumulation minus potential ablation as a function of altitude. Through an analysis of these elements alone it may eventually be possible to predict the longitudinal profile of a glacier. The obtaining of the last element of data will be discussed here.

Accumulation and ablation, in some areas, depend largely on altitude, and these quantities can be graphed as a function of altitude (see Fig. 1). On this figure, curve A represents the total accumulation of solid precipitation in a year's time; curve B represents the total mount of melting, evaporation, and erosion of snow or ice that can take place at each elevation. The difference between curves A and B determines the health or regimen of a glacier. In a geographic region of high precipitation and high melt rates (region 1, Fig. 1), the vertical gradient of the difference between yearly accumulation and ablation will be large. A glacier located in this area must transport relatively large quantities of ice and snow across a given difference in elevation. Therefore this glacier will be extremely active. A glacier located in region 2, however, where the vertical gradient of the difference between accumulation and ablation is small, need transport only a small quantity of snow and ice in order to remain in equilibrium. A slight decrease in accumulation will cause the firn limits[3] in region 1 to rise only slightly, but will cause the firn limits in region 2 to rise greatly with a resulting great decrease in glacier lengths. Thus glaciers in these two different regions will react quite differently to climatic changes even though both might be exactly in equilibrium with their local climate at every instant. The vertical gradient in the accumulation and ablation difference has been called the "energy of glacierization" and is a quantitative measure of the activity of a glacier. These data are the most essential aspects for an evaluation of the gross climatic environment of a glacier.

These climatic data are obtained by a special type of snow survey. The surveys are undertaken as close as possible to the end of each water-budget year; for mountain glaciers in the northern hemisphere this is usually early September. Ablation is determined by the amount of water lost from the glacier surface as measured at stakes or holes set in the ice which can be observed from one year to the next. Above the firn limit an excess of accumulation must be measured. This is somewhat more difficult than in ordinary snow surveys because this layer of accumulated snow is resting not on ground but on older snow. The first important problem then arises as how to determine the limits of a single budget year's accumulation. Figure 2 is a typical vertical section of a pit dug into a glacier. Snow density, hardness, wetness, grain size and other factors can be measured on the walls of this pit. All of these factors will show some discontinuities marking

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3/ The firn limit is a line or zone where accumulation equals ablation in any one year. It is, therefore, the dividing line between an area of predominant accumulation and an area of predominant ablation.

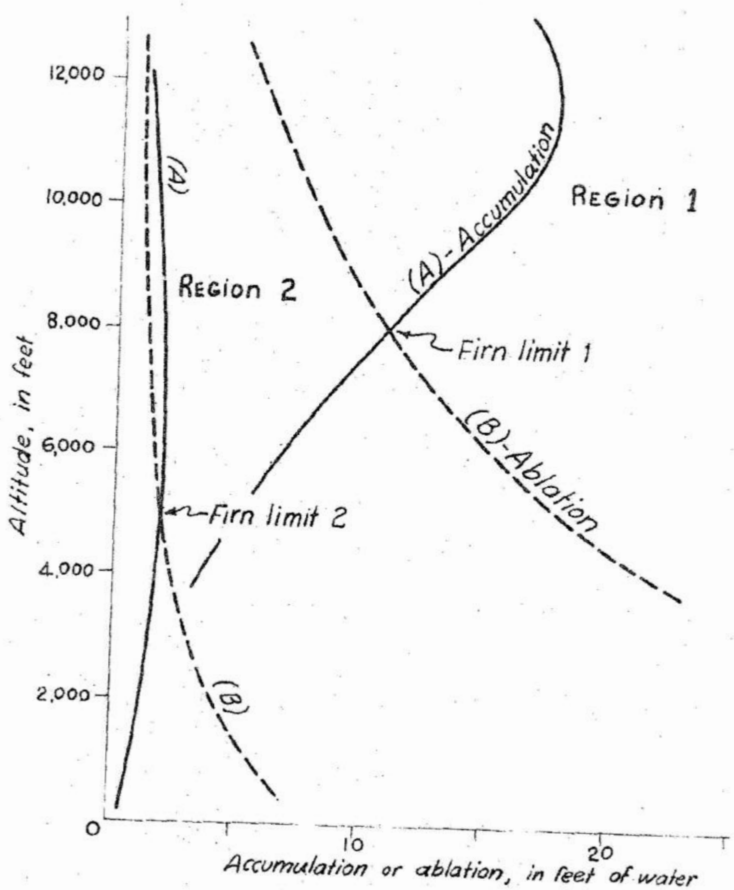

Figure 1. - Accumulation and ablation at varying altitudes for two types of glacier environments.

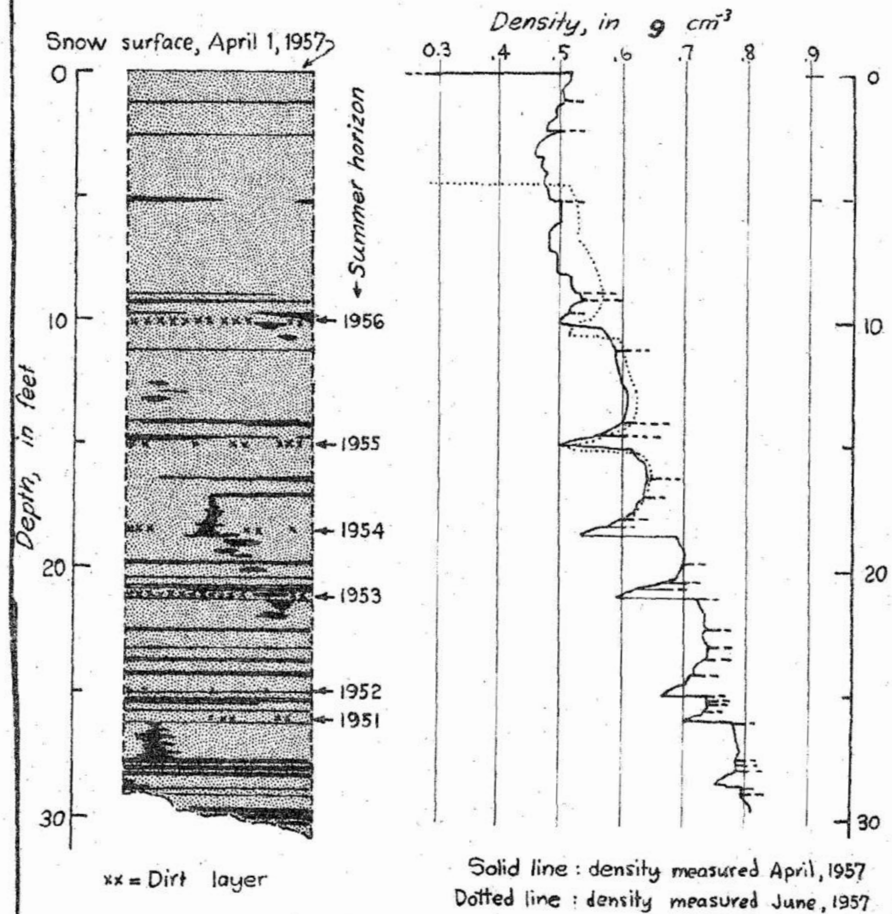

Figure 2. - Typical snow profile.

summer melt seasons. In addition, layers of dirt or dust may accumulate in summer. This dirt and the discontinuities in physical properties allow annual accumulations to be distinguished in pit walls. In order to save labor, coring augers and snow samplers are sometimes used, but the cores from these tools must be studied very carefully to determine annual layers. Frequently it is found that the average bulk density in a limited elevation interval is relatively constant. If this is true and if the density is known, the accumulation of snow in this interval can be measured easily at many points by using a thin probe.

The second difference between these surveys and conventional snow surveys is that the glaciologist is interested primarily in the total accumulation over a large area whereas the conventional snow surveyor is interested more in the accumulation at a few fixed points as an index to time variations. Glaciological data is usually compiled and reported in the form of maps of snow depth (water equivalent) distribution. Fortunately these data are not difficult to obtain because many glacier surfaces are quite smooth and small scale drifting effects are not important. Crevassed areas and steep slopes limit the accuracy obtainable with these surveys.

A third great difference between glaciological and conventional snow surveys is that the glaciologist can obtain data on the net accumulation of previous years at a single field excursion. Records of the difference between accumulation and ablation are preserved at depth (see Fig. 2) and these data can be obtained simply by digging deep pits or drilling deep holes. Furthermore, on some glaciers which have a very simple flow pattern the annual layers of accumulation emerge at the surface below the firn limit and can be identified. Even though these annual layers of snow are eventually recrystallized into hard glacier ice, the water content per layer does not change appreciably with time. Therefore, if a layer can be identified below the firn limit, it measures the excess of accumulation over ablation that occurred at a certain spot in the accumulation area sometime in the past. In glaciers that have nonuniform distribution of accumulation it is necessary to determine exactly where this spot in the accumulation area was. Furthermore on many glaciers it is quite difficult to identify annual layers without some ambiguity or uncertainty. A long record of snow-survey data may be quite valuable in helping to establish the dating of annual layers. On some glaciers in the Rocky Mountains it appears that the accumulation excess can be determined quite accurately from outcropping annual layers as far back as 170 years. These data might be of considerable value in extending hydrologic records backwards in time.

Studies of glaciers, therefore, involve special snow-survey techniques and draw on conventional snow survey data. These same studies may contribute to fuller knowledge of the long- and short-term variations in precipitation and runoff.

WATER-SUPPLY FORECASTING DEVELOPMENTS, 1951-1956

By

Max A. Kohler[1]

I'm sure it is realized that the ten minutes allotted for discussion of developments in the field of water-supply forecasting during the past six years is in no manner indicative of the volume of published material on the subject. In reviewing the literature, I find 12 papers on the subject have appeared in the Proceedings of the Western Snow Conference alone, and about as many elsewhere.

Perhaps the most nearly universal aspect of the works reviewed is the reliance upon the analytical, statistical approach. Since available observations are at best only reliable indices to the factors involved, we must resort to some form of correlation analysis, but it is imperative that we not lose sight of the physical assumptions inherent in the derived forecast relations. Statistical tests of significance assume the analyst has no *a priori* knowledge of the relationship considered, and they can never supplant the need for physical reasoning. From the physical point

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