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Estimating Localized SWE on the Yellowstone Northern Range

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ABSTRACT

After the large fires of 1988 in Yellowstone National Park, many research projects were initiated to study their effects. One of these studies involved the effects of fire on vegetation and ungulates on the northern winter range.

Because snow water equivalent (SWE) is a significant factor in animal foraging and movement, it was necessary to develop a method that could use data from National Weather Service (NWS) climatological stations and Soil Conservation Service (SCS) snow courses and SNOTEL(Snow Survey Telemetry) sites to predict SWE in areas of varying slopes, aspect, elevation, and forest cover. It was first necessary to estimate SWE at NWS climatic stations. The daily snow depth, precipitation and temperature values were used to estimate daily SWE. Daily SNOTEL SWE was used to estimate daily SWE at SCS snow courses. Algorithms were developed to estimate daily SWE for flat and open areas on the northern range not having significant drifting similar to data collection sites.

A multidimensional nomograph was developed from measured data to estimate SWE for any slope and aspect within the northern range area. The habitat cover type was used to adjust SWE for forested areas.

Techniques and relationships developed for the northern range would be transferable to other intermountain areas that accumulate a winter snowpack and that have daily climatic and/or snow pillow data.

INTRODUCTION

During the summer of 1988, wildfires burned much of the western United States. Yellowstone National Park (YNP) bounded by Idaho, Montana and Wyoming was one of these areas. About 36 percent of Yellowstone's 900,000 ha, was burned (Despain et al 1989). The majority of the area that experienced fires resulted in a canopy or mixed canopy and ground burn. This large burn event spawned a multitude of studies to investigate fire effects. One study was a modeling and field study of the effects of fires on vegetation and ungulates on the northern winter range (Turner et al in press). This study required knowledge of snow conditions at a resolution of 1 ha over the entire course of a winter. The work described here was designed in part to provide that information.

The northern range in YNP is currently utilized by approximately 17,000 elk (Gogan 1992), 500 bison (Meagher 1993) and fewer numbers of moose, mule deer, pronghorn antelope, and bighorn sheep. During mild winters, the majority of animals will winter within YNP. In severe winters, over one-half of the elk herd, many bison, and many of the other species move north, outside of YNP. In the higher elevations, snow can start to accumulate in October and melts out between mid-April and mid-May. Snow usually starts to accumulate in the lower elevations near the northern boundary in early November and disappears between mid-March and early April. Only a few animals winter in areas that exceed 150 mm SWE, and the majority of the elk move to areas having less than 70 mm SWE (Farnes, personal observation).

The northern range includes approximately 81,000 ha along the Yellowstone River drainage in the northern part of YNP, and additional areas north of Yellowstone in Montana (Figure 1). Within the northern range, there are two climatological stations: Yellowstone Park (Mammoth), elevation 1890 m; and Tower Falls, elevation 1911 m (Figure 1). Both are included in the National Weather Service (NWS) climatological data network. There are two snow courses on the winter range: Crevice Mountain, 2560 m; and Lupine Creek, 2249 m (Figure 1). The Northeast Entrance snow course and

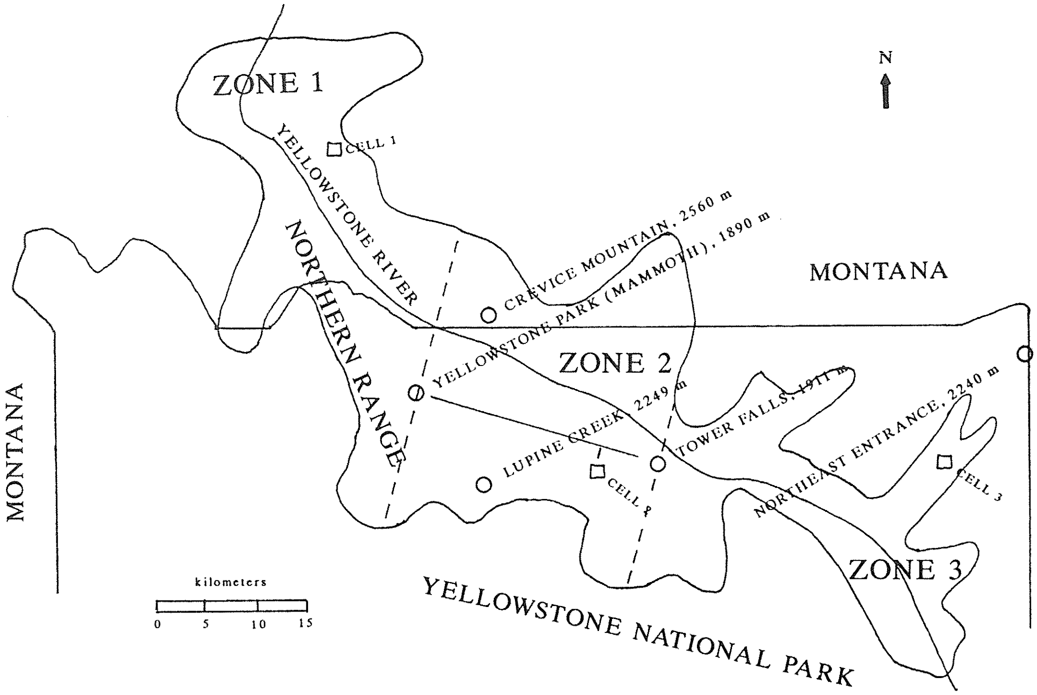

Figure 1. Northern Winter Range in Yellowstone National Park and Montana with zones and data locations.

SNOTEL site is just east of the study area at elevation 2240 m (Figure 1). These stations are part of the Soil Conservation Service (SCS) Cooperative Snow Surveys.

CLIMATIC STATIONS

Daily snow depth, snowfall, precipitation, maximum and minimum air temperature data are available from the two climatic stations. To calculate the daily SWE, the daily precipitation is summed starting the first day that snow is on the ground. The precipitation is accumulated when temperatures are below 0° C. Daily melt is estimated from degree-day units when temperatures are above 0° C and SWE remaining in the snowpack. SWE is reduced to zero when snow depth on the ground is zero. Daily snow densities can be calculated using snow depth and SWE. Daily SWE and densities were estimated from 1961 to present for both stations. At Yellowstone Park (Mammoth) the average seasonal maximum SWE is 57 mm on February 15. Tower Falls has an average maximum SWE of 116 mm on March 15. The season's maximum SWE at Tower Falls can be as low as 50 mm and as high as 200 mm. An example of the SWE annual worksheet is shown in Table 1.

SNOW COURSES

Lupine Creek is measured near the first of each month between January and May. Crevice Mountain is measured only near March 1 and April 1. Daily SWE values are estimated at these sites by prorating measurements using the daily SWE from the Northeast Entrance snow pillow. Estimates of daily SWE were generated from 1961 to the present for both sites. Lupine Creek has an average April 1 SWE of 259 mm while Crevice Mountain has an average SWE of 277 mm.

SNOW PILLOW

Daily SWE is available for the Northeast Entrance snow pillow, and the site has an average April 1 SWE of 190 mm.

TRUE SNOW WATER EQUIVALENT

Manual snow measurements with a federal sampler were made at the climatic stations in 1992 and 1993, and they indicate that the calculated SWE is near or slightly less than the measured SWE. The field measured SWE was multiplied by 0.94 to correct for overmeasurement. (Table 1, Farnes et al 1983). No correction was applied to

Table 1. Worksheet for Estimating Snow Water Equivalent at Climatic Stations

STATION: TOWER FALLS

MONTH: NOVEMBER YEAR: 1992 (93 WY)

Day	Depth Snow on Ground (cm)	Mean Temp (° C)	Melting Degree Day (° C)	Daily Melt (mm)	Daily Precip (mm)	Net Gain (mm)	Est SWE (mm)	Est Density (%)
1	0				0	0	0	-
2	3				25	25	25	8
3	8				25	25	50	6
4	8				0	0	50	6
5	20				102	102	152	8
6	13				0	0	152	12
7	13				51	51	203	16
8	51				203	203	406	8
9	58				51	51	457	8
10	64				127	127	584	9
	1/	2/	3/	4/	1/	5/	6/	7/

1/ From National Western Service climatological observations.
2/ Only recorded when mean daily temperature exceeds 0° C,
3/ Degree-days above 0° C.
4/ Calculated by multiplying degree-days by melt rate. Very seldom does mean daily temperature exceed 0° C until mid-March. If it does, melt rate is estimated to be 2 mm/degree-day after the first day with melting temperatures. In the spring, the accumulated SWE and precipitation that occurs during the melt period is divided by the accumulated degree-days to determine the melt rate for that season.
5/ The difference between precipitation and melt.
6/ Accumulated SWE obtained by adding net gain to previous day SWE.
7/ Density is calculated by dividing SWE by depth and multiplying by 10.

daily SWE values estimated at climatic stations. The Crevice Mountain daily SWE was multiplied by 0.91 to correct for overmeasurement, (standard federal cutter) and the Lupine Creek daily SWE was multiplied by 0.94 (sharpened federal cutter). No adjustments are made to the SWE from Northeast Entrance snow pillow as numerous studies have shown that hypalon pillows measure near true SWE.

With these adjustments, the SWE at all five data sites are compatible and represent the approximate amount of true SWE at level, open, and undrifted locations.

SWE FOR CELLS

To obtain SWE on each hectare of the northern ranage, it is necessary to develop a method to transfer SWE at level, open, and protected sites to cells with various aspects, slope, elevation and forest cover. For the model, these calculations were automated, and the logic is presented here to illustrate the process.

ELEVATION

The northern range is divided into three zones (Figure 1). To determine the SWE for a specific 1-ha cell on a specific date, the SWE vs. elevation relationship is calculated. For Zone 1, the SWE for a cell east of the Yellowstone River is determined from the SWE - elevation plot using Crevice Mountain and Mammoth. West of the river, the Lupine Creek - Mammoth plot of SWE vs. elevation was used. This estimates the SWE that would be at a given cell if it was level and open with no forest cover.

In Zone 2, Mammoth and Tower Falls are nearly the same elevation but Tower Falls has significantly more snow. Through manual snow measurements over the last three years (Farnes, Romme and Walker, unpublished data) and using data from other elk research projects, it was determined that the snow at any point between these two sites is proportional to the distance between the two stations. To determine the SWE for a cell in Zone 2, the SWE is calculated for a point between the two stations at the intersection of a line through the cell perpendicular to the Mammoth-Tower Falls (M-TF) line. North of the M-TF line, the SWE is obtained from the SWE vs. elevation relationship with Crevice Mountain. South of the M-TF line, the SWE vs. elevation plot uses Lupine Creek.

In Zone 3, SWE is determined using the SWE-elevation relationship between Tower Falls and Northeast Entrance.

For March 1, 1993, the true SWE (in mm) at the five measured stations was as follows: Crevice Mountain - 222; Lupine Creek - 196; Northeast Entrance - 145; Tower Falls - 136; Mammoth - 80.

Based on these data and the relationships developed above, the SWE (Cell 1 in Figure 1) at an elevation of 2000 m was estimated to be 107 mm at a level, open area on March 1, 1993 (Figure 2). Cell 2 (shown in Figure 1) similarly was 20 km from Mammoth at an elevation of 2000 m and on March 1, 1993, the SWE was 145 mm (Figure 3 and 4).

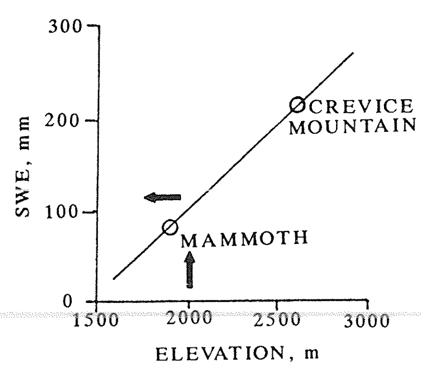

Figure 2. Relationship for estimating SWE for Cell 1 at 2000 m on March 1, 1993.

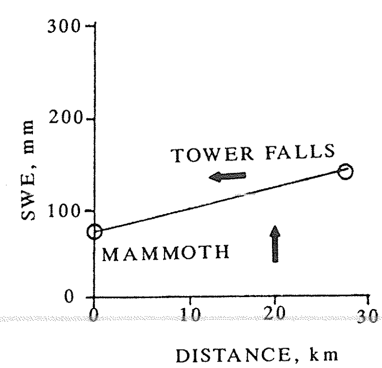

Figure 3. Relationship for estimating SWE for elevation 1900 m perpendicular to Mammoth-Tower Falls line 20 km from Mammoth on March 1, 1993.

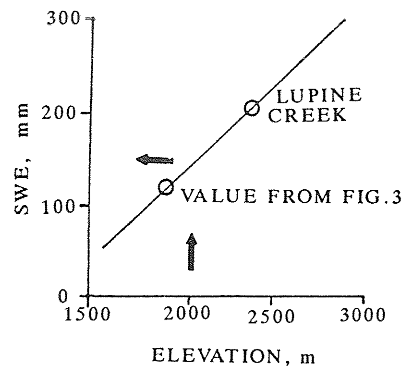

Figure 4. Relationship for estimating SWE for Cell 2 at 2000 m on March 1, 1993.

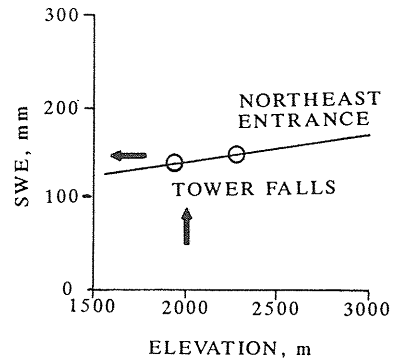

Figure 5. Relationship for estimating SWE for Cell 3 at 2000 m on March 1, 1993.

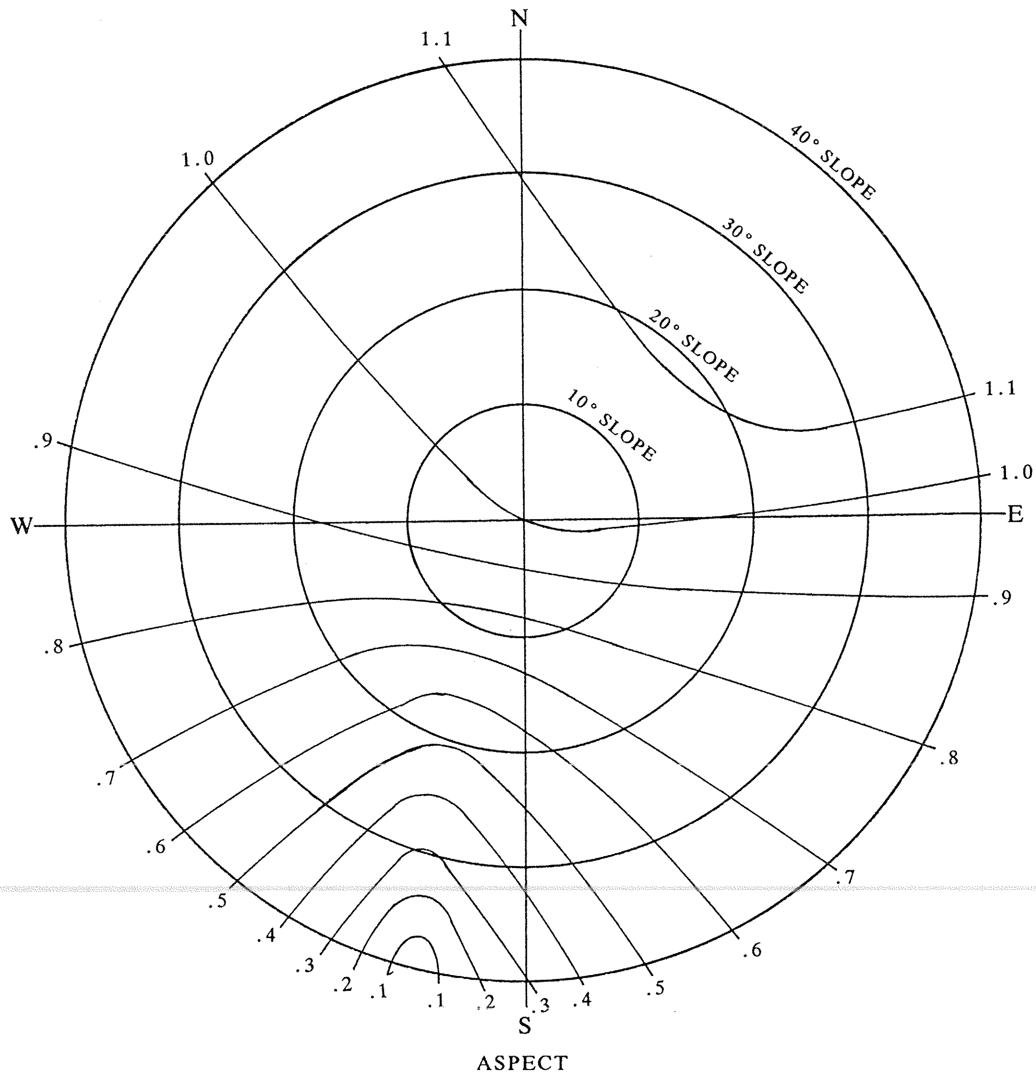

Figure 6. Factors for adjusting SWE for any slope and aspect on the northern range.

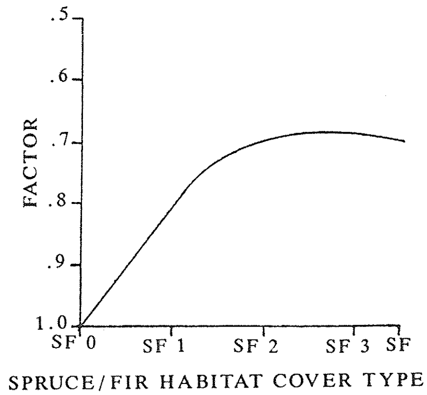

Figure 7. Adjustment factors for converting SWE in the open to SWE under a spruce-fir habitat cover type canopy.

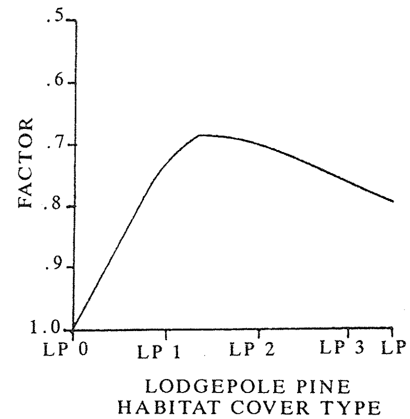

Figure 8. Adjustment factors for convering SWE in the open to SWE under a Loddgepole pine habitat cover type canopy.

On March 1, 1993 the SWE at the 2000 m Cell 3 (Figure 1) is estimated to be 140 mm (Figure 5).

SLOPE AND ASPECT

Over a three-year period, 1991-1993, 88 points at 12 separate locations on the northern range were sampled with the federal sampler. SWE at flat, open sites varied from 79 mm to 157 mm. SWE on different aspects and slopes was measured and compared to the level, open sites. These values were plotted on a spherical graph with slopes from 0 to 40° and 360° aspect.

The lines for adjustment factors were smoothed and a spherical adjustment graph was constructed (Figure 6). Using Figure 6, the SWE for each cell for a flat, open situation can be corrected to the slope and aspect of that cell. For example, if Cell 1 has a 20° slope and aspect of S 45° W, the SWE would be 107 x .64, or 68 mm. The SWE for Cell 2 (N 10° E aspect and 10° slope) would be 145 x 1.05 or 152 mm. Cell 3 (due south aspect and 30° slope) would be 140 x .4, or 56 mm SWE.

FOREST CANOPY

If the cell is forested, it is necessary to estimate the SWE under the forest canopy. Timber on the northern winter range is predominately lodgepole pine, but there are some spruce-fir and Douglas fir stands. Don Despain, the biologist with YNP, has determined habitat cover types for YNP and entered these data into the Yellowstone GIS (Despain 1990). Lodgepole pine has been classified into several cover types based on fire and age. LP 0 is an area recently burned, LP .5 has a stand age of approximately 50 years, LP 2 is approximately 200 years old and LP is a climax lodgepole pine forest.

After the fires of 1988, Farnes (1989) measured snow in various burned and unburned areas in YNP. Canopy cover was measured using the photo canopyometer (Codd 1959). Basal area was also measured. Habitat cover types were identified in each area sampled. These unpublished data were used to construct correction factors for SWE used on aspect, slope, and elevation (Figures 7 and 8).

If Cell 2 has a spruce-fir habitat cover type value of 2.5, then the SWE under the forest canopy is 67 percent of the SWE in the open cell (Figure 7) and would be 152 x .67, or 102 mm. If cell 3 is in a LP 1 habitat cover type, it would have an SWE of 56 x .73, or 41 mm (Figure 8).

CONCLUSION

Estimation of the SWE at any location on the northern winter range near YNP for past or present dates was needed by ungulate researchers. SWE information is used to explain previous or current animal sightings, to predict location, migration, forage availability and utilization, feeding patterns and mortality of wildlife under various snow patterns. Possible changes in winter travel routes related to tree mortality caused by fire, insects, or aging of forests, or by regrowth of forests could also be predicted.

Distributed SWE data could also be used for hydrologic studies of the effects of fire, logging, regeneration, and insect infestations in forests.

These procedures may be applicable to any area having relatively continuous snowpack through the winter months. The relationships used for the northern range might be applicable to nearby intermountain areas, but additional verification of this case study would be required.

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