1

Introduction

1.1 Perceptions of snow

There is a general lack of appreciation by society of the importance of snow to everyday life. One good example of this is found in the Rio Grande Basin in the southwestern United States and Mexico. The Rio Grande, the third longest river in the United States, is sustained by snow accumulation and melt in the mountain rim regions which provide a major contribution to the total streamflow, despite its flowing right through the heart of North America's largest desert (Chihuahuan). Because the majority of the population in the basin resides in a few large cities in the Rio Grande Valley, which are all located in the desert (see Figure 1.1), there is little realization on the part of the urban residents that snowmelt far to the north is an important factor in their lives. This same situation is true in many arid mountainous regions around the globe. Where agricultural water use predominates, however, the importance of snow for the water supply and food production is more widely known, at least by farmers and ranchers and the rural populace.

The importance of snow during and in the aftermath of a snowstorm is immediately evident because of its significant effect on transportation (see Figure 1.2). The effects of snowstorms on wagon trains (in the past), railroads, and motorized transport are widely documented by Mergen (1997). Except for very small countries, the effect of a snowstorm on transportation is localized and does not affect the entire country. Such local effects are evident in the United States as in the leeward areas of the Great Lakes where persistent and heavy annual snowfalls occur, such as over 370 in (940 cm) on the Tughill Plateau area of upstate New York (Macierowski, 1979). Areas just a short distance away, however, have annual averages of only about 65 in (165 cm) a year. Storm tracks or snowbands are relatively narrow, so that the majority of the population is seldom impacted but small regions can be severely impacted (see Figure 1.3). One exception to this in winter in the United States is when a low-pressure area tracks its way from the Gulf of Mexico all the

Cambridge University Press
978-0-521-82362-3 - Principles of Snow Hydrology
David R. DeWalle and Albert Rango
Excerpt
More information

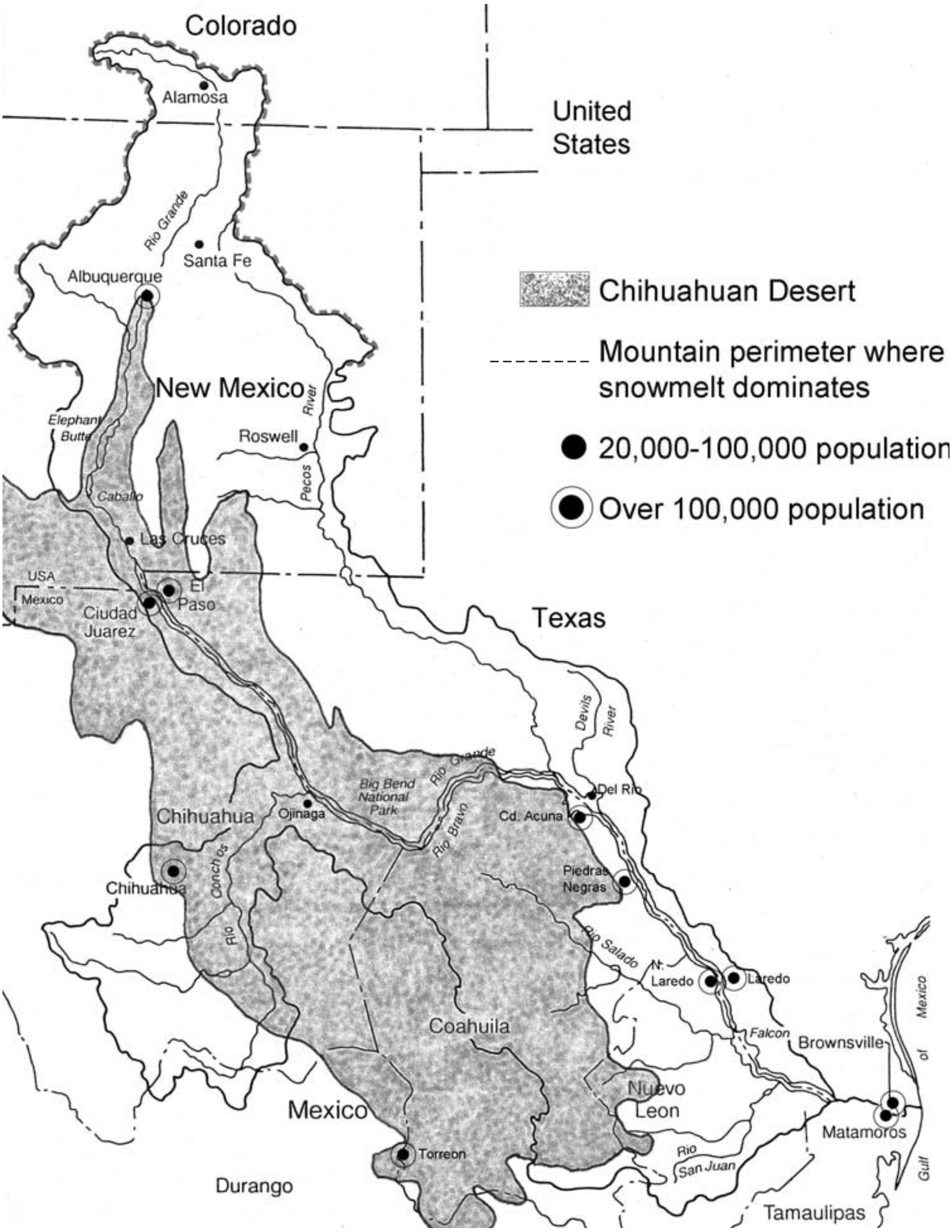

Figure 1.1 Location of the Rio Grande Basin in the United States and Mexico with large cities identified in relation to mountain snowpack areas and desert areas.


The Evening Bulletin
Snow Edition

Worst snow storm in R.I. history halts transit, strands thousands

Governor is told U.S. will send storm aid

Garrahy declares state of disaster

Innkeepers by chance, not choice

Megalopolis staggers under emergency status

Good Evening!

Figure 1.2 The effect of snow on transportation as documented on the front page of the Providence, Rhode Island, "The Evening Bulletin," on Wednesday, February 8, 1978 (from www.quahog.org/include/image.php?id=133).

way up the eastern US coast where the majority of the US population is concentrated. Figure 1.4 shows the snow depth map compiled from ground measurements associated with the "Blizzard of 1996" which was a "Nor'easter."

If the storm is particularly severe, normal transport can be shut down for extended periods. Figure 1.5 shows the clearing of mountain highways in the

Figure 1.3 Red Cross workers search for possible victims after a lake effect storm near Buffalo, New York, on January 28–29, 1977 (note that snow depth is up to the top of an automobile). (Courtesy NOAA Photo Library, wea00952, Historic NWS Collection and the American Red Cross.)

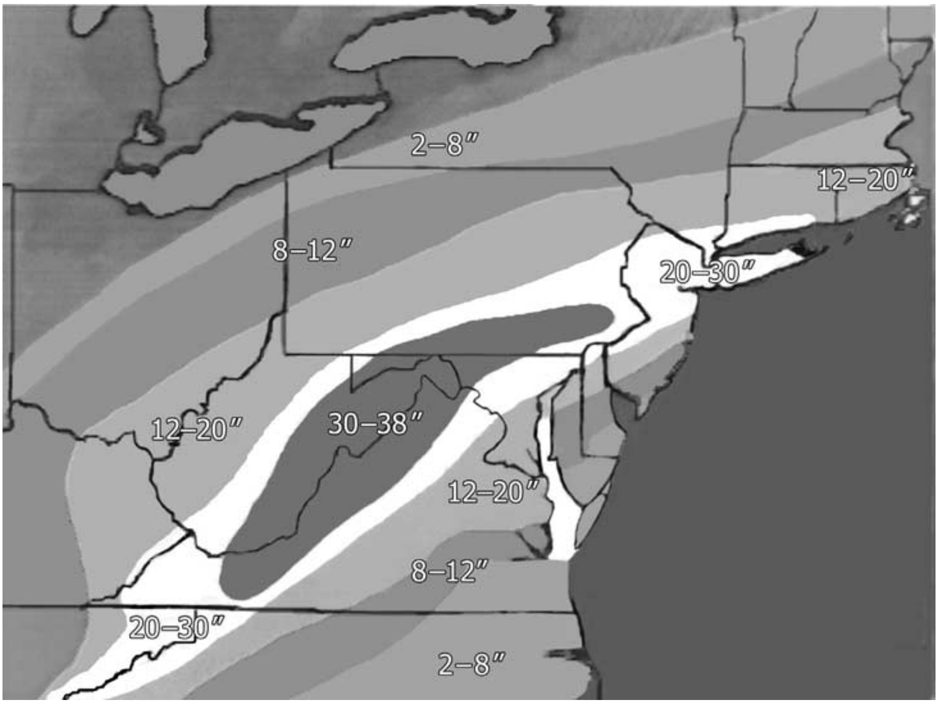

Figure 1.4 Snow depth map from January 6–8, 1996 associated with the "Blizzard of 1996," centered over the middle Atlantic United States (after WRC-TV/NBC 4, Washington, DC analysis). See also color plate.

Figure 1.5 Transportation department snow blower at work clearing Highway 143 between Cedar Breaks and Panguitch, Utah in 2005. (Courtesy R. Julander.) See also color plate.

western United States. Additionally, in these severe snowstorms, communication is frequently disrupted by downed utility lines. Those affected for that period of time would certainly support the (in this case, negative) importance of snow.

Because of the disruptions to human activities caused by extreme snowfalls, Kocin and Uccellini (2004) developed a Northeast Snowfall Impact Scale (NESIS) to categorize snow storms in the northeast United States. The scale is based upon the amount of snowfall, the areal distribution of the snowfall and the human population density in the affected areas. Maximum category 5 "Extreme" events are those like the January 1996 event (NESIS rating = 11.54) depicted in Figure 1.4 with up to 75-cm snowfall depths which affected about 82 million people over nearly 0.81 million square kilometers in the Northeast. At the other extreme, category 1 "Notable" events were those like the February 2003 event (NESIS rating = 1.18) with up to 25-cm snowfall depths which affected 50 million people over 0.23 million square kilometers. The NESIS ratings of storms combined with information about wind speeds controlling drifting during and after snowfall should significantly improve our appreciation of the severity of impacts of snowfall.

When a fresh snowfall blankets the landscape, most people will agree that snow is aesthetically pleasing and a positive visual experience. Less widely known and more important, however, is that a snow cover radically changes the properties of the Earth's surface by increasing albedo and also insulating the surface. Extremely cold air temperatures may exist right above the surface of the snow, but the insulating effect can protect the underlying soil and keep it relatively warm and unfrozen. In General Circulation Models (GCM), it is important to precisely locate the areas of the Earth's surface covered by snow because of the great differences in energy and water fluxes between the atmosphere and snow-covered and snow-free portions of the landscape. Because such differences are important in the reliability of simulations produced by GCMs, providing correct snow cover inputs to GCMs is critical.

In many areas of the world like the western United States, snow accumulation and subsequent melt are the most critical determining factors for producing an adequate water supply. To quantitatively estimate this water supply, including volume, timing, and quality, it is important to have a detailed understanding of snow hydrology processes, the goal of this book. As water demand outstrips the water supply, which is happening in most of the world today, this knowledge of snow hydrology becomes increasingly important.

The technology of remote sensing has had a major impact on data collection for measuring snow accumulation and snow ablation rates. The reasons for the ready application of remote sensing to snow hydrology are multifaceted. Significant snowpacks accumulate and deplete in remote, inaccessible areas that are easily imaged with remote-sensing platforms. These snowpack processes in mountain regions are active generally during the most inhospitable time of year which makes considerations of human safety important. The use of remote-sensing approaches is much safer than employing ground access during these times. In most cases, the appearance of snow in various types of remote-sensing data products is strikingly different from snow-free surfaces, allowing snow mapping in different spectral bands.

A surprising amount of biological activity occurs within and beneath the snow cover, especially so for deep snowpacks, because of warm soil conditions promoted by the insulating effect of the snow (see Jones *et al.*, 2001). This insulating effect protects many types of vegetation from the low air temperatures just above the snow surface. In many cases, plant survival is dependent upon the occurrence of a regular winter snowpack. In agriculture, this property is relied upon for the survival of the winter wheat crop which requires a snowpack of 10 cm or more (Steppuhn, 1981). For the world's winter wheat crop, the Food and Agriculture Organization (1978) has estimated that each centimeter of snow from 5–10 cm in depth would produce a crop survival benefit of \$297 000 000 cm^{-1} (Steppuhn, 1981).

Small animals survive beneath the snowpack for the same reasons as certain plants. About 20 cm of snow depth seems to be the breakpoint to allow such activity

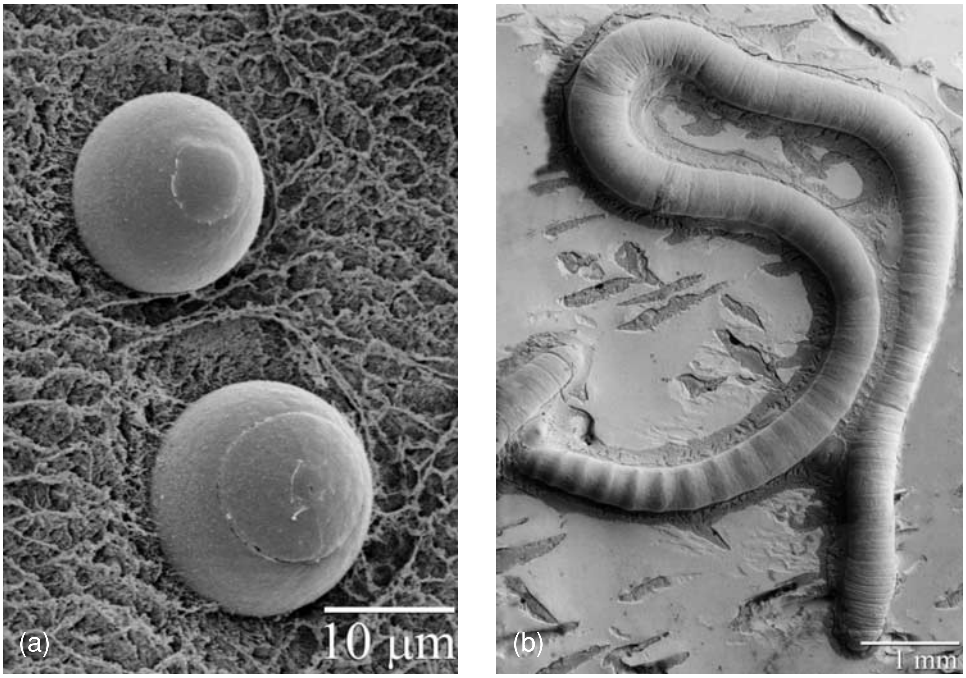

Figure 1.6 (a) Sample of red snow (containing green algae cells, *Chlamydomonas nivalis*) taken from a snowfield surface near the South Cascade Glacier and imaged with the Low-Temperature Scanning Electron Microscope (LTSEM) showing enlarged view of two individual cells. (b) LTSEM image of an ice worm (a species of oligochaetes) which was collected 1 m below the top of the seasonal snowpack near South Cascade Glacier. (Courtesy USDA, Agricultural Research Service, Beltsville, MD.)

(Jones *et al*., 2001). The snow itself is the habitat for various micro-organisms like snow worms and algae which are shown in Figures 1.6(a) and (b) taken with a Low-Temperature Scanning Electron Microscope. See Jones, *et al*. (2001) for further details on snow ecology.

1.2 History of snow hydrology

Although history suggests that technical understanding of snow hydrology was a relatively recent phenomenon, some evidence exists that the role of snow was understood by some very early in our study of the physical world. References to the philosophy of the ancient Greek, Anaxagoras (500–428 BCE), indicate a rather surprising early understanding of the relationships between river flows and freezing and thawing of water, for example (Franks 1898): *"The Nile comes from the snow* *in Ethiopia which melts in summer and freezes in winter"* (*Aet. Plac*. iv 1;385); *"And the Nile increases in summer because waters flow down into it from snows at the north"* (*Hipp. Phil*. 8; Dox. 561). Passages from the Bible also show an early general understanding of the role of snow in the natural world, most notably perhaps: "*For as the rain and the snow come down from heaven, And do not return there without watering the earth, And making it bear and sprout, And furnishing seed to the sower and bread to the eater*." (Isaiah 55:10, New American Standard Bible®, Copyright © 1995 by the Lockman Foundation, used by permission). These early references show that some basic concepts underpinning snow hydrology have existed for millennia.

Much later, literature from the writings of naturalist/geologist Antonio Vallisnieri (1661–1730) in Italy showed specific recognition of the role of snow in hydrology. He correctly theorized that rivers arising from springs in the Italian Alps came from rain and snowmelt seeping into underground channels (attributed to Lupi, F. W., www.killerplants.com/whats-in-a-name/20030725.asp).

In the United States during World War II, the US Army Corps of Engineers and the US Weather Bureau initiated the Cooperative Snow Investigations in 1944 (US Army Corps of Engineers, 1956). The snow investigations were organized to address specific snow hydrology problems that were being encountered by both agencies. In order to meet snow hydrology objectives of both agencies, it was deemed necessary to establish fundamental research in the physics of snow. An extensive laboratory program across the western United States was established and observations were gathered starting in 1945. Analysis of these data formed the basis for developing the basic relationships and methods of application derived to develop solutions to the key snow hydrology problems (US Army Corps of Engineers, 1956).

Three snow laboratories were established: the Central Sierra Snow Laboratory (CSSL), Soda Springs, CA (see Figure 1.7); the Upper Columbia Snow Laboratory (UCSL), Marias Pass, MT; and the Willamette Basin Snow Laboratory (WBSL) Blue River, OR. The drainage areas where the research was concentrated had areas as follows: CSSL, 10.26 km^2; UCSL, 53.61 km^2; and WBSL, 29.81 km^2. Although the major report coming from these studies was written in 1956 (US Army Corps of Engineers, 1956), this book, *Snow Hydrology*, is still an excellent reference book for students and forms the basis for much of the information on snow hydrology in basic hydrology texts.

Both the CSSL and WBSL received snow indicative of maritime-influenced climate conditions. The UCSL snowfall was influenced by both maritime and continental climate conditions. A fourth snow laboratory was established for cooperative snow investigations by the US Bureau of Reclamation and the US Forest Service at the Fraser Experimental Forest, Fraser, CO. Continuous measurements were made there starting in 1947. The climate conditions influencing snowfall at Fraser are

Figure 1.7 Instrumentation at the Central Sierra Snow Laboratory in Soda Springs, California. (Courtesy R. Osterhuber.) See also color plate.

more of a true continental origin than the UCSL. The emphasis at Fraser was on evaluation of various snow and runoff measurements, development of snowmelt-runoff forecasting techniques, and the effect of forest management on water yield from snow-fed basins. The final report of the project, *Factors Affecting Snowmelt and Streamflow* (Garstka *et al*., 1958), has also been identified as a significant contribution to understanding snow hydrology. Snow hydrology research has continued to the current day at the CSSL and the Fraser Experimental Forest.

Outside the United States, a number of snow laboratories and research watersheds were established. The Marmot Creek Basin (9.4 km^2), about 80 km west of Calgary, Alberta, Canada, was instrumented in 1962 to study the water balance in a typical subalpine spruce-fir forested watershed (Storr, 1967). A network of 40 precipitation gauges and 20 snow courses cover the basin. The overriding reason for establishing this research basin was to determine the effects of forest clearing practices on snow accumulation and streamflow. Treatments were performed in 1974 which involved clear-cutting five separate blocks ranging from 8–13 ha (Forsythe, 1997).

Work in Russia on snow hydrology began in the 1930s, but, as in the United States, specific field research sites were set up in the mid- to late 1940s. The primary field sites were the Valdai Hydrological Research Laboratory and the Dubovskoye

Hydrological Laboratory. Much Russian work on heat and water balance of snow, snow cover observations, and snow metamorphism is reported by Kuz′min (1961). In the same work, the arrangements of permanent snow stakes and instrumentation, like gamma ray snow water equivalent detection systems, are reported.

In 1959, the Chinese Academy of Sciences established the Tianshan Glaciological Station at the source of the Urumqi River in the Tianshan Mountains at 3600 m above sea level (a.s.l.) to provide comprehensive observations and studies of snowmelt and glacier hydrology. The station has full research facilities and living accommodation for both permanent staff and visiting scholars (Liu *et al*., 1991). Studies are conducted on the total Urumqi River basin (4684 km^2) and also on the part of the basin only in the mountains (Ying Qiongqia hydrometric station, 924 km^2). Recent studies at the Tianshan Glaciological Station have emphasized effects of global climate change, ice and snow physical processes, energy and mass balances of glaciers and snow, water balances of the upper mountain snow zone, and application of advanced observation technology, including remote sensing. Applications of outside investigators to participate in research at the Tianskan Glaciological Station are encouraged.

Several notable texts on snow hydrology also exist from early and recent literature. Kuz′min's (1961) summary book on *Melting of Snow*, which has been translated into English, is a rich source of information about early Russian studies. *The Handbook of Snow* edited by Gray and Male (1981) dealt with a wide variety of snow topics, including hydrology. Singh and Singh (2001) have written a book, *Snow and Glacier Hydrology*, that covers topics in snow hydrology and glaciology and some fundamentals of hydrology. Seidel and Martinec (2004) concentrate on remote-sensing applications in *Remote Sensing and Snow Hydrology*.

1.3 Snow hydrology research basins

Experimental basins established for snow hydrology research have had two major functions. First would be for the purpose of collecting all types of snow information for better understanding the physics of snow hydrology. An example of such a basin would be the Reynolds Creek Watershed in southwestern Idaho. The second purpose is for evaluating the effectiveness of snow management treatments to manipulate the quantity, quality, and timing of streamflow. The first example of this in the United States was the Wagon Wheel Gap experiment in the Upper Rio Grande Basin of Colorado (Bates and Henry, 1922; 1928). Both the data collection and snow management functions can be satisfied in the same research area. A good example of this would be at the previously mentioned Fraser Experimental Forest where long-term snow hydrology data have been collected and a classic, paired-watershed study was used to evaluate the effects of forest clear-cutting on snowmelt