ESTIMATED CONSUMPTIVE LOSS FROM MAN-MADE SNOW

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INTRODUCTION

Snowmaking is used at Colorado ski areas to extend the ski season into the early fall and late spring as well as to guarantee good snow conditions throughout the winter. Currently, approximately 2.5 million cubic meters of water are diverted annually by the states 32 ski areas to make snow over approximately 25 percent of their ski slopes. Man-made snow is usually applied to ski trails ranging in elevation from 2,600 to 3,100 meters.

Two years of research were undertaken to determine the amount of water consumptively used due to snowmaking in Colorado. This work was a major component of the Colorado Ski Country USA Water Management Research Project, an investigation designed to quantify the effects of ski area activities on local water resources.

Estimating runoff from man-made snow is important for water rights purposes throughout the western United States. By determining consumptive use due to snowmaking, ski areas can reduce required water rights by claiming return flows from water applied as man-made snow. To claim snowmaking credits, ski areas need to be able to estimate the quantity and timing of these return flows.

Consumptive water use was measured at two different stages during the snowmaking process:

Initial Loss: This is the consumptive water use which occurs during the actual snowmaking process due to evaporation and sublimation.

Watershed Loss: This is the consumptive water use that occurs from the time the man-made snow particle has fallen on the snowpack through spring melt. These losses are due to evapotranspiration and sublimation.

INITIAL LOSS

Study Method

Consumptive use during the actual snowmaking process was investigated using two procedures: (1) a series of mass balance experiments in which the water equivalent of man-made snow produced was measured and subtracted from the volume of water flowing through the snowgun, and (2) an energy balance procedure in which available energy was measured and used to estimate an upper limit on possible consumptive use from evaporation and sublimation which could occur during the snowmaking process.

Data were collected during 5 experiments in 1983-84 and 9 experiments in 1984-85 at Lake Eldora, SilverCreek and Vail ski areas under a variety of weather conditions and using different snowmaking equipment. Data collected included ambient air temperature; relative humidity; wind velocity and direction; water temperature, pressure, and flow; compressed air temperature, pressure and flow; and man-made snow depths, density, and distribution.

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Results

The mean initial consumptive loss based on mass balance measurements was 3.3 percent for the total 14 experiments and 5.8 percent for the 9 experiments conducted in 1984-85. The mean estimated loss using the energy balance procedure was 6.1 percent for the 14 experiments and 6.0 percent for the 9 experiments in 1984-85. These results indicate a close agreement between the estimated losses based on the energy balance procedure and the measured losses using the mass balance procedure.

Based on a thermodynamic sensitivity analysis performed as part of this study, it is known that ambient air temperature is a major factor in determining eventual consumptive loss during the snowmaking process. In order to quantify the effect of ambient air temperature on initial loss, a linear regression analysis was used to develop a statistical relationship predicting initial loss as a function of ambient air temperature. This relationship was developed using field measurements for the 9 experiments in 1984-85. The energy balance relationship falls within the 95 percent confidence intervals developed for the linear regression equation and both the energy balance procedure and the regression analysis demonstrate that loss decreases as temperature decreases.

WATERSHED LOSS

Study Method

Consumptive use can occur through evapotranspiration and sublimation after a man-made snow particle has landed on the snowpack until spring melt is completed. This consumptive use is termed the "watershed loss." The Subalpine Water Balance Simulation Model (Leaf and Brink, 1973a and 1973b), was employed to estimate the watershed loss from man-made snowmaking.

Field data for the watershed loss investigation were collected over a two-year period from October 1983 to August 1985 at six Colorado ski areas: Conquistador, Lake Eldora, SilverCreek, Snowmass, Vail and Winter Park. Data collected included: streamflow, temperature, relative humidity, wind direction, wind speed, precipitation, snowpack conditions, soil moisture, soil temperature and solar radiation. These data were then used in site simulation computer runs to show that the model was capable of simulating hydrologic processes at each of the six watersheds with acceptable accuracy. Prior to site simulation runs, an extensive calibration process based on 9-10 years of available data was completed in order to verify that the model was capable of reproducing regional measured runoff for the six ski area watersheds. This calibration procedure, along with two years of site simulation runs, demonstrated that the model could be used with sufficient reliability for estimating differences in runoff attributable to snowmaking.

To estimate watershed loss, open areas at each watershed characteristic of ski trails receiving man-made snow were selected for analyses. "Typical" dry, wet and average years were selected from the period of calibration for model simulation runs. For each year, a simulated water balance for baseline conditions was generated. A simulated water balance was then generated for the same area with man-made snow applied.

Results

A summary of results from the watershed loss investigation is presented in Table 1.

TABLE 1
WATERSHED LOSS RESULTS

Ski Area	(1) Type of Water Year	(2) Quantity Man-Made Snow Applied (Cm. of Water)	(3) Amount of Man-Made Snow Available for Runoff (Cm. of Water)	(4) Loss (Cm. of Water) (3-2)	(5) Loss (%) (4÷2)
Winter Park	Dry (1954)	35.89	27.33	-8.56	24
	Average (1959)	17.86	14.30	-3.56	20
	Wet (1957)	17.78	14.50	-3.28	18
Conquistador	Dry (1977)	47.80	31.95	-15.85	33
	Average (1979)	38.30	35.61	-2.69	7
	Wet (1975)	30.51	26.90	-3.61	12
Lake Eldora	Dry (1977)	30.63	26.62	-4.01	13
	Average (1975)	25.43	20.50	-4.93	19
	Wet (1980)	25.58	21.46	-4.12	16
SilverCreek	Dry (1954)	45.72	33.40	-12.32	27
	Average (1959)	30.48	24.69	-5.79	19
	Wet (1952)	20.35	18.36	-1.99	10
Snowmass	Dry (1977)	20.47	15.24	-5.23	26
	Average (1968)	15.27	12.70	-2.57	17
	Wet (1973)	15.24	12.93	-2.31	15
Vail	Dry (1981)	50.88	41.61	-9.27	18
	Average (1973)	35.66	30.71	-4.95	14
	Wet (1974)	30.63	27.94	-2.69	9

The watershed losses shown in Table 1 can be used as reasonable estimates of the watershed losses from snowmaking at the six areas studied in the selected average, wet and dry years. Extrapolation of these results to other areas can be done in accordance with the procedures outlined in a regionalized handbook developed from the results of this study. This handbook provides regional procedures specifically designed for estimating watershed losses for the range of hydrologic, geographic, weather and snowmaking conditions existing at Colorado ski areas.

REFERENCES

Leaf, Charles F., and Glen E. Brink, 1973a, Computer Simulation of Snowmelt Within a Colorado Subalpine Watershed, USDA Forest Service Res. Pap. RM-99, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, 22 p.

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