CORRELATION OF AVERAGE BASIN SNOW LINE ESTIMATES DERIVED FROM SNOTEL, AIRCRAFT, AND SATELLITE SNOW COVER DATA

by

Milan W. Allen 1/

and

Peter L. Palmer 2/

1 INTRODUCTION

Snow covered area (SCA) of mountain watersheds has long been recognized as an important parameter in seasonal streamflow forecasting. With the advent of earth resource monitoring satellites in the early 1970s, SCA data became available on a cost effective, repetitive basis. Several hydrologic models use SCA as a major parameter to produce volumetric and hydrograph forecasts (Peck, et al., 1981). This paper discusses two operational methods of estimating basin SCA: (1) National Weather Service (NWS) satellite snow cover mapping program, and (2) the U.S. Army Corps of Engineers aircraft snow cover mapping program. In addition, the relationship of these methods to the USDA Soil Conservation Service's (SCS) SNOTEL system is explored.

2 METHODOLOGY

Since 1981, the NWS has been producing SCA products derived from the GOES weather satellites. These products are prepared digitally from cloud free imagery during the snow melt season (Allen and Mosher, 1986). In 1988, the NWS developed area/elevation curves for 286 U.S. Geological Survey cataloging units (HUCs) in the West using thirty (30) second digital terrain data. The U.S. Army Corps of Engineers has been mapping snow cover for the last 15 years using fixed wing aircraft in the Upper Snake River basin in Wyoming and the Boise and North Fork Clearwater River basins in Idaho. During the melt season, the Corps flies each of these basins in their entirety using the aircraft altimeter to measure the elevation of the continuous snow line. As many as 50 observations are made and averaged to produce an estimate of average basin snow line (Reese, 1988).

In the late 1970s the SCS began installing an automated mountain snow pack data collection and telemetry system known as SNOTEL (SNOw TELemetry). The system reports snow pack water content, cumulative precipitation, and air temperatures on a daily basis, using meteor-burst telemetry (Johnson, 1987). The day of snow pack meltout at a particular SNOTEL site should be related to the elevation of the basin snow line at that time.

Presented at the Western Snow Conference 1989, Ft. Collins, Colorado

1/Satellite Hydrologist, Office of Hydrology, National Weather Service, Minneapolis, Minnesota.

2/Hydrologist, USDA Soil Conservation Service, Snow Surveys, Boise, Idaho.

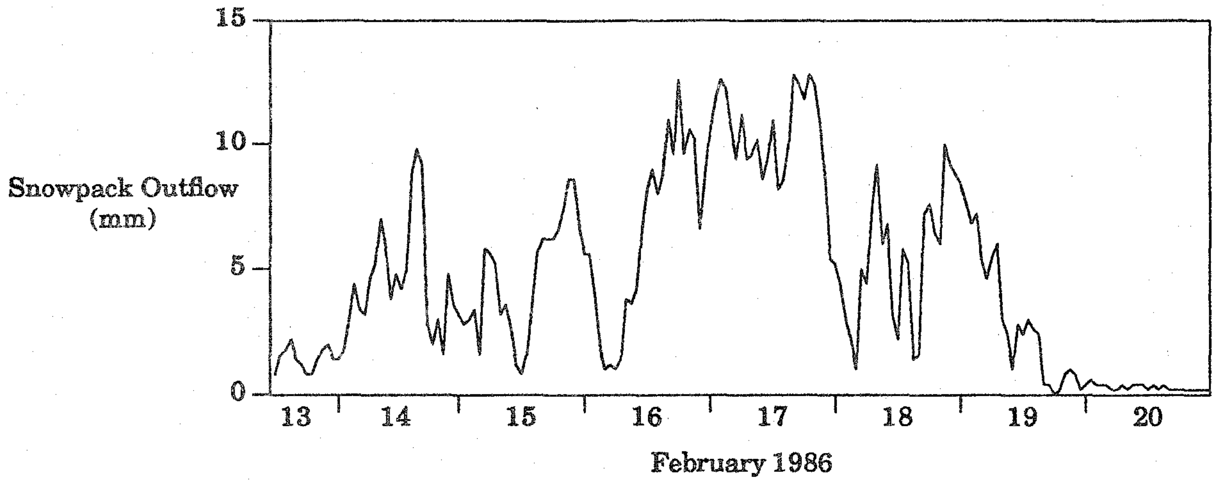

Figure 2. Hourly water release from a shallow snowpack at Blue Canyon during a major flood-producing storm in February 1986.

SUMMARY AND CONCLUSIONS

The intermittent snowpack zone accounts for a large proportion of the area of Sierra Nevada river basins and is the source of much of the runoff and floods that occur during mid-winter. Measurements of snowpack water equivalence over two decades at an index location illustrate the rapid fluctuation in water stored as snow in this elevation band. Snowpacks in this region do not accumulate and ablate in the relatively steady pattern found at higher elevations. Instead, the snow water equivalence rises and falls sharply over short time periods as snowfall, rainfall, and clear weather alternate. Snowmelt and water release to soils occur on most days of the winter and spring when snow cover is present. The shallow snow cover offers little delay to rainfall and can melt rapidly during warm storms. Improved monitoring of snowpack conditions at lower elevations is recommended to improve flood forecasts and as an aid in interpretation of snow covered area data.

ACKNOWLEDGEMENTS

We are grateful to Carl Wickstrom and James Marling of the National Weather Service's Blue Canyon observation station for providing access to the Blue Canyon records and to the National Weather Service for providing access to the site for installation of the snowmelt lysimeters.

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Because of the difference in timing of the three observation methods, it was necessary to develop a common base for comparison. Snow cover depletion curves were constructed from NWS satellite observations for the Upper Snake (HUC 17040101), Upper North Fork Clearwater (HUC 17060307), and Middle and North Forks Boise River (HUC 17050111) for the period 1985-1989 (except for the Clearwater basin which began in 1986). A discussion of the construction of snow cover depletion curves can be found in Moravec and Danielson, 1980. These curves were the basis for analysis of all three methods of snow line elevation estimation. The aircraft observations were plotted directly on the curves, along with SNOTEL meltout dates. The elevation of each SNOTEL site was converted to a percent of area above that site using NWS hypsometric curves to be comparable with the other measurements.

3 RESULTS

Satellite SCA for the Boise River above Lucky Peak was derived by combining the SCA for HUCs 17050111, 17050112, and 17050113 and satellite SCA for the North Fork Clearwater was derived by combining the SCA for HUCs 17060307 and 17060308 to coincide with the area mapped by the Corps. The Snake River above Jackson Lake is a sub-basin of HUC 17040101 but for comparative purposes the satellite SCA for the entire HUC was used. Table 1 shows the agreement between snow covered area derived from satellite data and Corps flights. With the exception of one observation on the North Fork Clearwater, satellite and aircraft estimates of SCA agree within plus or minus 5 percent. For May 16, 1986, a snow line elevation of 4980 feet was estimated for both HUCs 17060307 and 17060308 using satellite SCA of 40 percent and 12 percent respectively (27 percent combined), while the Corps estimated the total basin snow cover to be 40 percent. The discrepancy between the areal extent of snow cover estimates may be related to the aspect of the basin where altimeter readings were taken.

TABLE 1

COMPARISON OF SATELLITE AND AIRCRAFT SNOW COVER AREA

BASIN	HUC No.	DATE	PERCENT SCA NWS	PERCENT SCA COE
Clearwater	17060307, 17060308	860516	27	39
		860603	2	5
Boise	17050111, 17050112, and 17050113	850502	29	32
		860516	26	30
		860603	11	15
Snake Hdw.	17040101	860604	51	55

Table 2 indicates general agreement from year to year between snow line elevation and SNOTEL meltout date. Of special note is Grassy Lake which shows a variation of only plus or minus 5 percent basin SCA for the 4 year study period. This site provides a fairly accurate index of snow line elevation and could be a valuable hydrologic indicator in the upper Snake basin. In three of the four years studied, the peak flow for the Snake River above Jackson Lake occurred when the basin SCA (as measured by satellite) was between 29 and 38 percent. By the time the basin SCA drops below 30 percent (when the Grassy Lake site melts out), peak flows have typically occurred.

TABLE 2

SATELLITE SNOW COVER AREA ON SNOTEL MELTOUT DATE

BASIN	HUC No.	SNOTEL SITE NAME	PERCENT SATELLITE SCA ON SNOTEL MELTOUT DATE 85	86	87	88	PERCENT OF BASIN ABOVE SNOTEL SITE
Clearwater	17060307	Shanghi Summit	--	49	20	14	58
		Hemlock Butte	--	1	0	0	14
		Graham Guard Sta.	40	48	46	58	71
		Moores Creek Sum.	10	17	14	17	53
Boise	17050111	Jackson Peak	7	4	9	11	30
		Atlanta Sum.	7	9	9	11	19
		Trinity Mtn.	5	4	6	9	16
		Base Camp	62	68	54	48	83
Snake Hdw.	17040101	Grassy Lake	28	31	29	26	79
		Lewis Lake Div.	16	19	26	17	58

The results of the SNOTEL and satellite snow covered area analysis are summarized in Table 3. In all cases, except for the highest sites in the Boise, the SNOTEL sites reported meltout well after the satellite and aircraft observed snow line had receded above the elevation of the SNOTEL site. This reflects the tendency of the mountain snow pack to break up into patches during the melt season. SNOTEL sites are normally located in gently sloping, protected areas, which can hold snow patches during the melt season after the continuous snow line has exceeded that elevation.

TABLE 3

DIFFERENCE BETWEEN SATELLITE SNOW COVER AREA AND SNOTEL MELTOUT DATE AND SNOW LINE ELEVATION

DIFFERENCE BETWEEN SATELLITE SCA ESTIMATED SNOW LINE ON SNOTEL MELTOUT DATE

BASIN	SNOTEL SITE NAME	1985 DAYS	1985 EL.	1986 DAYS	1986 EL.	1987 DAYS	1987 EL.	1988 DAYS	1988 EL.	AVERAGE DAYS	AVERAGE EL.
Clearwater	Shanghi Summit	--	---	5	300	17	550	21	1250	14	700
	Elk Butte	--	---	9	700	12	550	30	750	17	667
	Hemlock Butte	--	---	12	700	14	1000	36	---	21	850
	Crater Meadows	--	---	10	500	11	850	32	---	18	675
	Lost Lake	--	---	13	400	33	---	36	---	27	---
	Cool Crest	--	---	15	1050	32	---	35	---	27	---
Boise	Graham Guard Sta.	15	1500	23	700	18	1000	8	500	16	925
	Moores Creek Sum.	34	2300	42	1700	29	2100	36	1900	35	2000
	Jackson Peak	36	1700	18	1200	21	1500	29	1300	26	1425
	Atlanta Sum.	30	1200	13	900	14	900	20	1000	19	1000
	Trinity Mtn.	35	1300	29	1100	16	800	20	1000	25	1050
	Dollarhide Sum.	4	200	0	0	3	200	4	200	3	150
	Vienna Mine	0	0	--	-100	--	-300	0	0	0	-100
Snake Hdw.	Base Camp	9	750	14	750	8	1100	11	1100	11	925
	Grassy Lake	24	1500	22	1200	17	1500	22	1500	21	1425
	Lewis Lake Div.	28	1450	23	1200	14	1000	24	1150	22	1200

4 SUMMARY

The relationship between satellite SCA and SCA from fixed wing aircraft is extremely good. As a result, in 1988, the Corps relied entirely upon satellite SCA and area elevation curves to derive the average snow line for the Upper Snake, North Fork Clearwater, and Boise basins. Though more work remains to be done to relate SCA to basin and snow pack conditions (e.g., snow line elevation, slope, aspect, and vegetation cover), it has been demonstrated that SCA can be used quantitatively to determine average snow line elevations by hydrologic basins.

The relationship between SNOTEL meltout dates and satellite observations of SCA was generally consistent for the four years of available data. SNOTEL sites always meltout later than satellite or aircraft observations would indicate. Most SNOTEL sites are solar protected allowing isolated snow patches to persist after the continuous snow line has receded up slope. Typically, SNOTEL sites melt out approximately 3 weeks after the snow line has receded past the site to an elevation approximately 1000 feet above the elevation of the SNOTEL site. On average, the differences for the North Fork Clearwater, Boise, and Snake are respectively, 21 days and 717 feet, 19 days and 921 feet, 18 days and 1188 feet for the sites in Table 3.

It is interesting to note that the Grassy Lake SNOTEL site showed a particularly close relationship to the timing of peak runoff in the basin. This limited data set suggests that both satellite data and SNOTEL data can provide information necessary to estimate basin SCA and snow line elevation for use in hydrologic models and to facilitate estimates of peak flow forecast dates.

Graphs showing the correlation of average snow line elevations derived from Corps flights, satellite SCA, and SNOTEL meltout dates for the data presented in the paper are available upon request.

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