RESEARCH AT THE CENTRAL SIERRA SNOW LABORATORY: HISTORY AND HOPE

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ABSTRACT

Snow studies on Donner Summit began in 1879 with the practical concerns of the Southern Pacific Railroad. Scientific work in the area was initiated by James Church to complement his research on Mt. Rose. Following World War Two, the Cooperative Snow Investigations of the U.S. Army Corps of Engineers and then-Weather Bureau chose Donner Summit as one of their "snow laboratories". Between 1945 and 1952, work at the Central Sierra Snow Laboratory generated much of our fundamental knowledge about snow physics and hydrology. Continuing research by the U.S. Forest Service and many cooperating agencies improved our understanding of forest-snow interactions, snow chemistry, physics of wet snow, snowmelt modeling, and mountain climatology. The facility and its parent research program have lost funding for fiscal year 1996 and beyond. The current status of the transfer of the Snow Lab to the University of California's Natural Reserve System is discussed.

INTRODUCTION

The Central Sierra Snow Laboratory (CSSL) is one of the nation's principal observatories of hydrological and meteorological phenomena in a mountain environment. Few, if any, sites in the mountains of North America can match the duration of basic monitoring of hydroclimatic events or intensity of process-related research as the Snow Lab. Snowfall has been measured for more than a century and precipitation has been measured for almost a century in the vicinity of the CSSL. Active hydrologic research has been pursued at the Snow Lab for a half century. In that half century, the research mission has changed several times, including topics such as basic physics of snow and energy exchange, applied runoff forecasting, developing techniques for snowpack management, understanding hydrologic impacts of other resource management activities, and evaluating broader ecological impacts. In late 1995, the facility lost federal financial support when its parent research project was eliminated because of the federal budget debacle. As of April 1996, the facility was being transferred to the University of California in an effort to maintain continuity of the unique long-term database.

The Central Sierra Snow Lab is located in the Donner Summit region of the Sierra Nevada of California (39°19'N, 120°22'W). This location is near Soda Springs just west of the mountain crest where Interstate Highway 80 crosses the Sierra Nevada at Donner Pass enroute between the cities of Sacramento and Reno. Lake Tahoe is about 25 km southeast of the Snow Lab. When first established, the term "snow laboratory" referred to a complete catchment of about 10 km^2 ranging in elevation between about 2100 m and 2800 m. However, with construction of the four-lane freeway through the heart of the catchment in late 1950s, the integrity of the basin for environmental research was compromised. Since the early 1960s, the name "Central Sierra Snow Laboratory" has referred to the former headquarters area of the complete catchment located near the basin's outlet and former stream gaging site as well as an assortment of small study plots in the vicinity. The area is subject to a maritime climatic influence, and most of the average annual precipitation of about 1300 mm falls as snow at temperatures close to 0°C (Osterhuber, 1993). Snow cover begins to accumulate between early November and late December and is augmented by about 15 storms in a typical winter. One or two major rain-on-snow events occur at the Lab in most years. About three-quarters of the annual precipitation falls in the period of November through March (Osterhuber, 1993). Average maximum water equivalence of the snowpack is about 100 cm and typically occurs in late March or early April. The period of seasonal snowmelt runoff

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Paper presented at Western Snow Conference 1996, Bend, OR

usually lasts from April through late May or early June. Vegetation around the CSSL is composed mainly of lodgepole pine (*Pinus contorta* var. *murrayana*) and red fir (*Abies magnifica*) up to 45 m in height.

Results of the initial and most intense period of research at the CSSL are thoroughly described in the summary volume of the Cooperative Snow Investigations, Snow Hydrology (U. S. Army Corps of Engineers, 1956). An eloquent personal account of those early years and the following decade was given by David Miller to the Western Snow Conference at the 1995 meeting in Reno (Miller, 1995). That paper described the start-up of the Snow Lab and the accomplishments of the projects based there through 1964. This current paper briefly highlights some of the past research activities based at the Central Sierra Snow Lab, focusing on the past three decades, and describes the current status of the facility. An extensive, though very incomplete, bibliography is suggestive of the wide range of research that has been pursued at the Snow Lab.

EARLY SNOW STUDIES ON DONNER SUMMIT

Snow measurements on Donner Summit began in 1878 with basic depth measurements for railway maintenance activities by the then Central Pacific Railroad. Many of the railroad's operations were based at Norden (2 km east of Soda Springs) to enable ready access to both sides of Donner Pass. Daily snowfall and total snowpack depth were measured near the actual pass (another kilometer east of Norden) until 1927 and then at Norden until 1985 (Osterhuber, 1993). The Cooperative Snow Surveys program of the California Department of Water Resources used the long-term snow data set of the Southern Pacific Railroad to produce a graph of seasonal snowfall and snow depth at Donner Summit. The time series was extended beyond 1985 with data from the CSSL. This popular reference item is found in many, if not most, homes and businesses in the Donner Summit, Truckee, and north Lake Tahoe area. This time series of snow information is believed to be the longest continuous record of snow amounts in the mountains of North America. This information has been widely cited in climatic studies, popular historical accounts of the western U.S., and by the news media. Dr. James Church of the University of Nevada at Reno, the pioneer of snow surveying and forest-snow interactions, conducted snow studies on Donner Summit to complement his work on Mt. Rose. Basic meteorological instrumentation and snowmelt lysimeters were set up near Soda Springs (Church, 1948). Presumably, this work led to the original Cooperative Snow Investigations, initially between the University of Nevada, Reno and then-Weather Bureau (Gerdel and Codd, 1945).

ESTABLISHMENT OF THE CENTRAL SIERRA SNOW LABORATORY

After the end of World War II, the U.S. Army Corps of Engineers and Weather Bureau acted on previous discussions and plans by organizing a joint research program in snow hydrology. This program was aimed at solving problems of runoff and flood forecasting in the mountains of the western United States that were of mutual interest to both agencies. The program would depend on a strong field component involving studies at three "snow laboratories" that were small (10 to 55 km^2), well-instrumented research catchments. One of these basins was that of Castle Creek in the headwaters of the South Yuba River near Donner Summit. This Central Sierra Snow Laboratory was selected to represent areas dominated by snow but that receive some mid-winter rainfall. Characteristics and operations of the CSSL are thoroughly described in various reports of the Cooperative Snow Investigations (e.g., Cooperative Snow Investigations, 1951; U.S. Army Corps of Engineers, 1956; and the Hydrometeorological Logs of the Central Sierra Snow Laboratory [1945-1946 through 1951-1952]). Miller (1995) places much of the research at the CSSL in perspective after a few decades have passed. From our vantage point, it seems that much, if not most, of the fundamentals of snow physics and hydrology were developed during the Cooperative Snow Investigations of 1945-1952, largely at the CSSL, and well described in the pages of Snow Hydrology. Since then, most snow research has been building on those fundamentals and refining some of the details.

FIRST PHASE OF FOREST SERVICE INVOLVEMENT AT THE CSSL

When the active data collection period of the Cooperative Snow Investigations was completed in 1952, the CSSL entered a period of relative dormancy for a few years. Although there was a minimal meteorological record at the CSSL from August 1952 through June 1957, the cooperative weather station at Soda Springs was maintained during this period and provided data continuity for the Donner Summit area. When the USDA-Forest Service research branch expanded its watershed management research program in the Sierra Nevada, the CSSL was an obvious choice for a field station. The Forest Service was primarily interested in following up on some of the forest-snow interaction work begun by Professor Church (e.g., Church, 1912) and studying erosion from forested watersheds. The CSSL proved to be an excellent base for both categories of research. Henry Anderson's group studied a wide range of forest influences on snow cover, micrometeorology, and runoff generation. Process-level studies were summarized by Anderson, et al. (1958a), Court (1957), Miller (1962), West (1959, 1961, 1962), Ziemer (1964), etc. Integrative watershed-scale analyses were described by Anderson (1956, 1958, 1960a, 1960b, 1963, 1970), Anderson and Pagenhart (1957), Anderson et al. (1958b), Rice and Wallis (1962); West and Knoerr (1959), etc. Miller (1995) interprets some of the long-term value of this period of research, which was the second research program he participated in at the CSSL.

FOREST SERVICE SNOW MANAGEMENT RESEARCH

In the mid-1960s, the snow and erosion/sediment research of the USDA-Forest Service's Pacific Southwest Forest and Range Experiment Station was split into two projects, and James Smith became the new leader of the Station's snow hydrology project. The general goals of the project remained focused on better management of water resources in the mountains, but increased emphasis on manipulation of vegetative cover for desired hydrologic outcomes. A planning document stated the project's mission as "determine and analyze the principles that govern the accumulation and melt of the snowpack, and to integrate these principles into multiple-use management plans that will help resource managers increase, capture, and store the water from the melting snow as it appears as streamflow." Much effort in this period went into developing a new snowpack monitoring tool: the isotopic profiling snow gage, which allowed repeated measurements of the same snow column. Prior studies had suggested the potential for gamma attenuation as an indicator of water equivalence (e.g., Gerdel et al., 1950; Gay, 1962; Anderson et al., 1963). Further development led to an operational gage capable of producing a density profile of a snow column (e.g., Smith and Willen, 1966; Smith, 1967; Smith et al. 1967; Limpert and Smith, 1974; Kattelmann et al., 1983). Insights to snowpack dynamics obtained through use of the profiling snow gage were presented by Smith and Halverson (1969) and Smith (1974). Instrumentation for measuring the liquid water content of snow was also under development at this time (e.g., Linlor and Smith, 1974; Linlor et al. 1975). Snowpack evaporation and means of suppressing it were another area of active research (e.g., Smith and Halverson, 1971; Krouse and Smith, 1974; Baldwin and Smith, 1978), as was water movement in soils and trees (Owston et al. 1972; Smith, 1972). The principles underlying snow management for augmenting and delaying water yield were outlined in a series of reports (e.g., Halverson, 1972; Halverson and Smith, 1974; Smith, 1975a, 1975b). In the late 1970s, the project became involved in describing the basic climatology of the Sierra Nevada and evaluating the environmental effects of weather modification in cooperation with the Bureau of Reclamation (Smith, 1978; Berg and Smith, 1980; Smith and Berg, 1980, 1982; Berg et al. 1983).

ENVIRONMENTAL IMPACT RESEARCH AT THE CSSL

Following the death of James Smith in 1980, Neil Berg became project leader of the snow hydrology unit. Research emphasis shifted somewhat toward evaluating hydrologic consequences of other resource development activities. Activities at the CSSL during this period were described by Berg (1987). Records from the CSSL were used in a few climate studies (Azuma, 1985; Azuma and Berg, 1990; Osterhuber, 1993). Several studies sought to improve basic knowledge of snowpack properties and processes to provide a better basis for evaluating environmental impacts as well as runoff forecasting (Berg, 1982; Kattelmann, 1985b, 1986a, 1986b, 1989; Kattelmann and McGurk, 1989; McGurk, 1983; McGurk et al. 1988; McGurk and Kattelmann, 1986, 1988; McGurk and Marsh, 1995). A few models of snow accumulation and melt were developed and tested during this period as well (Berg and Hannaford, 1983; Aguado, 1985; Kattelmann et al., 1985; McGurk, 1985). The hydrology of rain-on-snow events was explored in several studies (Berg et al., 1991; Bergman, 1983, 1987; Kattelmann, 1985, 1987; Kattelmann et al. 1991; McGurk et al. 1993). Studies relating to hydrologic consequences of forest management continued (Bergman, 1985; Kattelmann, 1982, 1985a, 1990; Kattelmann et al., 1983; MacDonald, 1986, 1987, 1989; McGurk and Berg, 1987). Other studies of evapotranspiration and vegetation interactions with snow were also pursued in the vicinity of the CSSL during this period (Barbour et al. 1991; Congalton and Pierce, 1986; Nachlinger and Berg, 1988; Palmer et al., 1983; Pierce and Congalton, 1988; Ustin et al. 1994). Development and refinement of measurement techniques in snow hydrology were the subject of several studies (Bergman, 1982, 1984, 1986a, 1986b, 1987, 1989; Kattelmann, 1984; McGurk, 1986, 1992; Osterhuber et al., 1994; Strachan, et al., 1994).

As part of a nationwide concern with "acid rain", different aspects of atmospheric deposition were investigated extensively at and near the Snow Lab (e.g., Berg, 1986, 1992; Berg and Woo, 1985; Woo and Berg, 1986a, 1986b). Research on sampling methods for snow chemistry analysis were conducted in collaboration with staff at the University of California, Santa Barbara (Marks et al., 1988, McGurk et al., 1989). The occurrence and chemistry of rime ice were studied at sites near the Snow Lab as well as in northern and southern California (Berg and Dunn, 1991; Berg et al., 1995). The greater concentrations of chemical constituents and considerable volumes of water found in rime ice at some sampling sites were compared to snow cover and precipitation (Berg, 1988; Berg et al. 1991).

In the early 1990s, the research mission at the CSSL expanded to include a fisheries component that involved studies in Castle Creek at the Snow Lab and at nearby locations. The broad question was how trout related to habitat conditions in these high-elevation headwater stream systems. Summer trout populations were censused through several years among 55 pools that exhibited high year-to-year variability. In addition, ice formation was studied as a possible critical factor in habitat restriction for trout (Berg, 1994). In a pool on the North Fork American River, trout use of cool water refugia and temperature stratification were also investigated (Matthews et al., 1994). The CSSL proved to be a good facility for winter fisheries research.

CURRENT COLLABORATION AND USE

The Snow Lab has had a strong tradition of collaborative research since the founding of the Cooperative Snow Investigations. The Bureau of Reclamation and Geological Survey were partners in the early research. When the Forest Service assumed operation of the Lab in 1956, the California Department of Water Resources also became involved. Other cooperators between the 1960s and 1980s included the Atomic Energy Commission, Bureau of Reclamation, California Air Resources Board, Desert Research Institute, East Bay Municipal Utility District, Kings River Water Association, NASA, National Weather Service, Pacific Gas and Electric Company, Soil Conservation Service, Southern California Edison Company, various National Forests, University of California, and University of Nevada.

Cooperative projects at the CSSL continue. One of the largest studies is a comparison of steel and hypalon snow pillows involving the California Cooperative Snow Surveys program and Natural Resources Conservation Service. This investigation allows more detailed study of the characteristics of snow sensors than was possible during the extensive dual sensor comparison. A new prototype device that uses the difference in naturally occurring gamma radiation received by sensors above and below the snowpack to estimate snowpack water equivalence is being tested by Sandia Labs and the Department of Water Resources. ETI Instrument Systems, Inc. has been testing new precipitation gages at the Snow Lab. The National Weather Service has installed one of their precipitation gages at the Lab. The Geological Survey was using ion-capturing columns to measure trace constituents of the snowpack at the CSSL in the mid-1990s. The site is also used for monitoring of trace quantities of pesticides and other toxics by the Central Valley Regional Water Quality Control Board. Oxygen isotope experiments were recently conducted by scientists from Utah State University. Micro-meteorological and snowpack data were used in another project based at Utah State to validate a new snowmelt model (Tarboton et al., 1995). The Snow Lab is one of the few objective sources of information for the news media on current and historical snow and weather conditions in the Sierra Nevada. Data, interviews, and images from the CSSL are used by several newspapers, radio stations, and television stations every winter. All of these activities depend on the routine snowpack and meteorological data collection program and the presence of an on-site hydrologist.

FOREST SERVICE WITHDRAWAL

Research on snow science has declined over time throughout the United States. Specifically within the USDA Forest Service, snow research work units were phased out in the 1980s in the Rocky Mountain area. Forest Service snow research in the Pacific Northwest also halted when key scientists retired or moved to new assignments. In August, 1995, staff in the Water Research Unit of the Pacific Southwest Research Station learned that Station managers, in conjunction with Forest Service staff in the Washington Office, had decided to terminate the research unit. Four full-time permanent positions were "unfunded" as of October 1, 1995, and these positions included the CSSL Lab Manager and the Lab Supervisor in Albany. Without an operating budget and without staff, the Lab would be forced to close. After fifty years, the Central Sierra Snow Lab faced a complete shutdown. This action would also adversely affect the nearby Onion Creek Experimental Forest, a 14 km^2 basin in the headwaters of the North Fork of the American River that has been administered by the research unit.

CURRENT PROSPECTS

Soon after the decision to terminate the project was announced, the Snow Lab Supervisor began contacting agencies and individuals in an attempt to find a new operator of the Lab. After contacting the Director of the University of California's Natural Reserve System (NRS), a promising prospect for the Lab was identified. The NRS administers over 30 sites around the state and uses them for educational and scientific studies. The sites are available not only to students, teachers, and researchers from the University, but to any qualified user from any public or private institution anywhere in the world. Each reserve is assigned to and managed by one of the UC campuses.

Between November 1995, and February 1996, several field trips were held to acquaint NRS staff with the research potential of the CSSL and the Onion Creek Experimental Forest. The two sites have much to offer the NRS for many reasons. Nearby UC holdings include the Sagehen Creek Field Station, which is about 15 km northeast of the CSSL on the east slope of the Sierra Nevada, and the Chickering Reserve, about 5 km southeast of Onion Creek. The NRS is also entering into a long-term agreement with a group of property owners who control the land between Onion Creek and the Chickering Reserve. To gain management control of Onion Creek would consolidate a block of over 40 km^2 of mature mixed conifer lands along the western crest of the Sierra Nevada. The area has extensive wildlife and forest stands with old-growth characteristics. The CSSL has a long-term data base and a treasure trove of research equipment that would become available to UC staff. Efficiencies in operation of the sites could be achieved by combining all the sites under a manager who might be sited at the Snow Lab, because it has the best winter access and facilities, and the present staff member could become a University employee instead of a Federal employee.

Negotiations between the Pacific Southwest Research Station, Tahoe National Forest, and NRS administration led to draft Memorandums of Understanding (MOU) on the management of the CSSL and Onion Creek. The terms of the MOU was set for 20 years, and would be renewable. Transfer of the Sagehen Creek Field Station from an academic department at UC Berkeley to the NRS should allow coordinated management of this set of research facilities in the central Sierra Nevada. The Museum of Vertebrate Zoology at UC Berkeley is the likely administrative home for the new elements of the Natural Reserve System. Dr. Jim Kirchner, a professor in the Department of Geology and Geophysics at UC Berkeley, agreed to become the faculty supervisor of the group of facilities. Professor Mary Power of the Department of Integrative Biology has also been playing a major role in facilitating the transfer.

Funding to support the CSSL, Onion Creek, and affiliated staff has been a major concern. PSW has agreed to contribute a yearly sum to maintain the structures and other facilities. The Cooperative Snow Survey program of California's Department of Water Resources has agreed to fund some of the winter staffing of the CSSL in conjunction with equipment evaluation and development. The USDA Natural Resources Conservation Service has also been supporting winter staff costs associated with equipment evaluations. Both agencies are under considerable pressure to develop new equipment to monitor both seasonal precipitation and snow water equivalent. The new equipment should match the existing precipitation gauges and snow sensors, yet not use toxic materials, radioisotopes, or require frequent service. The CSSL, with its long history of equipment development and testing, year-round staffing, and parallel snow and weather data collection, is an ideal facility at which to develop and test this type of equipment.

As of April, 1996, draft MOUs have been completed and are being reviewed by the NRS, Pacific Southwest Research Station, and Tahoe National Forest. Funding sources are being sought by the University to solidify a reliable base for operation of a combined CSSL/Sagehen facility and the satellite area in the North Fork headwaters. Final agreements are expected by June, at which time the MOUs would be signed and the transfer will be completed.

The role of the CSSL in snow hydrology and snow instrumentation should continue into the 21st century under the new management agreements. The Central Sierra Snow Lab is the primary remaining hydro-meteorological monitoring station in the Sierra Nevada with on-site staff and provides unique capabilities for both research and data collection activities. These features, in combination with the importance of long-term databases resident at the Lab, promise to extend the longevity of the CSSL. Members of the Western Snow Conference stand to benefit from the continued operation of the CSSL, and we hope that members will continue to support the CSSL by using the staff and facility as a base for instrumentation development and snow hydrology research.

ACKNOWLEDGMENTS

All the staff at the Central Sierra Snow Lab have maintained the continuity of the routine records and helped with special measurement programs. We particularly wish to recognize the long service of Jim Bergman as the officer in charge of the Lab. The efforts of Debbie Elliott-Fisk, Jim Kirchner, Mary Power, and Frank Gehrke in moving the CSSL toward the next phase of its history are greatly appreciated.

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