SNOW DEPTH VARIABILITY IN A SMALL ALPINE WATERSHED

by

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ABSTRACT

The effects of mountainous topography and wind result in widely variable snow depths in alpine basins. High variance among measured snow depths and limited accessibility in alpine watersheds complicates estimation of snowpack water equivalent (SWE). Snow surveys at eight snowcourses were used in a water-balance calculation for 1994 in the Andrews Creek Basin (drainage area of 183 hectares), Colorado. A mean snow depth from a single snowcourse in a forested area was compared to mean depths at seven additional snowcourses representing a variety of terrain around the watershed. The mean snow depth from the single snowcourse differed statistically from the other mean depths and underestimated the average snow depth, estimated by all eight snowcourses, by 1.2 meters. A water-balance calculation (comparing annual precipitation to measured runoff) indicated an estimated mean snow depth for the basin was substantially better when based on several snowcourses covering a range of conditions, rather than based on only one snowcourse.

INTRODUCTION

Estimating representative mean snow depths in various mountainous basins always has been problematic to the approximation of annual snow-water equivalent (SWE). SWE expresses snowpack-water content as the product of snow density and depth. In the Andrews Creek Basin of Colorado (fig. 1), field measurements were made near the time of maximum annual snow accumulation to estimate snow-depth variability throughout the watershed. Snow depth varied substantially (1–6 m) relative to snow density (30–38%), thus an accurate estimate of snow depth is critical for calculating SWE. In this rugged alpine watershed, several conditions complicated the measurement of snow depth, including inaccessibility of much of the snow-covered areas of the basin, extreme snow depths, steep slopes, and widespread avalanche risk. These conditions limit the extent of snowpack sampling in alpine basins, such as Andrews Creek; therefore, the number of measurements was limited, and a test was devised to determine whether mean snow depth was adequately estimated that produced a reasonable estimate of SWE.

METHODS

A simplified method is described to accomplish a feasible and safe snow survey. A careful approach to establishing snowcourses was critical because most of the terrain in the watershed was steep, about one-half the study area slopes 30 degrees or more, and avalanche potential was widespread. Although areas in the watershed with avalanche potential were avoided, a snow survey was designed that included the lower, intermediate, upper, and glacier areas of the watershed (fig. 1 and table 1).

Following the major stream drainage, eight snowcourse locations were chosen to include variable terrain throughout the watershed so that measurements of snow depth could be made at a variety of elevations and to represent variable slopes, vegetation, and aspects (fig. 1). The alignment of the snowcourses generally follows the long axis of the basin from east to west, ascending from the streamflow-gaging station (3,215 m) to the summit of Andrews Glacier (3,650 m). Many snow-depth measurements were made during the 1994 survey in forested places protected from the wind (lower snowcourse, 1A) and in open alpine areas (intermediate, upper basin, and Andrews Glacier snowcourses). Snow depths were measured with a rigid probe pole assembled with up to six 1-m sections of lightweight and durable metal alloy 2 cm in diameter. Snow depths were measured at 0.1-m increments; distance between measurements varied from 10 m to 100 m.

RESULTS AND DISCUSSION

Statistics summarizing the results of all snow-depth measurements are listed in table 1. Seventy-five measured snow depths ranged from 1.0 to 5.8 m; the mean snow depth was 3.3 m. Results of measurements made in 1992–93 in the lower part of the basin indicated that more than 10 snow-depth measurements on a single snowcourse were redundant. Variability of snow depth in the lower, forested area (snowcourse 1A) of the watershed was minimal, typically 0.5 m or less. However, depths along snowcourses in the upper areas of the watershed varied by 2 or 3 m. Thus, additional snowcourses in the intermediate and upper areas of the watershed sampled more of the variability in snow depth.

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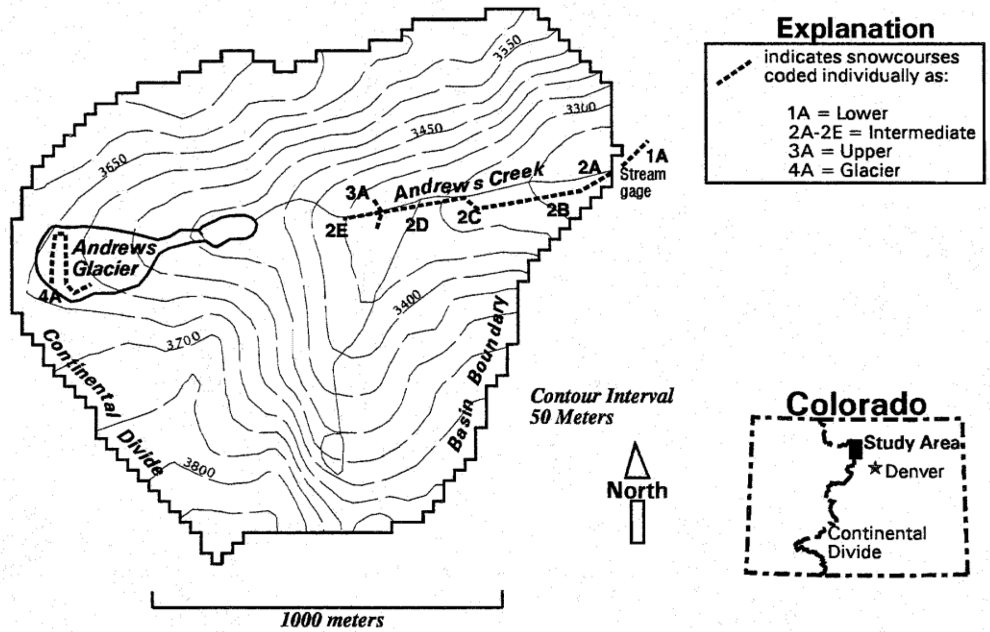

Figure 1. Location of snowcourses in study area, Andrews Creek, Colorado

Table1: Statistics of Snow Depths Measured at Eight Snowcourses

[Intermediate snowcourse 2E includes six measurements from other snowcourses to enable evaluation of mean depth in an 800-meter-long snowcourse spanning half the basin. Hence, total number of snow-depth measurements equals 75]

Snowcourse Name	Number of Snow-Depth Measurements	Sample Spacing (m)	Maximum Snow Depth (m)	Minimum Snow Depth (m)	Mean Snow Depth (m)	Standard Error of the Mean (m)	Variance (m^2)
Lower (1A)	10	10	2.4	1.6	2.08	0.095	0.09
Intermediate (2A)	10	10	3.9	2.0	2.59	0.196	0.38
Intermediate (2B)	10	10	4.2	1.0	2.91	0.338	1.15
Intermediate (2C)	10	10	3.9	2.2	3.15	0.174	0.30
Intermediate (2D)	11	10	4.9	3.2	4.11	0.181	0.35
Intermediate (2E)	9	100	4.1	2.1	3.38	0.223	0.45
Upper-basin (3A)	10	10	5.2	2.2	3.53	0.294	0.86
Glacier (4A)	11	40	5.8	3.3	4.76	0.259	0.74
All Snowcourses	75	variable	5.8	1.0	3.3	0.128	1.23

At the 95% level of confidence, the F-test statistic was used to evaluate the hypothesis that mean snow depths vary significantly between snowcourse measurements according to elevation. Mean snow depths between the seven above- and one below-treeline snowcourses were significantly different when compared to one another. However, in general, differences in mean values among the seven snowcourses above treeline were not statistically significant. The importance of this evaluation is that the differences between mean depths of the snowcourse above treeline and those below treeline reinforces the need to sample topographically different elevations to adequately represent the watershed snowcover. This finding is consistent with many studies suggesting basin snowpacks should be subdivided into zones of unique classifications to estimate snow depth (Kuzmin, 1969; Bartos, 1972; Steppuhn and Dyck, 1974; Sommerfeld and others, 1990; Elder and others, 1991). A mean snow depth for the watershed based solely on the lower snowcourse (1A) would underestimate the mean depth by 1.2 m; also, a mean from the highest snowcourse (4A) would overestimate mean depth.

To check the accuracy of the estimated mean depth and SWE, a water balance was calculated using values based on measured precipitation and runoff in Andrews Creek. The water balance was based on the period of snowmelt runoff for the full ablation season, April through September, 1994. Basin runoff was used as a reference for comparison to the estimates of annual snowpack-water content (P_s) and rain (P_r) in the water-balance equation: Runoff = $P_s + P_r - L_a$. Three of the four components were directly measured; losses to the atmosphere (L_a) were indirectly estimated as the residual of the water balance. Losses to ground water were unknown and were assumed to be minimal. The estimates for inputs and outputs to the water balance are summarized in table 2.

Table 2: Water Balance For Andrews Creek, 1994

Total basin runoff for 1994 snowmelt season from Andrews Creek		1,440,000 m^3
P_s	total annual snowpack water content (SWE)	1,300,000 m^3
P_r	total precipitation of rain and snow after snow survey (April 7 to Sept. 30)	821,000 m^3
Total input		2,121,000 m^3
L_a	residual (total inputs - total runoff) assigned as evaporative losses	681,000 m^3

Individual water-balance components were calculated as follows. The total runoff for the snowmelt season from May 9 through September 30, 1994, measured at the streamflow-gaging station was 1,440,000 m^3. Total water content held in the snowpack at the time of the snow survey, April 6, 1994, was estimated in two steps. First, mean SWE in the basin was estimated as: SWE (m) = mean depth (m) x mean density (percent). Where mean depth (3.3 m) was determined from all measured depths along the eight snowcourses, and mean density (350 kgm^{-3} or 35 percent) was determined from a depth-integrated measurement in one snowpit and from measurements at six points along the eight snowcourses. The product of mean depth and density yielded mean estimated SWE of 1.2 m. Second, multiplying mean SWE by the area of the basin and by the snow-covered area fraction determined from aerial photography (57%) gives an estimated total basin-wide SWE of: 1.2 m x 1,833,300 m^2 x 0.57 = 1,300,000 m^3. Precipitation after the snow survey, April 6, 1994, was measured with a Belfort rain gage with a Nipher shield located next to the gaging station. Assuming uniform distribution of precipitation over the basin, 821,000 m^3 of precipitation entered the basin after the snowpack measurements were made.

Residual of the measured components of the water balance is consistent with reported estimates of evaporation for the snowmelt season in other alpine watersheds (Dozier and Melack, 1989; Baron, 1992), which varied from 12 to 39% of total inputs. The value of 32% for losses to evaporation (L_a) that was determined indirectly in this study is within this range. Methods used in this study to estimate SWE and rainfall are validated by previous work. Proportions of these primary inputs of precipitation as snow (2/3) and rain (1/3) shown in the water balance are consistent with reports from surrounding and nearby alpine watersheds (Carroll, 1976; Sommerfeld and others, 1991; Baron, 1992). Thus, the estimate of mean snow depth seems reasonable. This finding is important because the annual SWE is the largest input to the watershed budget and, because it can be released over a period of a few weeks, SWE affects timing and duration of peak flows substantially.

SUMMARY AND CONCLUSIONS

A snow survey was conducted to test a method of estimating a representative mean snow depth based on a wide variability of snow-depth measurements in a steep alpine watershed in order to adequately estimate SWE. A key objective was to accomplish this task without making extensive measurements or taking great avalanche risk. Eight snowcourses in a variety of terrain settings were sampled in relatively accessible areas of the watershed. A mean snow depth was determined from all snowcourses and used to estimate SWE as a measure of annual snowpack-water content in a water-balance calculation. The agreement between annual inputs and outputs to the hydrologic system indicates the method determined a reasonably accurate mean snow depth for the watershed.

Mean values of snow depth from the snowcourses differed significantly between a forested location and seven other topographically different locations in the rest of the watershed. This difference indicates that snowpack should be measured at more than one index location.

Future snow surveys in this watershed will have a statistical basis on which to determine more effective snowpack-sampling schemes. Accordingly, snowpack measurements in other basins can be minimized where differences among snow depths are seen to be minimal upon review of preliminary measurements.

REFERENCES

Baron, J., Ed., 1992, Biogeochemistry of a Subalpine Ecosystem: Loch Vale Watershed, Springer-Verlag, New York, 247 p.

Bartos, L., 1972, An Evaluation of Areal Reconnaissance and Index Snow Sampling Techniques on a small Subalpine Watershed, M.S. Thesis, Dept. of Civil Engineering, Univ. of Wyoming. 69 p.

Carroll, T., 1976, An Estimate of Watershed Efficiency for a Colorado Alpine Basin, Proceedings of the Western Snow Conference, Calgary, Alberta, 69 p.

Dozier, J., and J. M. Melack, 1989, Snow, Snowmelt, Rain, Runoff, and Chemistry in a Sierra Nevada Watershed, Final Report Submitted to California Air Resources Board for Contract A6-147-32, 268 p.

Elder, K., J. Dozier, and J. Michaelson, 1991, Snow Accumulation and Distribution in an Alpine Watershed, Water Resources Research: 27, pp. 1541–1552.

Kuzmin, P. P., 1969, Theory of Formation and Methods of Computation of Snowmelt Floods, IAHS-AISH Pub. 85, vol. 2, pp. 591–98.

Sommerfeld, R. A., R. C. Musselman, and G. L. Wooldridge, 1990, Comparison of Estimates of Snow Input With a Small Alpine Catchment, in J. of Hydrology: 120, pp. 295–307.

Sommerfeld, R. A., R. C. Musselman, G. L. Wooldridge, and M. A. Conrad, 1991, The Performance of a Simple Degree-Day Estimate of Snow Accumulation to an Alpine Watershed, *in*: Snow, Hydrology, and Forests in High Alpine Areas (Proceedings of the Vienna Symposium, August, 1991), IAHS Publ. no. 205, pp. 221–228.

Steppuhn, H., and G. E. Dyck, 1974, Estimating True Basin Snowcover, in Proceedings of Interdisciplinary Symposium: Advanced Concepts and Techniques in the Study of Snow and Ice Resources, Monterrey, Ca., Dec., 1973, Santeford, H., and J. Smith, Eds., National Academy of Sciences, Washington, D.C., pp. 314–328.