Snow Surveys and Water Supply Forecasting

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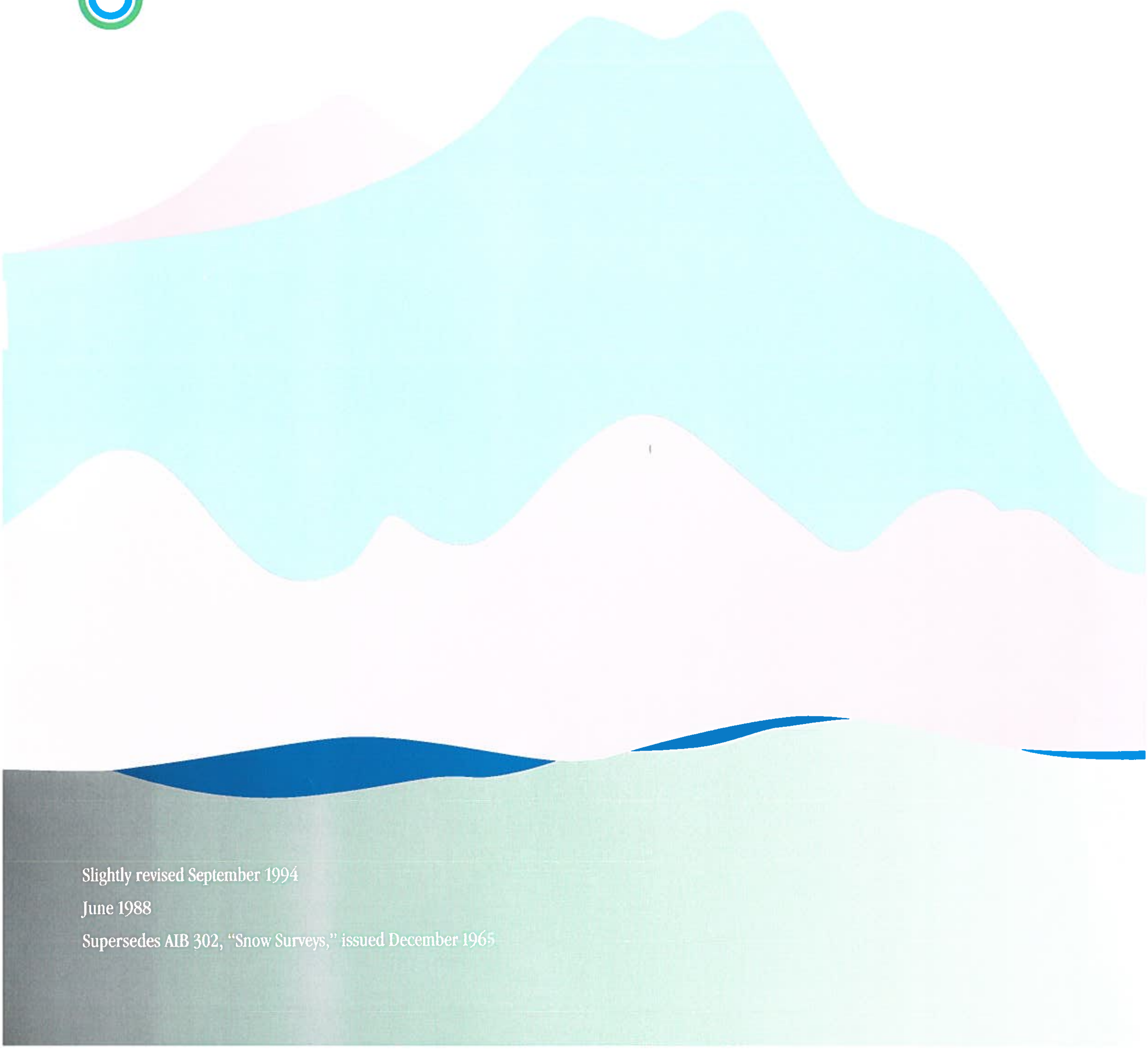

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Contents

Introduction

The beauty of snow is fascinating, and millions of Americans enjoy the snow-covered landscape as a playground. But beyond its esthetic and recreational appeal, snow plays a vital role in our lives as a primary source of the water supply in the Western United States.

Increasing and often conflicting demands for water in the West have heightened public awareness of the need for sound management decisions concerning water. Although the West's high mountain ranges hold a vast snowpack that provides 50 to 80 percent of the year's water supply, nature cannot be relied upon to provide an uninterrupted, dependable supply of meltwater to meet all the downstream requirements. To moderate this variability, reservoirs and canals have been built to serve the growing needs of agriculture, industry, and communities. But successful water management begins with an adequate knowledge of the primary source of water in the West: snow.

Obtaining accurate and timely information on the extent and water content of the mountain snowpack requires specially trained people and unique equipment. The Federal, State, and private cooperative snow survey program directed by the U.S. Department of Agriculture's (USDA) Soil Conservation Service (SCS) has met those needs since the mid-1930's and continues to evolve in response to increasing demands of water users, and changing definitions of beneficial water use. With a computerized data collection network and forecast system, the program also fills many other requirements for hydrological and climatological data useful in natural resource management and research.

This booklet describes the cooperative snow survey program. It is intended to provide the general public as well as water resource professionals with a better understanding of the importance of snow, snowpack surveys, and water supply forecasting in natural resource management.

Mountain Snowpack and the Water Supply

To the casual observer, the process by which we get water from the mountain snowpack is simple: the weather cools as winter approaches and precipitation changes from raindrops to snowflakes. Snow accumulates in winter, and with the warming of spring and early summer it melts, producing streamflow (fig. 1).

In reality, the relationship between the snowpack and the amount of snowmelt runoff is complex. It depends on many factors, primarily moisture content of the soil, ground water contributions, precipitation patterns, fluctuation in air temperature, use of water by plants, and frequency of storm events. These factors change throughout the year and from year to year. Their relative importance varies depending on location.

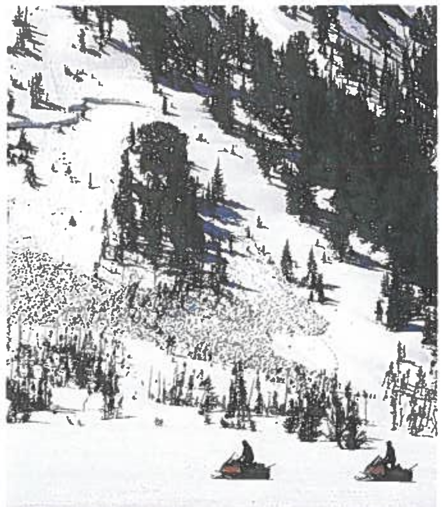

Figure 2. *Skiers may prefer light, powdery snow, but heavy, wet snow contributes more to the water supply.*

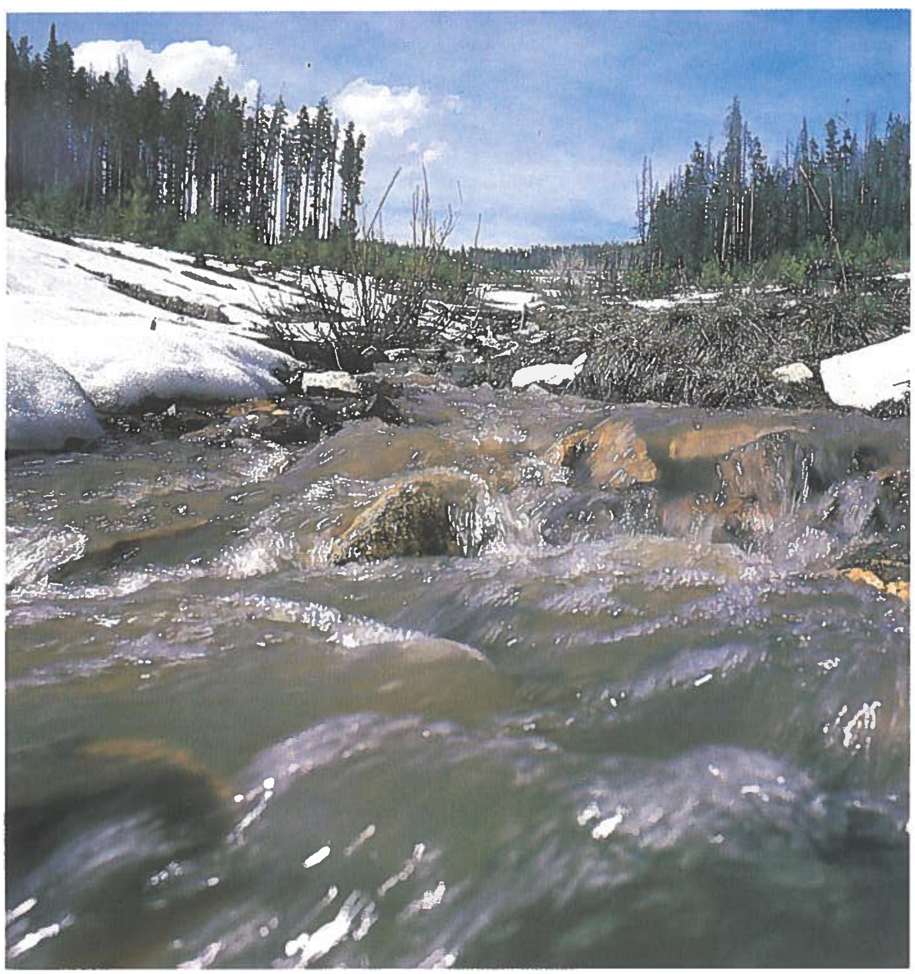

Figure 1. *Melting snow produces streamflow – a vital source of water for people living in the West.*

The stage is set for the snow-water year even before the first snowflakes fall. The amount of moisture that accumulates in the soil early in winter, before the snowpack develops, will affect runoff the following spring. Dry soils absorb more of the meltwater than wet soils. The amount of moisture that is absorbed depends on soil characteristics as well as precipitation. Wind, air temperature, storm frequency, and the amount of moisture in the atmosphere determine the accumulation of the snowpack. How the snowpack accumulates affects its density (amount of water per unit volume of snow) and texture (crystalline structure). Density increases as the snowpack becomes deeper and the lower layers are compressed. Wetness of the snow also affects density. Compression affects the crystalline structure of the snowpack. Density and crystalline structure affect how fast the snowpack melts and how much water it yields.

Air temperature and availability of atmospheric moisture determine how wet or dry the snow is. Typically, the west slope of the Cascade Range, in response to the Pacific Ocean's strong influence, receives heavy, wet snow. One foot of that snow, newly fallen, can produce up to 1.5 inches of water. In other areas, such as the Wasatch Mountains in central Utah, the snow is much drier. It is light and powdery – excellent for skiing – and 1 foot of fresh snowpack might contain only an inch of water (fig. 2).

Winds can redistribute the snow into drifts. Drifts differ from the surrounding snowpack in texture and density because of the weight of additional snow. On unsheltered snowpacks, high winds can evaporate the snow cover at temperatures lower than 32° F – a process called sublimation. Mountain snowpacks do not melt steadily. Melting varies according to weather, ground temperature, and exposure to the sun's rays. A snowpack begins to melt when it becomes "isothermal," that is, when its temperature from top to bottom equalizes at 32° F. Before reaching this isothermal state, the snowpack has different temperatures at different depths. Ground temperature, air temperature, and exposure to incoming solar radiation affect how quickly it becomes isothermal. South-facing slopes and open areas receive the most solar radiation and have the highest melt rates.

Water Management

Figure 3. *Because of the very low annual rainfall in the West, many areas such as this field of alfalfa depend on irrigation.*

Figure 4. *Snowmelt-fed rivers support wildlife such as elk.*

The Western United States requires a dependable supply of reasonably priced, good-quality water if the economy is to prosper and the quality of life is to remain high. Vast areas that receive just a few inches of annual rainfall produce bountiful crops, but only with irrigation (fig. 3). Decisions on the types of crops to plant, the number of acres, meeting instream flow requirements, and irrigation scheduling all depend on reliable forecasts of the year's water supply. Much of the power for cities as well as agriculture and industry is generated by hydroelectric energy. Water is truly the life blood of the West.

Wise management of existing water resources in the United States is essential. Water management, however, is complex even under the best of circumstances. Supply, demand, and cost are subject to the climate, environment, and to numerous economic and social influences, domestic and international. The decisions made early in the year, based on the best available information, often require significant revision as more data become available.

The Columbia and Colorado Rivers are two examples of extremely complex snowmelt-fed river systems. The area draining into the Columbia River comprises about 258,000 square miles, which includes 40,000 square miles in Canada. Along the river, Federal agencies have built 30 major dams for power generation, flood control, and irrigation storage. The Columbia and its tributaries support a wealth of fish and wildlife, including several species of fish such as salmon, which live in the sea but spawn in the river's fresh water (fig. 4). Barge traffic on the river is a major link in the area's transportation network for marketing agricultural and other products. Because many communities and industries and millions of acres of agriculture depend directly on this river system for survival, effective and timely management is critical.

Like the Columbia, the Colorado River also begins in high mountain country. It drains about 247,000 square miles. Huge population centers in southern California and Arizona consume enormous quantities of water, as do the expanding agricultural developments, and demands for water of the Colorado are intense. As in the Columbia, numerous storage facilities have been constructed, impounding snowmelt water to produce electricity, irrigate farms, supply water to cities and towns, and prevent floods. Unlike the Columbia, however, the Colorado picks up dissolved salts as it flows through ancient deserts and areas shaped by prehistoric inland seas. Heavy withdrawal of water, evaporation, and irrigation return flows can increase salt concentration downstream and thereby lower the quality of the water. Because multistate agreements and compacts regulate the quality and quantity of streamflow on the Colorado River, accurate management of streamflow and water use is imperative.

Most smaller river basins throughout the West also have management requirements for limited water resources that are just as important for their users. Management decisions are vital every year for big rivers or small, but the years of vast surplus and extreme shortage intensify the demands for management excellence and the importance of snow surveys.

Snow Surveys

Since 1935, most of the American West has relied on the U.S. Department of Agriculture's cooperative snow survey program for predictions of meltwater runoff. This program is a Federal, State, and local partnership directed by the Soil Conservation Service. Its survey activities encompass Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Alaska and southern Canada are partners also. California has an independent program.

Snow surveys in the West date back to around 1906, when the University of Nevada's Dr. James Church laid out the first western snow course. Dr. Church also invented key sampling procedures and equipment. The next three decades saw a proliferation of snow survey activity throughout the West. In some States, independent power or irrigation companies spearheaded the surveys; in other States, universities or State engineers were in charge.

Federal leadership of snow survey activities came as a result of the unprecedented western drought of 1934. Agricultural leaders requested USDA's help in forecasting water supplies for the ensuing crop-growing season. Because many of the watersheds and streams were interstate, Federal help was needed to coordinate the surveys and to develop uniform procedures and equipment for surveying and forecasting (fig. 5).

To find out how much water will be available in summer, snow surveyors from SCS and the other cooperating agencies collect data from some 900 snow courses several times each winter. They determine the depth and the water content of the snowpack and estimate the amount of runoff from the mountain watersheds.

In 1977, SCS began developing a network of automated radiotelemetry data sites for collecting snow survey data. This snowpack telemetry (SNOTEL) network (570 remote sites) provides SCS offices with daily or more frequent information on streamflow potential. The information is especially valuable during periods of flood or drought.

The information collected by the telemetry system (see box, page 11) and snow surveyors (see box, page 9) is translated into water supply forecasts that SCS State offices issue monthly from January to June in cooperation with the National Weather Service. Major sectors of the Western economy – agriculture, industry, and recreation – base their plans on these forecasts.

Figure 5. *The snow surveyors are well equipped for a full day's work.*

Manual Surveys

Manual surveys require two-person teams to measure snow depth and water content at designated snow courses (fig. 6). A snow course is a permanent site that represents snowpack conditions at a given elevation in a given area. A particular snowpack may have several courses. Generally, the courses are about 1,000 feet long and are situated in small meadows protected from the wind.

Measurements generally are taken on or near the first of every month during the snowpack season. The frequency and timing of these measurements varies considerably with the locality, the nature of the snowpack, difficulty of access, and cost. On occasion, special surveys are scheduled to help evaluate unusual conditions. The manual surveys involve travel and work in remote areas, often in bad weather, but reliable data are obtained. Locations that are too hazardous or costly to measure on the ground can be equipped with depth markers that can be read from aircraft (fig. 7). Snow depth can be measured in this way with a high degree of accuracy. Although the amount of water in the snowpack is not measured, it can be reliably estimated from the observed snow depth.

SCS conducts intensive training in snow sampling techniques, safety, and mountain survival. On-the-job training and an annual "west-wide" school develop the needed skills. The school has become known throughout the Western United States and Canada for its unique training program offered to SCS employees and others engaged in the cooperative surveys. A critical part of the training is the overnight bivouac in a snow shelter the student constructs (fig. 8). Many graduates have credited this training with bringing them safely through unforeseen, hazardous situations.

Figure 6. *The surveyors are approaching a typical snow course marker. This is one of the nearly 900 they or others will encounter several times each winter.*

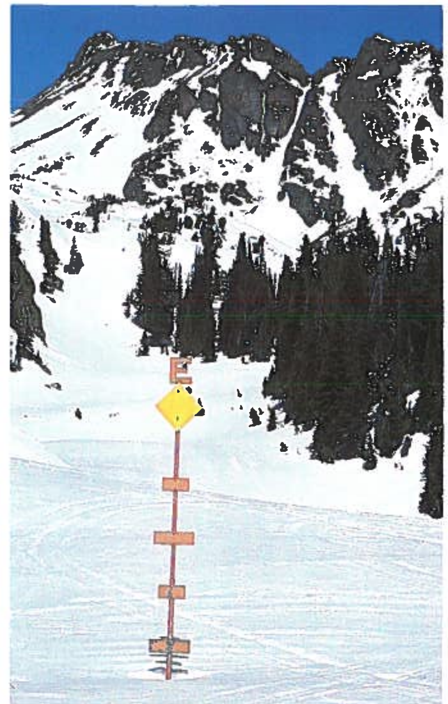

Figure 7. *Another form of manual surveying is reading depth markers from aircraft for locations too hazardous or costly to measure from the ground.*

Figure 8. *Students attending the "west-wide" school learn to construct snow shelters such as this trench shelter.*

Conducting Manual Surveys

The surveyor makes certain that the tube is clear of all snow and soil before taking the snow core sample (fig. 9). The team uses a strong, lightweight, graduated aluminum tube and a weighing scale.

One surveyor measures the snow depth while the other records data (fig. 10). From 5 to 10 measurements are taken at regular intervals along a snow course. Snow depth is measured by pushing the tube down through the snowpack to the ground surface and extracting a core.

In taking an accurate snow core sample, the surveyor must verify that the tube has reached ground level by examining the base of the tube and finding soil (fig. 11). After clearing out the soil from the tube, the surveyor determines the amount of water in the snowpack by weighing the tube with its snow core and subtracting the weight of the empty tube (fig. 12). An average of all samples taken is calculated and used to represent the snow course.


Figure 9


Figure 10


Figure 11

Figure 12

SNOTEL

Even though the data from the snow courses provide a valuable body of information, the typical schedule for manual surveys results in weeks with no specific insight into the condition of the snowpack. In that time, intense storms may be adding an abnormally large amount of snow or rain; perhaps an unseasonable warm spell at high elevation is resulting in a rapid melt with ensuing flood hazards.

Snow surveyors and water managers realized early in the development of the program that timely forecasting and management decisions required more frequent measurements and additional information. They also needed a way to survey particularly remote and hazardous snowpacks. SNOTEL's automatic sensing and data transmission were the solution.

Sensing Devices. A typical SNOTEL remote site consists of measuring devices and sensors, a shelter house for the radio telemetry equipment, and an antenna that also supports the solar panels used to keep batteries charged (fig. 13). A standard sensor configuration includes snow pillows, a storage precipitation gauge, and a temperature sensor. The snow pillows are envelopes of stainless steel or synthetic rubber, about 4 feet square, containing an antifreeze solution. As snow accumulates on the pillows, it exerts pressure on the solution. Automatic measuring devices in the shelter house convert the weight of the snow into an electrical reading of the snow's water equivalent – that is, the actual amount of water in a given volume of snow.

The precipitation gauge measures all precipitation in any form that falls during the year. The temperature sensor determines the minimum, maximum, and average daily readings.

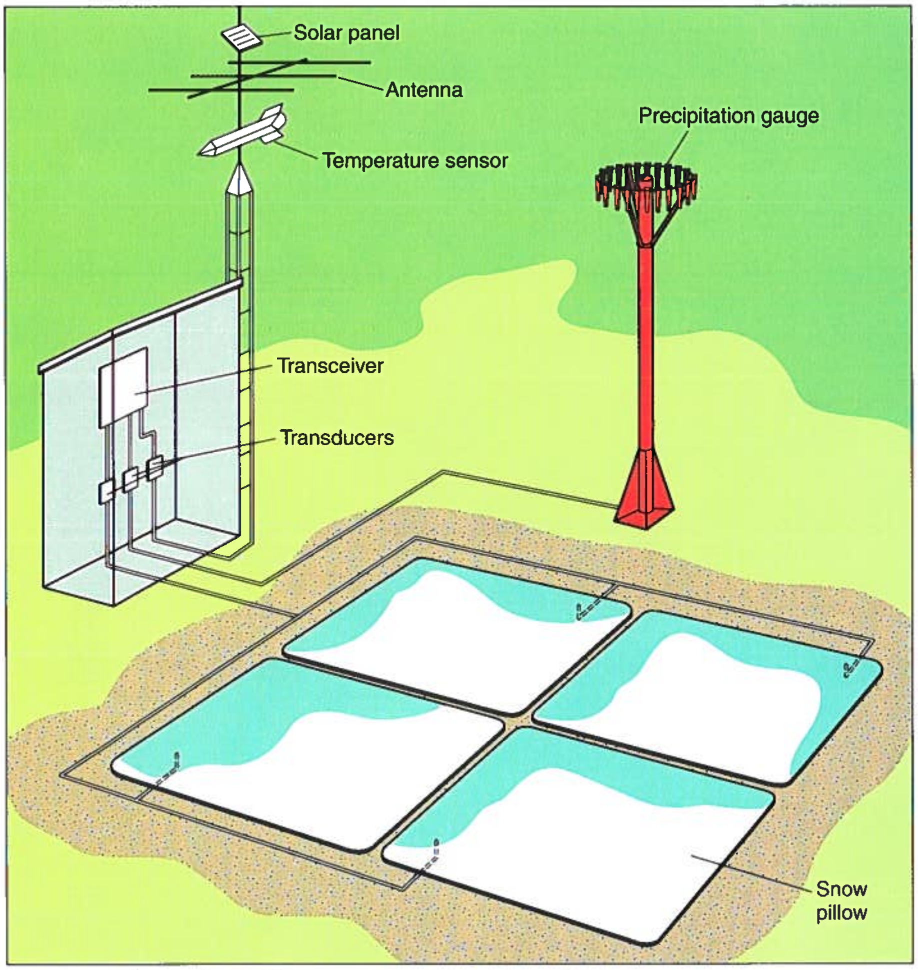

Figure 13. *This drawing depicts a typical remote SNOTEL site. Pressure pillows are used for measuring snowfall, a storage precipitation gauge provides current information about conditions at the site, and a temperature sensor measures the existing temperature.*

Additional sensors can be incorporated into a particular site for measuring wind speed and direction, soil temperature, snow depth, and a variety of other weather and environmental aspects. The configuration at each site is tailored to the physical conditions, the climate, and the specific requirements of the data users.

Telemetry. SNOTEL uses the principle of radio transmission by meteor burst. Radio signals are aimed skyward where the trails of meteorites reflect or reradiate the signals back to Earth.

The meteor burst technique allows communications between two locations as much as 1,200 miles apart. Two master stations – at Boise, Idaho, and Ogden, Utah – cover the 10 Western States, an area of about 1 million square miles. By cable, the master stations feed the data to SNOTEL's Centralized Forecasting System in Portland, Oregon. The Alaska Meteor Burst Communication System (AMBCS) for snow surveys is similar. All remote SNOTEL sites are interrogated daily on a regular schedule. Additional interrogations can be conducted on demand, and any special reporting requirements can be programmed into the site's microprocessors. In the Alaskan system, hourly interrogations are conducted, and the data are made immediately available to cooperating agencies.

Quality Control. The sites are designed to operate unattended for 1 year in severe climates. Each site receives preventative maintenance and sensor adjustment annually. The reliability of each SNOTEL site is verified by ground truth measurements taken during regularly scheduled manual surveys. These readings are compared with telemetered data to check that values are consistent and compatible. Any values found to be beyond specified limits are carefully examined and edited to ensure a continuous, high-quality record. Every year each site's performance is compared against established performance standards. Sites not meeting rigid criteria undergo a thorough field evaluation to correct any site deficiencies.

Remote surveys

Billions of sand-sized meteorites enter the atmosphere daily. As each particle heats and burns in the region 50 to 75 miles above the Earth's surface, its disintegration creates a trail of ionized gases. The trails diffuse rapidly, usually disappearing within a second, but their short life span is adequate for SNOTEL communications to be completed (fig. 14).

The process has three major steps: (1) master stations request data from remote sites; (2) sites respond by transmitting their current data; (3) and finally a master station acknowledges receipt and signals the site transmitter to stop. This complex exchange, taking place in a fraction of a second, is possible thanks to microprocessors.

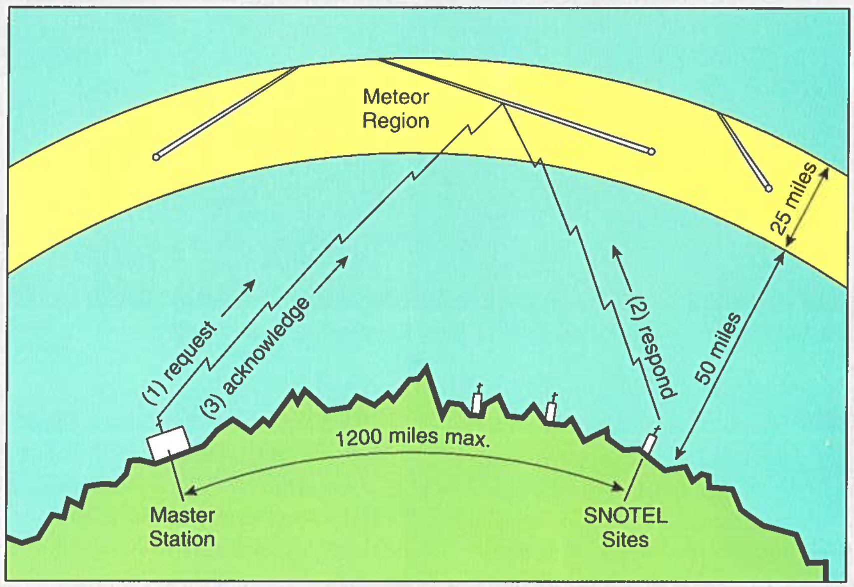

Figure 14. *Depicts meteor burst technique.*

The Centralized Forecasting System

Figure 15. *An irrigation water supply ditch carries snowmelt water to the fields.*

The snow survey program has a centralized forecasting system (CFS), which is automated for handling information related to water supply forecasting such as streamflow, precipitation, snow depth and snow water equivalent, and reservoir data. These data are available for the current water year (October 1 through September 30) and for historical water years. Numerous routines and interactive programs for manipulating water supply data are included in utility programs within CFS. These are mainly intended to aid in applying snow survey program information for conservation in the field.

CFS was developed and is operated by the Water Supply Forecasting Staff at the SCS West National Technical Center (WNTC). CFS is accessible to up to 64 simultaneous telecommunications users. A manual is available that outlines many CFS products, access methods, and primary contacts. CFS is the primary focal point for snow survey data analyses, streamflow forecasting, data exchange, and product dissemination. It serves as the delivery system to make snow survey and related planning information available to local conservation districts and SCS offices where it is incorporated into their conservation application programs. It is complementary to SCS's Field Office Computing System (FOCS), which is designed to automate conservation planning activities. CFS also provides access to hydrologic data and interpretative products for a wide variety of governmental agencies and the general public. The system can be accessed by most computers, and it is menu driven for ease of use.

Hydrologists use the computer programs in CFS to generate streamflow predictions throughout the West and to analyze and interpret hydrologic and meteorological data into meaningful products useful at the local level. The data in CFS are also important for natural resource management planning. These data reside in an automated database consisting of monthly data for 900 snow courses, 600 stream gauges, 300 reservoirs, and 1,200 precipitation stations as well as daily data from 570 SNOTEL sites and 2,000 climatological stations. Data are exchanged daily with the National Weather Service and numerous agencies as well as private entities.

The 10 Western States and Alaska publish a monthly Water Supply Outlook Report which is generated by CFS. Special reports can be created and stored that include data for specific SNOTEL sites and during specific time intervals. Several utility programs are available that are designed for snow survey personnel use in quality control for measured data and forecasts. Various hydrologic models in CFS provide users with an array of forecast products.

Other CFS programs relate snow survey streamflow forecasts to irrigation planning at the farm level. These programs incorporate crop consumptive use data and irrigation planning routines from SCS State Irrigation Guides. Several routines concern topics such as center-pivot sprinkler evaluation, irrigation project screening, and regression analysis for relation of streamflow forecasting to local farm and irrigation district supply ditches (fig. 15).

Summary

The major reason for the snow survey program with its extensive data collection network has always been the forecasts of annual streamflow volume at specific points along a river system. These forecasts are a vital input to water management. Irrigation, reservoir operation, domestic water use, power generation, fisheries management, and flood control are typical of the activities dependent on streamflow (fig. 16). Others are concerned with the actual measurements rather than forecasts, and the management of certain resources such as wildlife and range can be tied directly to these data (fig. 17). Traditionally, information has been distributed by SCS in each State through the monthly mailing of printed water supply outlook reports from January through May. Also, a west-wide report for the same period is published in cooperation with the National Weather Service. The final product for the water year is an annual snow data summary. Snow data are maintained in a national archive.

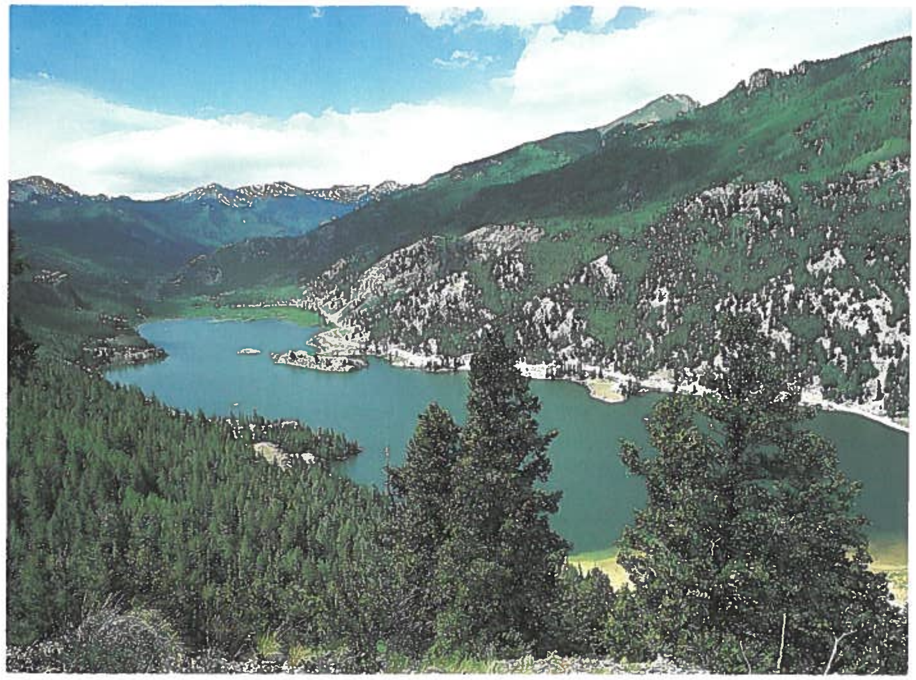

Figure 16. *Reservoirs such as Lake San Cristobal in Colorado are dependent on streamflow.*

The modern snow survey program, with realtime data provided by SNOTEL and CFS, is delivering a broader range of more timely information than is possible with printed reports. And the information is keyed to the specific needs of SCS and conservation district offices and an expanding user community: news media, civic organizations, emergency agencies, recreation managers, and others.

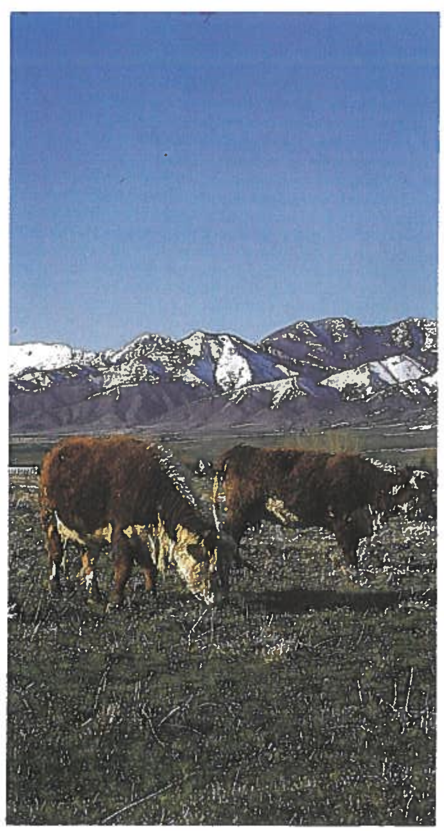

Figure 17. *Range management can be tied directly to annual streamflow volume data.*

Resource management agencies such as USDA's Forest Service, U.S. Department of the Interior's Bureau of Land Management and Bureau of Indian Affairs, National Weather Service River Forecast Centers, or State departments of fish and game and forestry require up-to-date water supply information. CFS presents opportunities for SCS to work cooperatively with these agencies to accomplish soil and water conservation objectives.

Demands are increasing for the often limited water supply in the western river systems (fig. 18), and forecasts must be as current and reliable as possible. The computer access provided through CFS not only makes the latest data instantly available, but it provides many standard and customized analysis procedures to support specific needs for information.

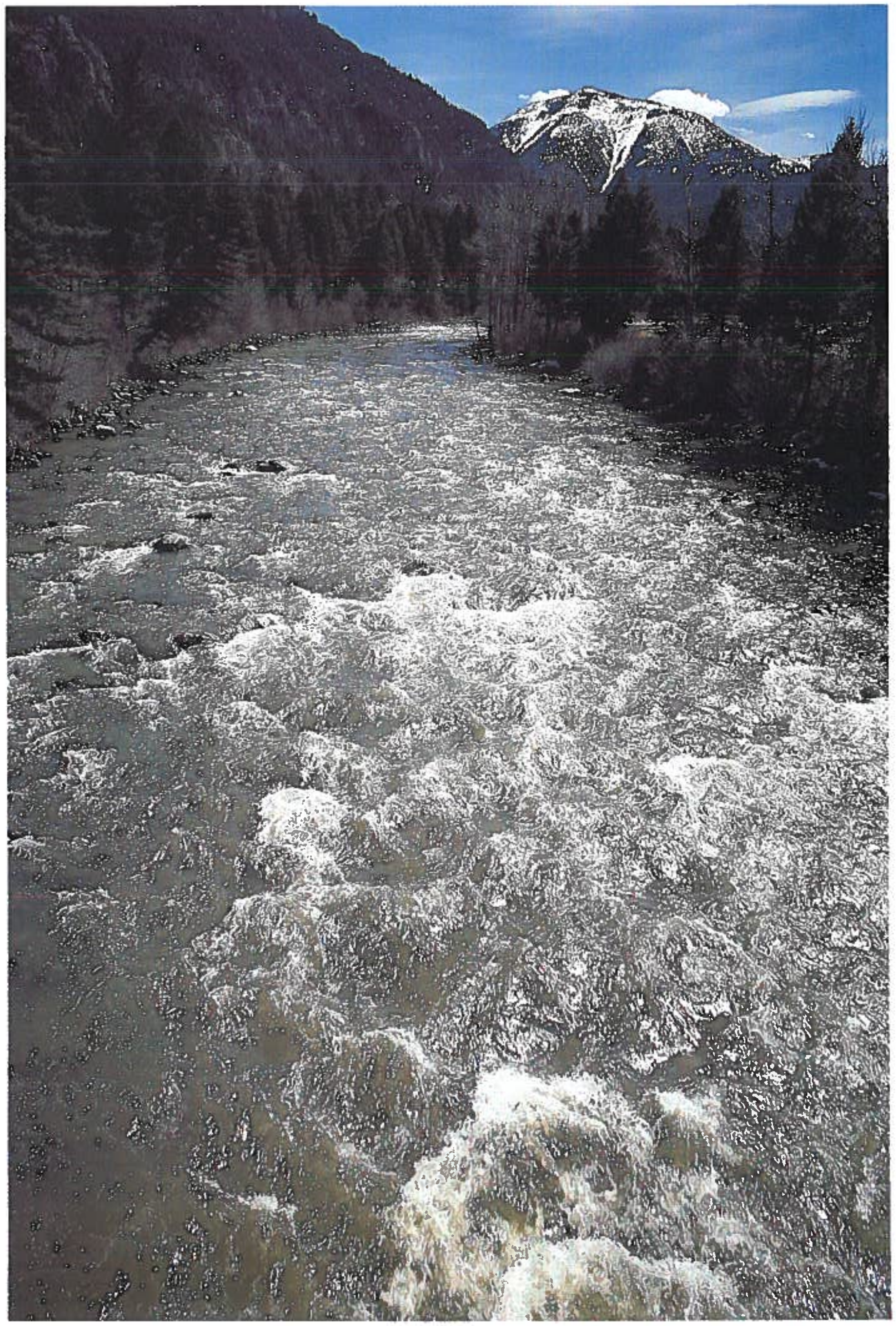

Figure 18. *Many Americans mistakenly believe that there is an inexhaustible supply of water. But even rivers like the Gallatin River in Montana face increasing demands for this limited resource.*

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