Chapter 3
Collection and Analysis of Basic Data

3-1. General Introduction

Knowledge of snowfall amounts, the amount of snow accumulation on the ground (snowcover), and their spatial distribution throughout the watershed or basin area of interest is essential for the effective use of snowmelt runoff models. Thus, operational snowmelt forecasting programs must include activities to measure or acquire accurate snowfall and snowcover data.

a. Goodison, Ferguson, and McKay (1981) define snowfall as “the depth of fresh snow which falls during a given 'recent' period.....a single storm, a day, a month or a year.” They also define snowcover as “the amount of snow on the ground at the time of an observation.” They note that, “The ground may be either completely or partly covered.” The amount of snowfall and snowcover is influenced by many variables and, thus, typically can vary substantially over even relatively small areas. Variation over regions can be great.

b. The accurate measurement of snowfall and snowcover at a given point and of the spatial distribution of snowfall and snowcover over the basin is difficult and can consume the resources that are available to operational snowmelt forecasting programs. The parameters that are measured to define snowfall and snowcover are snow depth, snow water equivalent (water content), snow density and location, and extent of the snowcover. Table 3-1 summarizes the techniques that are available to measure snowfall and snowcover. Some methods allow for the measurement of snowfall and snowcover at a point, while others are adapted to the measurement of the areal extent of the snowcover.

3-2. Summary of Snow and Snowcover Parameters

a. *Snow depth*. Snow depth is routinely measured using graduated snow rulers that are installed to the ground surface. In recent years, snow depths have been successfully measured with acoustic snow depth sensors, which can be interfaced to remote data-collection systems. These sensors employ ultrasound range finders that measure the distance from a fixed elevation above the snowpack to the snowpack surface. The sensor is installed at an elevation greater than the highest expected snow depth before snowfall and the baseline is electrically set in the transducer or data-collection system. The acoustic snow depth system can operate with a ±1-cm accuracy (Metcalfe, Wilson, and Goodison 1987). The accuracy of snowfall measurements with snow rulers, snow boards, and snow gauges are affected by siting conditions and observer bias. Thus, at each observation station, multiple measurements are usually made to acquire a representative depth measurement. The literature documents the effects of siting or exposure on the accuracy of snowfall measurements. Peck (1972), Goodison (1978a), and Larson and Peck (1974) discuss the proper siting of measurements that minimize the local effects of drifting. Snow depth is usually expressed in inches or centimeters.

b. Snow water equivalent (water content). Snow water equivalent (SWE) is defined as the equivalent depth of water in the snow that is sampled and is normally expressed in inches or centimeters of water. The water content of either newly fallen snow or of the accumulated snowpack has been traditionally measured by weighing a vertical core taken through the snowpack. This measure is the basis of snow surveys, which are conducted throughout the United States to obtain the spatial distribution of SWE in a watershed or region. Measurement of SWE is subject to a variety of errors (Work et al. 1965, Goodison 1978b). Probably the most common error results from the field acquisition of an incomplete core of snow in the sampler tube. This may be caused by clogging of the cutter by corky snow, obstructions such as stones or sticks, or sticking of the snow to the tube. Such things can generally be detected by comparing the length of core with depth of the snow at the time the core is taken. Another source of error is the sampling of ponded water in the lower portion of the core, resulting from poor snowpack drainage. In such cases, the water equivalent may be computed by multiplying the depth of snow by densities obtained at nearby sample points. Any dirt or other foreign matter must be removed from the cutter end of the sample before the core is weighed. At sites where frequent observations are made, care must be exercised to avoid holes

Table 3-1
Snowfall and Snowcover Measurement Techniques

Measurement Class	Method Name	Application	Parameter Measured	Characteristics of Method
Simple linear measurement	Graduated snow ruler	Fresh snowfall	Depth	a. Point measurement; representativeness of measurement location of concern. b. Preparation of measurement site needed for each new snow event.
		Accumulated snowpack	Depth	a. Point measurement; representativeness of measurement location of concern. b. Measurement frequency a function of personnel availability.
	Snow board	Fresh snowfall	Depth	a. Point measurement; representativeness of measurement location of concern. b. Preparation of measurement site needed for each snow event.
Gravimetric	Precipitation gauges a. Nonrecording bucket gauge	Fresh snowfall Accumulated snowfall	Water equivalent, in. Water equivalent, in.	a. Point measurement; representativeness of measurement location a concern. b. Capture efficiency a function of gauge baffling and local wind regimes. c. Preparation of gauge needed for each new event.
	b. Recording weighing/tipping bucket gauges	Accumulated snowfall	Water equivalent, in. Snowfall rate, in./hr	a. Point measurement; representativeness of measurement location a concern. b. Capture efficiency a function of gauge baffling and local wind regimes. c. Can provide a continuous record. d. Gauge maintenance relatively infrequent depending on chart life and bucket capacity.
	c. Electronic balance	Accumulated snowfall Snowfall rate	Water equivalent, in. Snowfall rate, in./hr	a. As per recording precipitation gauges. b. Can provide rapid response times.
	Snow samplers (snow tubes)	Accumulated snowfall (snowpack)	Depth Water equivalent, in.	a. Point measurement; representativeness of measurement location a concern. b. Measurement frequency a function of personnel availability.
	Snow pillows and snow triangles	Accumulated snowfall (snowpack)	Water equivalent, in.	a. Point measurement; representativeness of measurement location a concern. b. Can be adversely affected by 'bridging' caused by ice lenses. c. Large and bulky; installation difficult. d. Can provide a continuous record.
Calorimetric	Freezing, alcohol solution or dilution calorimetric methods	Any snow sample	Liquid water content of snow sample (weight basis)	a. Point measurement; representativeness of measurement location a concern. b. Requires careful sample management prior to analysis c. Analysis relatively complex. d. Frequency of analysis determined by personnel availability.

Table 3-1 (continued)

Measurement Class	Method Name	Application	Parameter Measured	Characteristics of Method
Electromagnetic A. In situ sensors	a. Gamma radiometers	Accumulated snowpack	Water equivalent, in.	a. Point measurement; representativeness of measurement location of concern. b. Gamma radiation can be harmful to health. Cannot be left unattended in field. c. Can provide density profiles of snowpack.
	b. Acoustic sensors	Accumulated snowpack	Depth	a. Point measurement; representativeness of measurement location of concern. b. Setup, installation needs calibration. c. Can provide a continuous record with frequent readings. d. Adaptable to automatic data capture.
	c. Optical snow gauge (transmissiometer)	Snowfall	Snowfall rate, in. Snowfall mass conc., g/cc	a. Point measurement; representativeness of measurement location of concern. b. Output a function of snow particle size and crystal type and fall velocity. c. Can provide a continuous record with instantaneous readings. d. Adaptable to automatic data capture.
B. Remote sensors (satellite or airborne mounted)				GENERAL: Remote sensor data generally do not represent point measurement but rather are applicable to wide-area surveys. Depending on data use resolution of the sensor data may be of concern. Except for visible photos, data are acquired in digital formats, and thus efficient input to automated data systems is possible.
	a. Natural terrestrial gamma radiation	Accumulated snowpack	Snowpack extent Water equivalent, in.	a. Background gamma radiation survey must be winter flight survey. b. Data are amenable to automated data analysis systems. c. Groundtruthing survey needed.
	b. Visible photography	Accumulated snowpack	Snowpack extent	a. Weather and clouds interfere with data acquisition. b. Computerized data systems require analog data to be digitized before use.
	c. Microwave	Accumulated snowpack	Snowpack extent Water equivalent, in.	a. Weather and clouds can interfere with data acquisition. b. Groundtruth information desirable.
	d. Radar-accumulated snowpack	Snowpack extent	Depth	a. Data acquisition possible in presence of clouds and certain weather conditions.
	e. Multispectral images	Accumulated snowpack	Snowpack extent	a. Weather and clouds can interfere with data.

left by prior sampling. Observer blunders such as misreading the snow depth or sampler weighing scales also happen. A comprehensive discussion of the methods used to take snow core measurements is available.

c. Snow density. Snow density is defined as the weight of snow per unit volume of snow and has the units of pounds/cubic foot or grams/cubic meter. Snow density is obtained by dividing the SWE by the depth of snow as would be measured when taking snow core readings or by simply weighing a known volume of snow.

d. Areal extent of snowcover. The location and extent of snowcovers are usually estimated using remotely sensed data that can discriminate between snowcover and no snowcover. Snowcover extent is often expressed as a percentage or fraction of the total drainage area of interest that is covered by accumulated snow. In a number of snowmelt runoff models, it is desirable to know snowcover extent within a number of defined elevational zones in the watershed area.

3-3. Measurement of Snowfall and Precipitation

a. Snowfall depths. Snowfall is measured at a point using a snow ruler or snow board, limited-capacity nonrecording snow gauges, recording-weighing-type precipitation gauges, or high-capacity precipitation-storage gauges. The depth of snow that has fallen during some recent period can be measured with a graduated rule (snow ruler). Snowfall depths are sometimes measured on a snow board whose surface has been kept free of snow before the snowfall. The water equivalent of the newly fallen snow can be estimated knowing snow density, or the snow can be melted in samples taken from on top of the snow board.

b. Nonrecording precipitation gauges. Nonrecording snow gauges have been used extensively to measure snowfall water equivalent. In Canada and the United States, this type of gauge has been designated as the official instrument for measuring snowfall water equivalent. The MSC Nipher shielded snow gauge (Goodison 1978a) is the Canadian standard, whereas the NWS alter-shielded 20.3 cm (8-in.) standard gauge (Larson and Peck 1974) is the United States standard. Nonrecording snow gauges need to be emptied frequently, usually once a day. The accumulated snow is melted and either weighed or measured in a glass that is graduated to obtain the water equivalent.

c. Recording precipitation gauges. Recording-weighing type of precipitation gauges measure both solid and liquid precipitation. In these gauges is a simple spring balance, whose mechanical displacement is recorded on a chart or converted to an analog electrical output. These outputs can be recorded onsite or telemetered by telephone, radio, or satellite (Metcalfe, Wilson, and Goodison 1987). The Universal and Fisher Porter are examples of the recording-weighing-type of precipitation gauges. The capacities of these gauges are 300- to 600-mm water equivalent, and the collection orifice is 20.3 cm (8 in.) in diameter. In cold climates, these gauges require an antifreeze charge, typically ethylene glycol, to prevent freezing in the collector. In addition, a layer of light oil is added to prevent evaporation. Alter shields are suggested for these gauges to reduce wind effects on collection efficiency. Recording-weighing type of precipitation gauges need to be visited periodically to check calibration, to empty the storage devices when capacity is reached, to change charts, and to replenish and mix antifreeze and oil. Large-capacity storage gauges, up to 2540 mm of water equivalent, are used at remote or unattended sites, such as mountainous regions characterized by high precipitation. Antifreeze, oil, and an alter shield are suggested with these. They can be automated for telemetry by connecting the storage gauge to a float and stilling well in an adjacent shelter.

d. Measurement errors. The effects of wind on gauge catch have been reported by Peck (1972), Goodison (1978a), and Larson and Peck (1974). Methodologies have been developed for adjusting the measured gauge catch to account for the effects of different meteorological variables (Hamon 1973, Rawls et al. 1975).

3-4. On-ground Measurement of Snowcover

a. Snow pillow. The snow pillow is a nondestructive technique for measuring the SWE of the snowcover. The snow pillow has been used extensively in the western United States, most notably by the U.S. Natural Resources Conservation Service in their SNOTEL network (Crook 1986). Snow pillows are constructed with various shapes, sizes, and materials; they are fluid-filled pillows in which fluid pressure responds to the weight of snow that is lying on them. The pressure of the fluid in the pillow is measured with a manometer or pressure transducer, which may be interfaced to a digital data-collection and transmission system. The pillows are made from butyl rubber, neoprene rubber, sheet metal, or stainless steel. Discussions of differing types of pillows and the specifics of design and operation are presented by Davis (1973) and Cox et al. (1978).

(1) Pangburn and McKim (1984) discussed a potential snow triangle to avoid the hydraulic problems associated with fluid-filled pillows. The snow triangle replaces the fluid-filled pillow with a plywood triangle having an area of 1.5 m^2. The plywood triangle is placed on three load cells that provide an electrical output proportional to the weight of snow on the triangle.

(2) Both snow pillows and snow triangles are affected by bridging caused by ice lenses forming in the snow pack. This bridging stops the pillow or plywood triangle from sensing the full weight of the overlying snow so that there is decreased or lagged detection of SWE. Snow pillows can be an effective instrument for monitoring SWE where formation of ice lenses is not prevalent, such as in shallow snow packs or in deep mountainous packs in the western United States.

b. Radioisotopic gauges. Radioisotopic gauges have been used to make measurements of snowpack water equivalent at remote, unattended sites and to transmit these data to a central receiving station. These gauges depend on the fact that the water in the snowpack attenuates any gamma radiation that is emitted by any source under the snowpack. The intensity of the radiation received by a detector above the snow surface is related to the snowpack's total water equivalent, provided background radiation levels are known. One of the first radioisotopic gauges was developed by USACE in 1955. The USACE gauge consisted of a cobalt 60 gamma ray source placed at the ground surface and a Geiger-Muller radiation-detector type (G-M tube) suspended 4.6 m (15 ft) overhead. Since this first development, many systems have been tested. More recently, radioisotope gauges have become portable (Young 1976) and use naturally occurring uranium as a source (Morrison 1976). They have been used to profile SWE and density (Smith, Halverson, and Jones 1972). Care must be exercised when making these measurements to avoid inappropriate radiation exposure to operating personnel. In addition to artificial radiation sources, natural radiative emissions from elements in the soil can be used to measure SWE at a point.

c. Snow surveys. The common practice for making snow surveys is to sample and measure the snow water equivalent at a number of points along an established line called a snow course. Snow courses are located with the objective of obtaining data representative of a given area, the number of samples depending largely upon the terrain and meteorological characteristics of the area. Other factors such as accessibility, availability of funds, and purpose for which the data are to be used, must, of course, be considered in the establishment of the network of sampling stations.

(1) Selection for a snow course site should be based on the same general requirements as for precipitation gauges, with the following being considered:

(a) Meteorological conditions with respect to storm experience.

(b) Position with respect to large-scale topographic features.

(c) Position with regard to local environmental features, such as exposure, aspect, orientation, and ground slope.

(d) Conditions on the site itself, such as local drainage and the occurrence of brush and rocks.

In addition, snow courses should be located to adequately sample ranges in elevation, and they also should be so located that they are representative of average basin melt conditions, as well as basin snow accumulation. As is the case for precipitation gauges, snow courses should be located in areas well protected from wind, since wind erosion and drifting snow cause unrepresentative snow accumulations. An ideal location would be an opening in the forest surrounded by hills for protection from high winds and sloped sufficiently to permit runoff of water beneath the snowpack. The number of sample points is variable, depending largely upon the consistency of the distribution of snow. Sample points are located with the objective of avoiding variations in snow depth from causes such as drifting, interception by trees, and the presence of boulders or other obstructions. If protection from wind is altogether lacking, the sampling points must be spread over a wide area to average out variations caused by drifting.

(2) In general, five sample points are probably adequate for well-located snow courses upon which there is a minimum of irregularities caused by drifting or wind erosion, if the ground surface is smooth and clear of all obstructions, and if the snow course is not too close to the forest or other local obstructions to be influenced by local irregularities in deposition. When conditions are less than ideal, however, additional snow course points are required to adequately sample the water equivalent.

(3) Although care is exercised in selecting locations having stable physical features, there may be changes affecting the deposition of snow at sampling points. A common change in physical features is the removal of all or a portion of the surrounding timber by fire, cutting, bug infestation, or severe wind storms. On the other hand, an opposite effect can be produced by the growth of brush or timber in the vicinity of the sampling points. In the latter case, annual changes may not be detectable; nevertheless, the change over a period of years may be significant. Another important effect of physical changes is improper drainage of free water as a result of obstructions such as beaver dams or accumulation of debris in drainage channels in the snow-course area. Occasionally, physical features may change sufficiently to necessitate abandonment of the snow course. Often, however, the location is acceptable despite some changes in physical features. In such cases records must be adjusted.

(4) Basic data from snow courses are obtained under cooperative arrangements among various Federal, State and private organizations. The many details pertaining to snow surveying for obtaining the water equivalent of the snowpack at a given point are beyond the scope of this manual; for details see the comprehensive reports on snow surveying by U.S. Soil Conservation Service (1972), Atmospheric Environment Service (1973a,b), and World Meteorological Organization (1974).

3-5. Remotely Sensed Measurement of Snowcover

a. Aircraft measurements. Aircraft measurements have been used historically to define the spatial distribution of snowpacks, especially in inaccessible, remote areas where point snow-course measurements could not be obtained. Smith, Cooper, and Chapman (1967) found that measuring the distribution of snow by aerial photography was a practical methodology for areas of complex relief, and that snow depth could be determined in such areas with high precision. Others have used aerial overflights for determining snowline elevation—for example, in the Columbia River Basin by both the USACE and British Columbia Hydro and Power Authority. Aircraft surveys can be an effective method of gathering data on snow depth and snowline; however, such surveys are limited to suitable flying conditions and can be relatively expensive and time-consuming (Rango 1977; Goodison, Ferguson, and McKay 1981).

b. Airborne gamma survey. As previously mentioned, the water contained in snowpack attenuates gamma radiation. Natural terrestrial gamma radiation is emitted from the potassium, uranium, and thorium radioisotopes in the upper 20 cm of soil. The levels of this natural terrestrial gamma radiation are monitored using sensors in a low-flying aircraft (150-m altitude). When adjusted for background, the intensity of the radiation can be can be related to SWE. Terrestrial gamma surveys are conducted before snowfall to obtain background readings (Bissell and Peck 1973, Loijens 1975).

(1) Airborne gamma survey technology was originally developed in the USSR (Russia) in the 1960s (Kogan et al. 1965) and has developed into a fully operational tool for the U.S. National Weather Service (NWS) (Carroll and Allen 1988). Mean areal SWE can be obtained with a root mean square error of less than 1.25 cm by calculating the difference between measurements made over bare ground and snow-covered ground. The accuracy of this method is affected by many things, including changing soil-moisture conditions and radon gas (Vadnais 1984; Carroll and Jones 1982, 1983). The great advantage of aerial gamma surveys is their large-area coverage, which minimizes the effect of high local variation.

(2) The NWS has developed a National program that includes two terrestrial gamma radiation systems on low-flying aircraft over a network of more than 1600 flight lines covering portions of 25 U.S. States and 7 Canadian Provinces. The limitations of airborne gamma surveys are their restrictions to relatively flat areas and the precise navigation needed to correlate to groundtruth data.

c. Satellite observations. Remote sensing of snowcover using satellites has been studied since the 1960s and used most successfully for delineating snow-covered areas. To date, however, there are no operational automatic snowcover mapping algorithms. Historically, the two principal satellite systems used for snowcover delineation in the United States have been the LANDSAT and Advanced Very High Resolution Radiometer (AVHRR) systems. Imagery from LANDSAT has a swath width of 185 km, a pixel size of 30 m, and a return interval of 16 days. Cloud cover in imagery may lengthen the period between usable images. Moreover, the tradeoff between large area coverage and high spatial resolution of the LANDSAT imagery is the large data volumes. A single LANDSAT scene contains over 200 megabytes of data, which makes analysis of large river basins, covered by several images, or time sequences of images, difficult without workstation-level or better computers. LANDSAT data have proven useful for the study of medium to small river basins.

(1) Snow mapping from satellites has developed mainly since the 1970s. Rango and Itten (1976) used both supervised and unsupervised computer classification techniques to map snow-covered area from LANDSAT MSS data. Snow in trees and melt-freeze snow were classified, but the criteria were not specified. Martinec and Rango (1981) used LANDSAT MSS data to estimate the distribution of SWE over an alpine basin. Dozier (1989) addressed the problem of calculating snow reflectance from LANDSAT Thematic Mapper data and used the difference in reflectance in Bands 2 and 5 to discriminate snow from clouds and bare ground. Crane and Anderson (1984) used Defense Meteorological Satellite Program (DMSP) data to discriminate clouds from snow and water clouds from ice clouds. Baumgartner, Seidel, and Martinec (1987) demonstrated the supplementation of LANDSAT data (high spatial resolution) with AVHRR data (high temporal resolution) for improved snowcover depletion estimates. An automatic mapping method was developed by Dozier and Marks (1987) for using the information in digital elevation models without requiring precise registration of the images to the models. This method required the use of an atmospheric transmission model and the knowledge of grain sizes and contaminants. Dozier (1989) demonstrated automatic snow mapping based on apparent planetary (spectral) reflectance. Thresholding and normalized difference ratios for Bands 1, 2, and 5 were used to identify snow in shadow and to discriminate sunlit rocks, soils, and clouds from sunlit snow. AVHRR data were used by Baglio and Holroyd (1989), registered to a digital elevation model, to test an interactive snow-mapping system.

(2) In an operational setting, image data from the AVHRR on the National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites and image data from the Geostationary Operational Environmental Satellite (GOES) are used for snowcover mapping. The resolution of AVHRR images is about 1 km, making the data usable for large river basins and regional coverage. These data are collected and disseminated by the NWS National Hydrologic Remote Sensing Center (NWS 1992) and provide daily maps of the percentage of snow cover in approximately five elevation bands for each of more than 500 major river basins in the western United States and Alaska. The NWS also provides complete coverage of the United States and Canada, with additional basin boundary sets to map snow cover for

the upper Midwest, the Great Lakes, New England, and Canada. These data are electronically accessible to end-users, in near real-time.

(3) Passive and active microwave sensors have been used for snowcover measurements and can operate in all weather conditions. Since 1978 the NIMBUS-7 satellite has provided data from the Scanning Multi-Channel Microwave Radiometer (SMMR) with a resolution of 30 km^2. SMMR is a five-frequency, dual polarized instrument that measures the upwelling microwave radiation from 6.6 to 37.0 GHz (Gloerson and Barath 1977). Goodison and Walker (1993) have found that SMMR data were sufficient to measure snow extent and SWE, when the snow was dry, in the Canadian prairie where ground measurement stations are sparsely located. Moreover, time-sequential data have shown the promise in the detection of wet snow. Others have shown the utility of passive microwave SMMR data to map snowcover properties over relatively flat homogeneous areas like the Canadian prairies (e.g., Chang, Foster, and Hall 1987; Rango, Chang, and Foster 1979), and at large scales, the maps compare well with the NWS product. In 1987 the DMSP launched another microwave radiometer, the Special Sensor Microwave Imager (SSM/I). The SSM/I is a four-frequency dual polarized radiometer that operates in the frequency range of 19.3 to 85.5 GHz. Measurements from this instrument have been shown to be useful for mapping snowcover extent, and algorithms to recover SWE are being developed. The goal for disseminating these data is near real-time for operational use. The main problems with passive microwave data are coarse resolution and lack of any general algorithm for estimating SWE that works in areas that are not large, flat, and homogeneous.

(4) The future looks promising for using remote-sensing inputs for operational snow hydrology models, as well as for research. Automatic classification algorithms for mapping snowcover extent and SWE appear to be forthcoming within the next decade. While no single sensor system or platform currently offers real-time frequent measurement of even snow-covered areas, the rapid evolution of remote-sensing and computing technologies, including geographic data systems, will allow the merging of sensor data sets (orbital, airborne, and ground based), which should improve operational forecasts substantially.

3-6. Snow Analysis

In addition to snowcover measurements, other hydrometeorological data are required for snowmelt simulation and hydrologic forecasting. These variables include air temperature and precipitation at a minimum; however, if energy budget methods are employed, such variables as wind speed, dew point, solar radiation, and others would need to be available. Table 3-2 summarizes the required data types, along with comments on their purposes and applications. Besides the data requirements described in Table 3-2 for snow analysis, physical data on standard streamflow measurements and watershed characteristics must be obtained. The application of a snowmelt simulation model typically takes the path of calibrating the transformation models in warm (nonsnowmelt) conditions and then calibrating the snowmelt routine to input the melt for the transformation model for the accumulation-ablation period. To do this the hydrologist requires long-term continuous discharge records (preferably greater than 10 years) for calibration and validation. The physical data, such as area-elevation data, type and density of land cover, slope and aspect of watershed elements, are of prime importance in mountainous areas. This is particularly important for distributed systems that compute snowmelt based on distinctly defined zones of elevation, subwatersheds, or hydrologic response units (HRUs).

Table 3-2
Data Requirements for Snow Analysis

Data Type	Physical Element or Purpose	Application
Streamflow (*Q*)	a. Continuous discharge b. Runoff volumes	a. Hydrograph analysis, model calibration b. Water supply analysis, forecasting
Precipitation (*P*)	a. Basin moisture input b. Estimate of SWE	a. Hydrograph analysis, model calibration b. Water supply forecasting
Air temperature T_a	a. Rain/freeze interface b. Index to all energy exchanges c. Factor in energy budget estimates	a. Modeling snow accumulation b. Modeling snowmelt (temp . index) c. Modeling snowmelt (energy budget)
Snow water equivalent (SWE)	a. Estimate of precipitation b. Index to basin water supply c. Snowpack quantity during ablation	a. Analysis, model calibration b. Water supply forecasting c. Modeling snowmelt
Areal snow cover	a. Extent of basin snow cover b. Snowline elevation	a. Model calibration b. Parameter in forecast models
Snowfall	a. Estimate of SWE, precipitation b. Accumulation of snow	a. SWE, precipitation applications b. Avalanche forecasting
Snow density	a. Estimate of SWE, precipitation b. Condition of snow	a. SWE applications b. Avalanche conditions, snow loads
Snow depth	a. Estimate of SWE, precipitation b. Estimate of weight	a. SWE, precipitation applications b. Snow load on structures
Snow albedo	Solar energy absorption	Modeling (energy budget), design floods
Solar radiation	Solar energy flux	Modeling (energy budget), design floods
Wind velocity (*v*)	Estimate of convection/condensation energy flux	Modeling (energy budget), design floods
Dewpoint temperature T_d	Factor in estimate of condensation energy flux	Modeling (energy budget), design floods