THE SCS SNOW SURVEY WATER SUPPLY FORECASTING PROGRAM: CURRENT OPERATIONS AND FUTURE DIRECTIONS

BY

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INTRODUCTION

In 1935, following passage by both houses, the President approved Public Law 74-76, which established within the Department of Agriculture a Soil Conservation Service (SCS). The mission of the SCS is to provide national leadership in the conservation and wise use of soil, water, and related resources through a balanced, cooperative program that protects, restores, and improves those resources. The SCS promotes soil and water conservation through a program of resource inventory and sound conservation practices.

The SCS is charged with the responsibility for making and coordinating snow surveys in the western states and Alaska and preparing forecasts of seasonal water supplies in snowmelt dominated streams. The Service's snow survey and water supply forecasting program is a prime example of the application of resource monitoring to soil and water conservation.

In the western United States, approximately 75 percent of seasonal volume streamflow originates from the melting mountain snowpack in the spring and summer. Therefore, predictions of summer water availability can be made by inventorying the mountain snowpack during its accumulation in the winter and early spring. These water supply forecasts provide much needed planning information for reservoir operations, irrigation, hydroelectric generation, fish and wildlife management, and many other concerns.

SNOW SURVEYS AND WATER SUPPLY FORECASTING

In the early 1900's, Dr. J.E. Church, Jr., meteorologist and Professor of Classics at the University of Nevada, developed procedures for measuring depth and water content of snow samples taken in mountain watersheds. In 1906, he established what is considered to be the first western snow course on Mt. Rose, in the Lake Tahoe basin. He compared the average water content of his snow samples with runoff observed during the snowmelt season, and developed a method for forecasting the rise of Lake Tahoe. By 1932 this work had spread to other locations in the Sierra Nevada, the Rocky Mountains, and the Pacific Northwest.

As a result of the unprecedented western drought of 1934, Congress authorized the USDA's Bureau of Agricultural Engineering to develop standardized snow sampling equipment and methods and to conduct snow surveys for the purpose of forecasting irrigation water supplies. In 1939, the division of irrigation was transferred to the SCS, and the Federal-State-Cooperative Snow Survey program has remained there ever since.

In the current SCS snow survey program, a network of over 1800 snow measuring sites (called snow courses) is used to predict spring and summer streamflow at over 500 forecast points in the western United States. The SCS conducts snow surveys on or about the first of each month, January through June. In areas where water supply forecasts must be updated more frequently, mid-month measurements are conducted. This is common in basins with large multi-purpose reservoirs.

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Snow samples are taken by inserting a special hollow aluminum tube down through the snowpack to the ground. The bottom end of this tube is fitted with a steel cutter tip, which cuts through dense snow and ice layers. The inside of the cutter tip has a slightly smaller diameter than the rest of the tube which prevents the snow core from sliding out through the bottom when the tube is extracted from the snowpack. The diameter of the cutter tip is 1.485 inches. One inch depth of water this diameter weighs exactly one ounce, hence a scale calibrated in ounces can be used to weigh the water content of the snow sample.

After the snow tube is driven through the snowpack to the ground, the snow depth is recorded by reading the scale inscribed along the tube's length, then the tube and its snow core are extracted and weighed. By subtracting the weight of the empty snow tube, the water content of the snow sample is obtained. Typically, five or ten samples are taken at each snow course. These samples are averaged to produce one value of snowpack water content for each snow course.

After snow course measurements are made, the data are entered into the Centralized Forecast System computer (CFS) in Portland, Oregon, through remote computer terminals. CFS is the name given to the assemblage of hardware and software which support streamflow forecasting and hydrometeorologic data base management for the SCS in the western U.S. The Centralized Forecast System is linked to SCS field, area, and state offices throughout the West by a telecommunication network.

In addition to snow course data, streamflow forecast procedures require input from precipitation and streamflow information as well. The precipitation data is usually collected by the NWS (National Weather Service), but occasionally SCS, Forest Service, or other data sources are used. Streamflow data is typically acquired from the USGS (U. S. Geological Survey), USBR (U.S. Bureau of Reclamation), and the U.S. Army Corps of Engineers.

When all necessary data have been collected and entered into CFS, a streamflow forecasting program known as WYFOR (Water Year FORecast) generates various forecast products for over 500 forecast points westwide. These products include basin snowpack, precipitation, and reservoir analyses; seasonal volume streamflow forecasts; high and low flow date and duration forecasts; and lake level forecasts. Seasonal volume forecast equations are typically multiple regression in nature, and are based on historical relationships between mountain snowpack, fall and spring precipitation, soil moisture conditions, and baseflow conditions. Figure 1 shows the April-July forecast equation for the Boise River near Boise, Idaho, and is typical of forecast equations for watersheds that are snowmelt dominated. Eight snow courses are used in this equation, and provide 65 percent of the equation's results. Spring precipitation, as measured at three NWS stations, contributes 15 percent to the equation, and a fall base flow parameter contributes 8 percent. This base flow term provides an index of antecedent groundwater conditions, and, indirectly, antecedent soil moisture conditions.

The SCS reviews its forecast accuracy periodically. A primary tool in this review is a component of CFS called FEAR (Forecast Error Analysis Review). FEAR includes a database of over 50,000 historical forecasts, with software to analyze the data by state, basin, period of forecast, forecast point, and length of record. Forecast accuracy improves with time through the forecasting season as more of the necessary hydrologic parameters become known. Figure 2 illustrates the improvement in forecast errors from the February 1 forecast date through April 1. On February 1, only about two-thirds of the winter's snow has accumulated. The remaining snow accumulation must be estimated for forecasting purposes, leaving much room for error. The average absolute forecast error for the Boise River February 1 forecast is 17.3 percent. By March 1, over 80 percent of the winter's snowpack is usually in place, and the March 1 forecasts demonstrate improvement in accuracy over earlier season forecasts. The average absolute error for the Boise River drops to 15 percent on March 1. On April 1, most of the season's snowpack is in place, and these forecasts show considerable improvement. The forecast error for the Boise River April 1 forecast is only 10.4 percent. A recent FEAR analysis of all forecasts in the western U.S. show the mean April 1 forecast error to be about 19 percent (Shafer and Huddleston, 1984).

Figure 1: Boise River nr Boise, Idaho
April-July Streamflow Forecast Equation

$$Y = 8.16\ X1 + 7.01\ X2 + 22.53\ X3 + 0.97\ X4 - 851.14$$

$$r = 0.985$$
$$s.e. = 120.13$$

Y = April-July Natural Streamflow (Thousands of Acre Feet)

X1 = Moores Creek Summit + Bogus Basin + Road Creek + Couch Summit Snow Courses (Max Mar or Apr Water Content)

X2 = Atlanta Summit + Jackson Peak + Vienna Mine + Trinity Mountain Snow Courses (Max Mar or Apr Water Content)

X3 = Idaho City + Anderson Dam + Centerville NWS Precipitation (April + May + June)

X4 = Fall Base Flow, Boise River near Boise (Oct + Nov + Dec)

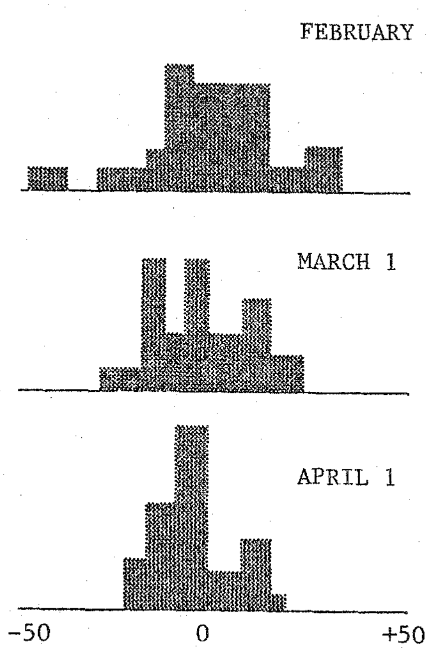

Figure 2: Forecast Errors (Percent) for the Boise River near Boise, Idaho 1962-82.

Streamflow forecasts are prepared by hydrologists at the SCS West National Technical Center in Portland, Oregon. Forecasts are then reviewed by state snow survey personnel, and coordinated with NWS river forecast centers, before being released around the 10th of each month, January through May. A state and westwide publication containing water supply forecasts and other information is prepared and mailed after release of the forecasts. More than 8,000 individuals receive one or more of these state reports.

Because the value of water supply products is related to their timely delivery, the delay of publication and mailing can reduce their usefulness significantly. For this reason, the Centralized Forecast System was developed around the goal of automated dissemination of water supply products.

THE CENTRALIZED FORECAST SYSTEM (CFS)

In 1983, a major reorganization of the SCS Snow Survey Program created a data analysis group at the SCS's West National Technical Center in Portland, Oregon (Barton, 1983). The primary functions of this group include streamflow forecasting, data base management, hydrologic modeling, and data dissemination. A commitment to provide the water user community with more frequent and timely water supply information required the use of automated data processing procedures in all facets of the program's operations. The Centralized Forecast System (CFS) was created to accomplish these requirements (Shafer & Huddleston, 1986). CFS is implemented on a Data General MV 8000 minicomputer and can handle up to 72 users simultaneously. A user-friendly menu system (Figure 3) offers easy product access to novice users.

The WYFOR (Water Year FORecast) program is the primary tool in CFS for streamflow forecasting and report generation. WYFOR provides data management for all data types required for current water year forecasting (including snow course, precipitation, streamflow, and reservoir storage). At the end of the water year, these data are verified and archived in CFS's Operational Data Base (ODB). ODB is a custom relational data base, which allows data retrieval and report generation based on user specified attributes.

In addition to streamflow forecasting and water supply-related data base management, CFS also includes a climatological data base, containing daily precipitation and maximum/minimum temperature observations for NWS stations in the western U.S. Information for over 2,000 stations is available for their period of record. Several analysis routines are available to summarize this data and produce products which have significant value for many conservation planning activities conducted by the SCS. These analysis routines include:

TAPS: Temperature and Precipitation Summary. This routine summarizes daily temperature and precipitation values at selected stations for the period of record. Results include monthly average precipitation and temperature values (average maximum, minimum, and mean), monthly cumulative degree days, extremes of period, and probability analyses of monthly precipitation and temperature exceedence values.

FROST: Frost Free Analysis. This routine summarizes daily minimum temperature values at selected stations for the period of record. Results include last frost date in spring and first frost date in fall for 24, 28 and 32 degree temperature thresholds at three probability levels.

GROWTH: Crop Growth Period Analysis: This routine analyzes daily minimum temperature values at selected stations for the period of record. The result is a table of the number of days in the growing season whose minimum temperature exceeds 24, 28, and 32 degrees, at five probability levels.

CFS is also the depository for remote sensing data related to snow hydrology. Two operational programs, both directed by the National Oceanic and Atmospheric Administration (NOAA), currently collect snow cover information using remote sensing technology. A mapping program for 271 drainage basins in the West and Midwest uses GOES (Geostationary Earth Satellite) imagery and digital interpretation techniques to produce basin snow covered area values (Allen, 1986). An airborne gamma radiation snow survey program measures the snow water content at over 1,000 flight lines in 16 states and 5 Canadian provinces (Carroll, 1986).

Access to CFS is open to all Federal, State, and local agencies, as well as the general public. A simple users agreement is all that is required to access the system. There is currently no charge for this service.

THE SNOTEL SYSTEM

In the late 1970's the SCS began installing an automated mountain snowpack data collection and telemetry system known as SNOTEL (for SNOw TELemetry). The system reports snowpack water content, cumulative precipitation, and air temperatures on a daily basis, using ionized meteorite trails in the upper atmosphere as the reflective medium for radio transmission (Barton & Burke, 1977). Early each morning, master stations at Boise, Idaho and Ogden, Utah send a radio signal skyward requesting data from the 550 SNOTEL remote sites in the west. These signals are reflected down to the sites by meteorite trails located between the master station and the site. If the site recognizes its address in the data stream, it transmits its current stored data back to the master station via the same meteorite trail. The master station then forwards the data to the SNOTEL central computer in Portland, Oregon via data phone lines. The information is then instantly available to snow survey specialists and other cooperators throughout the west.

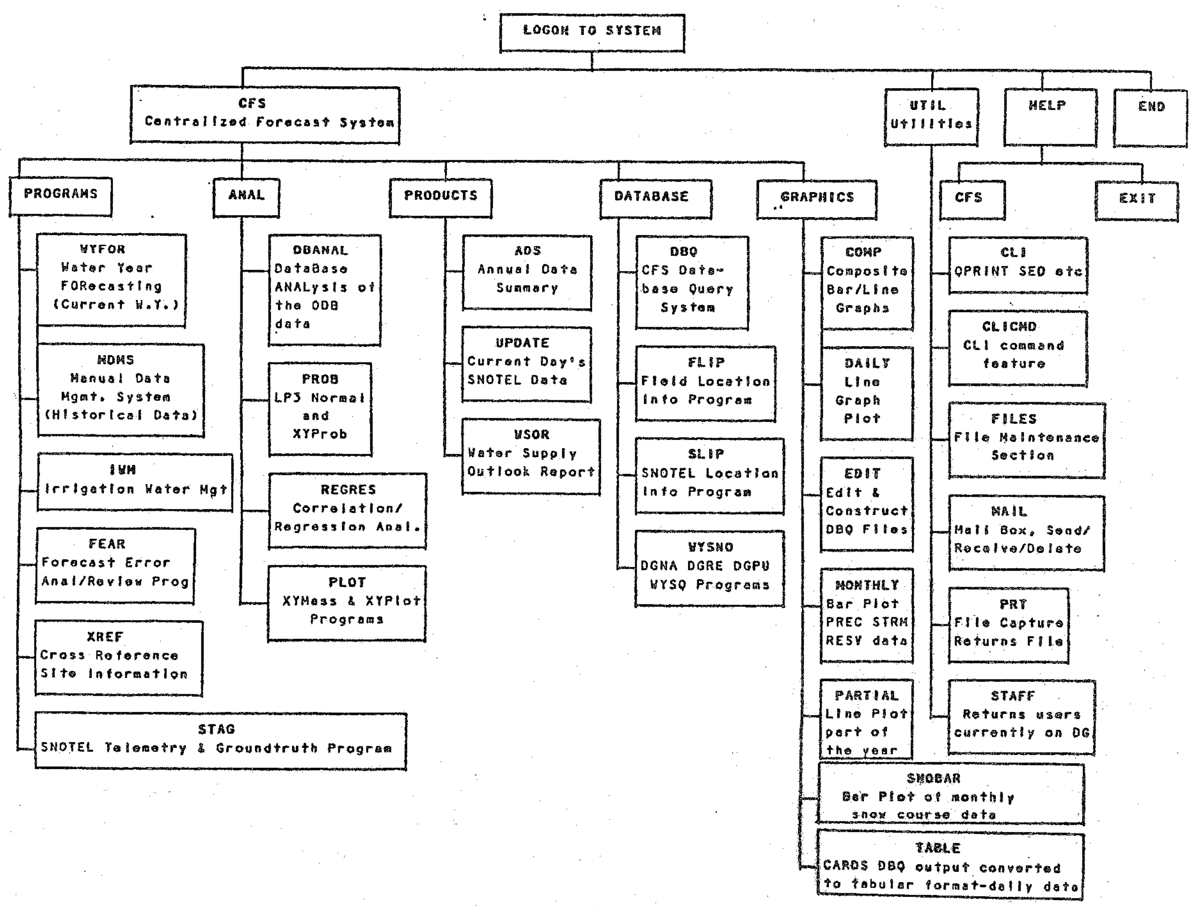

Figure 3: The Centralized Forecast System Menu System

The principle snowpack sensor used at SNOTEL sites is the snow pillow: a steel, butyl rubber, or hypalon envelope filled with an antifreeze solution. As the snowpack accumulates on top of these pillows, the antifreeze solution is forced through copper or steel plumbing into a manometer, or standpipe in the instrument shelter. The height of the fluid in the manometer, corrected for specific gravity of the antifreeze solution, is equal to the height of the water content of the snow overlying the pillow. An electronic pressure transducer translates this hydraulic head into an equivalent voltage value that can be telemetered to the central master station. A storage precipitation gage at each SNOTEL site measures all forms of precipitation throughout the year. These gages function in a similar manner to the snow pillow system.

SNOTEL data is already replacing some manually made snow course measurements, providing more timely and frequent information, as well as avoiding some of the dangers inherent in mountain winter travel. SNOTEL also allows updating of critical streamflow forecasts between regularly scheduled snow surveys. In the future, more snow course measurements will be discontinued as the period of record of SNOTEL data grows.

Perhaps SNOTEL's greatest contribution to water conservation lies in the incorporation of its daily meteorologic data into computer based hydrologic models. These models allow short term daily hydrograph forecasting which is essential for flood forecasting and operation of major reservoirs. Modeling efforts using daily SNOTEL data are being undertaken in cooperation with other federal and state agencies. Initial results have shown that SNOTEL data can be combined effectively with other climatic data to achieve acceptable model calibrations.

USES OF SNOW SURVEY DATA AND WATER SUPPLY FORECASTS

The value of streamflow forecasts to irrigated agriculture alone has been estimated at $43.4 million annually (Elliot, 1977). Indeed, the agricultural sector is the largest single user of snow survey information and products. However, there are many other uses of snow survey information as well:

Reservoir Management: Many Federal agencies, such as the Bureau of Reclamation and U.S. Army Corps of Engineers, rely on snow survey data for operation of major dam controlled reservoirs in the western U.S. Many of these reservoirs are managed for irrigation storage, flood control, and hydropower generation. The conflicting demands of reservoir regulation require careful planning to maximize the benefits. The SCS is currently developing operating guides for many locally operated small irrigation reservoirs. These reservoirs are usually operated for the sole purpose of storing irrigation water, and may pass high flows downstream in high runoff years. These guides allow operators to utilize the flood control potential of the reservoirs, thus reducing downstream flooding and streambank erosion in high runoff years.

Snow Load Maps: In many western states, building design codes must include estimates of expected roof snow load forces. Designing a structure to withstand the forces of snow loading require detailed climatological information for the area (Sack, 1987). SCS snow course data has provided much of the information required to compile snow load maps, used in many western states for design purposes.

Annual Precipitation Maps: Estimates of average annual precipitation for an area are required for a multitude of planning, engineering, and design projects. In the sparsely populated mountainous regions of the west, snow survey information may provide the only available index of average annual precipitation.

Drought Monitoring: In 1987 and 1988, many portions of the West experienced near drought conditions. Snow surveys provided advanced warning in these low water years, enabling federal, state, and local agencies to take appropriate actions.

The SNOTEL system monitored mountain precipitation during the summer and fall seasons as well. This provided an index of soil moisture useful in predicting the efficiency of the coming winter's snowpack in producing runoff.

Fish & Game: Snow survey data is used by fish and game specialists in a variety of ways. In high snowpack years, big game may require special feeding activities to enable them to survive the winter. Streamflow forecasts are used in the Columbia River basin of the Pacific Northwest to prepare for poor juvenile salmon and steelhead migration conditions (Buettner, 1988). In low runoff years, hatchery smolts may be released early in order to take advantage of higher streamflows to assist fish migration. In addition, fish traps are set to catch smolts and transport them around the dams on the Columbia, expediting their migration to the ocean.

Recreation: Winter recreation has increased dramatically in the last few years. Skiers, snowshoers, and snow machiners rely on snow survey information when planning outings. River and reservoir recreation have also increased in the last few years. The West contains most of the country's remaining free flowing rivers, and more and more people make float trips every year. Commercial outfitters, private float parties, and river management agencies use snowpack data and streamflow forecasts for recreation planning purposes.

Acid Precipitation Monitoring: Several studies have been conducted on the acid content of precipitation as measured in the mountain snowpack (Farnes, 1985). Monitoring the pH of high elevation snowpacks can provide an index of acid precipitation deposition, giving advanced warning of conditions which could cause loss of aquatic life, dying forests, and other problems now appearing in the Eastern Unites States, Canada, and Europe.

Avalanche Forecasting: Avalanche forecasters in the western U.S. are quickly becoming aware of the usefulness of SNOTEL data for operational daily forecasting. Highway departments and recreation specialists in particular are using daily SNOTEL information for road closure and ski area avalanche control decisions. New snow fall data and air temperature parameters are especially important in avalanche forecasting. Some SNOTEL sites have been fitted with additional sensors, such as wind speed and run, and are interrogated several times daily, to improve the forecasters knowledge of avalanche conditions in an area.

FUTURE DIRECTIONS

In 1987, a Productivity Improvement Program (PIP) committee was formed by the SCS "to evaluate the most effective organization for accomplishing the Snow Survey program objectives, to identify activities of the program that could be modified to increase accomplishments, and to determine those activities which are inherently governmental versus those which could be considered commercial in nature" (USDA, 1988). The PIP report was completed and endorsed by the Chief of the SCS in April, 1988.

In the summer of 1987, a committee was formed to update the existing Snow Survey Program Long Range Plan (LRP). The final draft of the LRP has been awaiting the completion of the PIP study in order to incorporate its recommendations. As a member of the committee that is drafting the LRP update, and after consultation with the Snow Survey Program Manager, I can report on several areas of future direction as outlined in both the LRP and the PIP report:

-- The SCS will continue efforts in snow course reduction as the period of record and reliability of SNOTEL increases. A manual snow course reduction plan was prepared in 1982, which requires rigorous statistical evaluations before snow courses can be discontinued and their data replaced with telemetered SNOTEL data. This will ensure that data quality and integrity will not be compromised. The full implementation of the snow course reduction plan will provide significant financial and technical advantages to the program.

-- The SCS remains committed to improving the usefulness and timely delivery of water supply products to the water user community. The present structure of CFS will be enhanced in the future to include more graphics products and links to other federal and state agency data bases. CFS enhancements will retain compatibility with the Service's new computer system, FOCAS (Field Office Communications and Automation System) allowing SCS field offices in every county to instantly access real-time water supply information, and rapidly disseminate this to water users. The monthly Water Supply Outlook Reports, published in each western state, is not timely enough to provide water managers with information needed to make critical decisions. The PIP report recommends a two year phase out period to replace the published report with increased automated (computer) access and one annual data summary report for archival purposes.

-- In keeping with the commitment to improve the usefulness of water supply products, the SCS is pioneering the development of reservoir operating guides for small reservoirs. These guides are a tool which allow reservoir managers to incorporate SCS streamflow forecasts into reservoir operations, thus reducing downstream flooding in high snowpack years and improving water conservation in low years.

-- The SCS is currently in the second year of a 5 year upgrade plan which will ultimately replace all first generation remote site transceivers, both master stations, and the central computer facility with new state of the art equipment. The LRP will direct the development of a plan for the ongoing operation, maintenance, and replacement of capitalized equipment. A new SNOTEL data management system has recently been installed in each state's snow survey office (Grimsted, 1987). This system, known as 3B2GS, will be enhanced over the next few years to improve the efficiency and quality of SNOTEL data management.

-- The SCS is committed to increasing the use of hydrologic models in operational forecasting. SNOTEL will provide much of the data required to drive these models. The PIP report recommends that "the Snow Survey Program Manager in concert with State Conservationists will evaluate river basin simulation modeling efforts to ascertain the effectiveness of operationally producing hydrograph and seasonal water volume forecasts with existing computer models that use SNOTEL data" (USDA, 1988).

-- The SCS will expand efforts to integrate Snow Survey products and expertise into other conservation programs. The top three resource management priorities of the SCS are soil erosion, water conservation, and upstream flood management. Future national priorities will likely include improving surface and ground water quality by reducing non-point pollution from agricultural lands. Water supply forecasts and related products can assist in a program to improve water quality. CFS's climate data base may be expanded in the near future to include the entire United States. This will assist in conservation planning activities on a nation-wide basis. An increased awareness of available snow survey products by all SCS specialists and a commitment to integrate these products into conservation programs can assist in addressing nationwide conservation priorities.

SUMMARY

The Soil Conservation Service operates a Snow Survey and Water Supply Forecasting program in the western United States, for the purposes of providing information on forthcoming water supplies from streams that derive most of their runoff from snow melt. Snow surveys began in the early 1900's in the Sierra Nevada mountains, and quickly spread to the rest of the mountainous West.

In the current SCS program, a network of over 1800 manual snow courses, and over 500 automated SNOTEL sites are used to predict spring and summer streamflow at over 500 forecast points west-wide. Streamflow forecast information, as well as other water supply related products, are available from state and west-wide published reports, and from the Centralized Forecast System computer.

In addition to water supply forecasting, snow survey data is used in a variety of other applications. These include reservoir management, snow load and average annual precipitation maps, resource monitoring, wildlife management, recreation, and avalanche forecasting.

Future directions for the program include continued efforts in manual snow course reduction, improving usefulness and timely delivery of water supply products, developing reservoir operating guides to improve water conservation, increasing the use of hydrologic simulation models in operational forecasting, and expanding the integration of Snow Survey products and expertise into other SCS conservation applications.

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