N76-16570

UTILIZATION OF LANDSAT MONITORING CAPABILITIES FOR SNOWCOVER DEPLETION ANALYSIS

A. G. Thompson, *WRRI, University of Wyoming, Laramie, Wyoming*

ABSTRACT

LANDSAT images for three snowmelt seasons have been utilized to map and analyze snowcover depletion on a small river basin in southeastern Wyoming. Results indicate that snowcover-runoff curves established from repetitive LANDSAT coverage may be used in conjunction with streamflow data to provide low-cost seasonal runoff forecasts having a high degree of accuracy. Additionally, detectable variations within a snowpack might provide temporal estimates of peak flows.

INTRODUCTION

Runoff from melting snows provides most of the usable water supply for the Western United States; but unfortunately this runoff is not timed to meet the water requirements of crop production, hydroelectric power generation, or municipal needs (Garstka, Love, Goodell, 1958). The need to plan for expected water supply has led to runoff forecasting programs such as the snow survey administered by the Soil Conservation Service (SCS). The economic value of the SCS water supply forecasts has been estimated at between $32 million and $65 million per year accruing to agriculture alone (Nelson, 1969). While estimates of forecast value vary according to source, it is generally accepted that forecasts are necessary and worthwhile, particularly as competition for available water supplies increases.

Whether a particular runoff forecast procedure is based on some form of index method or rational method, all procedures have one thing in common: raw data are required and the costs of raw data are continually rising. Snow course measurements for the SCS in the states of Colorado, Montana, and Wyoming presently cost $300-$400 per snow course per year, and this figure is expected to rise as high as $500 in the near future.

(U.S. Department of Agriculture, SCS, 1975). Any new forecasting procedure under consideration must cost less or no more than those now being used and provide accuracy as good as or better than that presently available. The LANDSAT satellites now provide information usable for forecasting procedures which may satisfy the requirements of cost and accuracy.

The value of knowledge concerning the areal extent of snowcover has been recognized for some time. The close relationship between snowcover depletion and accumulation for a given basin has been well documented (Leaf, 1971). The main problems confronting users of snowcover data have been the high cost of the data if aerial photography was used and the inaccurate data obtained from snowcover estimations (U.S. Army Corps of Engineers, 1960). The LANDSAT satellites provide snowcover information on a regular basis and at minimal cost. The purpose of this study was to examine the snowcover monitoring qualities of LANDSAT data with respect to runoff forecasting.

A small basin of 404 km^2 (156 mi^2) with substantial ground truth available was used as a test area. The study utilized LANDSAT data covering 3 snowmelt seasons. Study results indicated a poor relationship between snowcovered area at a given time and total runoff for the melt season in this basin. However, an excellent relationship was established between snowcover as a percentage of total basin area and the accumulated runoff to a given image date as a percentage of the total seasonal runoff. Additionally, analysis of variations of reflectance within the snowpacks indicated a relationship between these variations and climatological parameters which might be used in the temporal estimation of peak flows.

Results show that LANDSAT data is operationally useful from the standpoints of both economics and accuracy. LANDSAT data may aid in overcoming the high cost of data acquisition and data acquisition problems brought about by physical or legislated limitations.

STUDY BASIN AND DATA BASE

That portion of the Little Laramie River basin above the United States Geological Survey streamflow gage 06661000 near Filmore, Wyoming, comprises the test basin used for this study (Fig. 1). The basin lies on the east-facing slopes of the Medicine Bow Mountain Range in southeastern Wyoming, 64 km (40 mi) west of Laramie, Wyoming. This portion of the basin covers an area of 404 km^2 (156 mi^2) and rises from 2316 m (7600 ft) in elevation at the Filmore gage to

3659 m (12,005 ft) at the top of Medicine Bow Peak. The general area-elevation of the basin is as follows:

Elevation	Area	
3353 m (11,000 ft)	1%	
3048 m (10,000 ft)	19%	
2743 m (9000 ft)	55%	
2438 m (8000 ft)	82%	Figure 2

Vegetation of the basin consists of prairie grasses and sagebrush on the valley floor and lower slopes with lodgepole pine and fir-spruce krumholz forest on the higher slopes and mountains. Low vegetation and scrub trees are characteristic of the alpine areas of the basin. The forest crown cover exceeds 70 percent only in scattered stands of lodgepole pine.

This particular basin was chosen as a test site because it is centrally located in the LANDSAT image track, because flow data for the Filmore gage are available for a continuous period of 38 years, and because the basin contains two sub-basins which act as hydrometeorological observatories for the Wyoming Water Resources Research Institute (WRRI). The Nash Fork Creek and Libby Creek sub-basins contain 13 WRRI hydrologic or meteorologic instrument stations (Fig. 2). Recorded data for solar radiation, temperature, precipitation, wind, and streamflow are available for some of the sites for a period of 8 years. Precipitation, solar radiation, and temperature data from the Little Brooklyn Lake instrument site at 3170 m (10,400 ft) elevation were used as base data for yearly comparisons.

This portion of the Little Laramie River basin is also the location of 5 SCS snow courses. Data are available for all 5 courses for a continuous period of 27 years. The average April 1 water equivalent of these 5 snow courses correlates with the flow totals at the Filmore gage with $R^2 = .79$.

Ground truth data were collected for the 1975 accumulation and early melt season at 5 WRRI meteorologic instrument stations from 2560 m (8400 ft) to 3231 m (10,600 ft) elevation (Fig. 2). Readings of snow depth, water equivalent, and snowpack temperature were taken at each of the 5 sample sites. Photometer readings were also taken filtered for direct light and the approximate ranges for the 4 LANDSAT MSS bands. These data were collected from 18 Feb 75 to 13 May 75 concurrent with LANDSAT overflights or as close as weather, time, and the usual field problems permitted.

Positive 18.54 cm (7.3 in) x 18.54 cm

transparencies of all MSS bands were ordered for each scene that offered any possibility of interpretation of the snowcover for 1973, 1974, 1975. Of 27 scenes available for the snowmelt seasons, 15 scenes could be used to map snowcover. Several of these were marginal at best and could be used only with color enhancement and then only for total snowcover. It was hoped to attain a good number of scenes for the 1975 melt season as two satellites were imaging; but cloud conditions and image accession problems combined to limit the usable scenes to 5, of which 2 were marginal for snow mapping. Quality of the images received usually ranged between 5555 and 8888. Distortion of individual band images presented problems in only several instances and these were rectified with the aid of a zoom transfer scope.

METHODOLOGY AND EQUIPMENT

The snowcover was mapped for each usable MSS 5, MSS 7, 4-band color diazo composite, and in some cases an MSS 5 high-density black diazo. The mapping was done on a Bausch and Lomb ZT4 Zoom Transfer Scope at a scale of 1:250,000. Tonal and color variations within the snowcover were mapped in addition to total snowcover. The respective areas were measured with a K & E compensating polar planimeter with an average combined instrument and operator error of less than 1 percent. As a check on mapping accuracy, all snowcover scenes for 1973 were independently remapped after two months. Area measurements and snowpack shapes were found to be essentially the same for the two trials. Differences that were noted stemmed from increased experience in distinguishing clouds from snow.

Initially the color enhancement diazo process was used experimentally to facilitate mapping of snow-covered scenes which had cloud interference. Test composites showed that a false color infrared diazo composite had variations in the snowpack which took on a bluish tint and corresponded closely to tonal variations in MSS 5 and MSS 7 black and white transparencies. Trials were run on each band for color, exposure time, and developing of the diazo film to arrive at a combination that provided the desired image enhancement, not only for snow mapping but for general use of the composite. Once the desired colors, exposure times, and developing times were set, a color composite could be made which was standard enough to allow comparison from scene to scene and from season to season. The final composite had MSS 4 as yellow, MSS 5 as red, and both MSS 6 and 7 as cyan. A 3-band composite leaving out MSS 6 undesirably reduced the apparent color variation within the snowpack.

Photometer readings were taken in order to examine reflection variation between bands during the melt season. A Science and Mechanics Model A-3 photometer was used with filter modifications filtered for:

MSS 4: .48 μm-.59 μm
MSS 5: .59 μm-.66 μm
MSS 6: .70 μm-1.1 μm
MSS 7: .83 μm-1.1 μm

For each reading of each band another reading was taken of an 18 percent grey scale card at the same time. The figure then used for analysis was the ratio of the grey scale photometer reading to the snow photometer reading for each filter. Use of the grey scale card provided a basis for reflectance comparison between bands, sites, and observations.

A Joyce-Loebl MKIIICS automatic recording microdensitometer and a Spatial Data Systems Model 401/704 Datacolor/Edge Enhancer System were also used for image analysis, but only quantitatively to this point due to time considerations and mechanical problems. Snowcovered areas delineated by the systems were comparable to those obtained by manual mapping; however, the same problems exist in differentiating between clouds and snow. Computer compatible tapes of LANDSAT scenes were not used for this study due to the cost of the tapes for a monitoring situation.

ANALYSIS AND RESULTS

Use of the snowcovered area of a basin as a forecasting index of total runoff does not appear promising based on this study. Table 1 shows the progression of snowcover depletion during the snowmelt seasons for which LANDSAT coverage was available. Actual snowcovered area for given dates in 1973 seem to approximate or exceed the area for similar dates in 1974, although the total April 1-July 31 runoff for 1973 was 716 m^3/sec (25,300 cfs) as compared to 917 m^3/sec (32,393 cfs) for 1974. Also, the snowcovered area is consistently higher for the 1975 season than for 1974, yet the respective April 1-July 31 flows for the 2 years are nearly equal, with 933 m^3/sec (32,959 cfs) for 1975. This same relationship is also borne out by characteristic snow depletion-runoff curves derived for the individual seasons. The relationship becomes even less in light of the fact that the hydrograph rise did not really begin until May 9 in 1975, as compared to April 15 for 1974 and April 20 of 1973.

Meaningful statistical analysis is not possible with only three data points, but it should be noted that the flows for 1974 and 1975 represent fairly normal flows compared to the seasonal average over 58 years of record of 863 m^3/sec (30,478 cfs) and as such do not represent extremes which might account for error. The difference between flows and snowcover is not accounted for either in these seasons by late-season precipitation. The question also arises as to whether snowcover for such a small basin on a given index date would vary enough from year to year to suffice as an accurate runoff index. However, this is only one basin and significant yearly snowcover variations may be found in other basins, particularly larger basins (Rango, Salomonson, Foster, 1975).

Far more promising results for the use of LANDSAT snow mapping for total runoff forecasting were obtained in comparing basin snowcover percentages to accumulated runoff to dates of the LANDSAT scenes. For better comparison between yearly melt seasons, the parameters were made dimensionless with X = snowcover/total basin area and Y = accumulated runoff/total April 1-July 31 runoff (Table 1).

Nonlinear regression using MSS 5, MSS 7, and color-composite derived data established a semi-logrithmic relationship between the X and Y parameters. The color composite data realized the highest relationship, with $R^2 = .98$ using 11 data points and $\text{Log}_{10}Y = 2.03888 + (-.0156482)X$. Figure 3 shows the plotted composite data and the resultant curve on a standard graphic scale. Initially, all data derived from all scenes starting with the last scene showing 100 percent snowcover were used, with $R^2 = .91$. However, the 100 percent data points were dropped since they were not reflective of the last actual date of 100 percent snowcover and hence not indicative of accumulated runoff at the beginning of snowcover depletion.

Although the individual snowcover depletion curves vary considerably for each year, the dimensionless depletion-accumulation curve (Fig. 3) holds for each of the test years regardless of varying weather conditions, depth of snowpack, water equivalent of snowpack, and total runoff. Such close relationships as were found are consistent with the literature on snowcover depletion-runoff accumulation relationships and with a snowpack's position as a "thermometer" of physical factors affecting the yearly melt cycle. The obvious implication of the dimensionless depletion-accumulation relationship is that if the snowcovered area can be accurately determined at any point during the melt season and if streamflow data are available, then the total expected runoff may be accurately forecast. Also, a short-term picture of the time distribution of runoff might be formulated by comparison to yearly hydrographs. Using the depletion curves derived from the dimensionless curve for 1973, 1974, 1975, the peak flow dates came at 47, 46, and 40 percent, respectively of the April 1-July 31 total runoff.

While the dimensionless curve established may be unique to a single basin, the availability of LANDSAT data makes the development of similar curves for any number of basins simple and relatively inexpensive. Also, the accuracy of LANDSAT data for areal measurements of the size of snowpacks is dependable (Barnes, Bowley, 1973). Further, LANDSAT provides a scale that is workable for small basins and rivers. Streamflow data can be obtained with relative ease from a gage that need not be located in the severe conditions of a snowpack area for use in conjunction with snowcover data. Table 2 shows color and tonal variations within the snowpacks mapped from MSS 5, MSS 7, and color composites as percentages of total snowcovered area. The areas mapped were analyzed to determine possible significance of the variations noted. It was felt these variations stemmed from (1) areas of melting snow detected in MSS 7; (2) differing reflectance characteristics of metamorphosed snow; or (3) scattering of light reflectance due to ground vegetation showing through shallow snow.

Nonlinear regression of these variation values against accumulated runoff percentages gave a lower R^2 (= .62), which was the highest for this series and attributable to the composite data.

In examining the first variation possibility, the photometer readings collected for 1975 were analyzed. If MSS 7 was detecting any areas of melting snow, a change in photometer readings for MSS 7 relative to the other filtered bands was hypothesized. Cloud problems prevented comparison of photometer readings to the LANDSAT data for the early melt season in May 1975. However, analysis of variance showed no significant difference for the MSS 7 reflectance for the sample data from the 5 sample sites. MSS 7 appears to be of little aid in direct measurement of areas of snowmelt. This is supported by the fact that the MSS 7 bandwidth is .8 μm-1.1 μm, while the greatest decrease in reflectance of melting snow occurs between 1.1 μm and 1.3 μm (Weisnet, McGuiness, 1974).

Multiple regression of the variation data against accumulated average daily temperature from March 1 to scene date and accumulated precipitation from March 1 to scene date produced an $R^2 = .88$. Again this was the value from the composite data and was the highest. Solar radiation was not used in the multiple regression since instrument problems did not provide sufficient continuous data for the 3 melt seasons.

This relation suggests that the area of variation as mapped reflects accumulated heat supply and additions of precipitation, usually in the form of snow. Ground truth samples measured the changes in depth in the early melt season. By 13 May 75, ground vegetation was showing through the snow at the 2 lower sample sites. Also by this date, surface snow at the lower elevations had been thawed and refrozen and was generally frozen at the hour LANDSAT overflights were made. It was also noted at the sites that light spring snowstorms would cover the lower elevations and the metamorphosed snow. This fresh snow would remain past the hour of overflights. Also in the accumulation period of the snowpack for 1975, snow on the valley floor was usually light and vegetation showed through the snowcover. The area of the valley floor in the accumulation period scenes nearly always showed up as an area of color or tonal variation.

With such a small sample as 3 seasons for one basin, meaningful statistical conclusions are difficult to arrive at. However, the variation data do appear to evidence an inverse relationship to the time of the runoff hydrograph peak. The date of the runoff peak has varied over 39 years at the Filmore gage from May 12 to June 28 with the average time as June 6. Peak dates for the 1973, 1974, 1975 melt seasons were June 11, June 6, and June 16, respectively. Peaks having the highest flows are characteristic of the latter part of May.

Since a river's hydrograph is sensitive to heat requirements for the melting of a snowpack, it is felt the color and tonal variations as mapped reflect the melt cycle variations indirectly by depicting the depth changes near the outer limits of the receding snowpack. Further work is necessary, but these variations might be used in the estimation of peak flow dates and for more accurate forecasting of the time distribution of runoff.

CONCLUSIONS

1. Color composites of LANDSAT scenes provide the best all-round snow mapping capability, particularly for manual interpretation.

2. Prospects for use of snowcovered area as a sole index for total runoff from basins of the size used in this study do not appear favorable with any degree of acceptable accuracy based on the results of this study.

3. The use of dimensionless snowcover-runoff curves developed from LANDSAT imagery appears to be a viable method of obtaining low-cost forecasts of total runoff and short-term forecasts of time distribution of seasonal runoff within acceptable accuracy.

4. Mapping of color or tonal variations within receding snowpacks as an indirect measure of the snowpack melt cycle may lend itself to usable estimates of peak flow times and runoff distribution as additional LANDSAT data become available.

5. Analysis of changing snowcover characteristics provides indicies of data parameters that are much more difficult and expensive to acquire on a monitoring basis than are LANDSAT images.

6. LANDSAT provides a scale and resolution of data that are necessary for work concerning smaller basins of the size used in this study.

7. The major drawback to operational use of LANDSAT data in runoff forecasting is the hands-on time required from data collection to user at the present time. However, as the operational value of LANDSAT type data becomes more and more apparent, distribution systems will undoubtedly increase in number and speed of delivery.

REFERENCES

Barnes, J. C., and C. J. Browley, Mapping Snow Extent in the Salt-Verde Watershed and the Southern Sierra Nevadas Using ERTS Imagery, in Proceedings of the Third ERTS-1 Symposium, NASA Sp-351, Vol. 1, pp. 977-994, U.S. Government Printing Office, Washington, D.C., 1974.

Garstka, W. U., L. D. Love, B. C. Goodell, Factors Affecting Snowmelt and Streamflow, 189 pp., USDI Bureau of Reclamation and USDA Forest Service, 1946-53 Cooperative Snow Investigations, U.S. Government Printing Office, Washington, D.C., 1958.

Leaf, C. F., Areal Snow Cover and Disposition of Snowmelt Runoff in Central Colorado, USDA Forest Service Research Paper, RM-66, 19 pp., Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 1971.

Nelson, M. W., Social and Economic Impact of Snow Survey Data and Water Supply Forecasts, 7 pp., Idaho Snow Survey Supervisor, for presentation at the Western Snow Conference, Salt Lake City, Utah, April 15-17, 1969.

Rango, A., V. V. Salomonson, and J. L. Foster, Seasonal Streamflow Estimation Employing Satellite Snowcover Observations, NASA preprint X-913-75-26, 34 pp., Goddard Space Flight Çenter, Greenbelt, Maryland, 1975.

U.S. Army Corps of Engineers, Runoff from Snowmelt, Engineering Manual 1110-2-14061, 413 pp., U.S. Government Printing Office, Washington, D.C., 1960.

U.S. Department of Agriculture, Soil Conservation Service, Snow Survey Headquarters for Colorado, Montana, Wyoming, Telephone communication, 1975.

Weisnet, D. R., and D. F. McGuiness, Snow Extent Mapping and Lake Ice Studies Using ERTS-1 MSS together with NOAA-2 VHRR, in Proceedings of the Third ERTS-1 Symposium, NASA Sp-351, Vol. 1, pp. 995-1009, U.S. Government Printing Office, Washington, D.C., 1974.

TABLE 1

1973, 1974, 1975 LANDSAT-derived snowcovered areas as percentages of total basin area for MSS 5, MSS 7, and color composites, and accumulated runoff as percentage of total runoff, April 1-July 31.

Date	MSS 5 %	MSS 7 %	Color Composite %	Accumulated Runoff %
12 APR 73	99	99	99	2
18 MAY 73	58	57	57	12
5 JUN 73	32	31	32	34
23 JUN 73	16	15	13	67
11 JUL 73	6	1	2	87
25 APR 74	100	100	100	3
31 MAY 74	30	28	30	34
18 JUN 74	21	18	18	67
6 JUL 74	7	2	6	88
2 APR 75	100	100	100	.2
17 MAY 75	77	77	77	7
4 JUN 75	57	50	48	18
13 JUN 75	42	39	39	33
22 JUN 75	29	30	24	52

TABLE 2

1973, 1974, 1975 LANDSAT-derived snowpack variations for MSS 5, MSS 7, and color composites as percentages of total snowcover area.

Date	MSS 5 Grey Tone %	MSS 7 Grey Tone %	Composite Bluish Color %
7 MAR 73	17	18	--
25 MAR 73	21	24	0
12 APR 73	19	24	58
18 MAY 73	59	59	63
5 JUN 73	41	35	86
23 JUN 73	56	56	100
11 JUL 73	83	100	100
25 APR 74	38	41	--
31 MAY 74	43	64	57
18 JUN 74	57	56	78
6 JUL 74	86	50	86
15 MAR 74	14	16	15
17 MAY 74	-- Clouds	-- Clouds	--
4 JUN 74	40	56	--
13 JUN 74	45	33	39

Figure 1

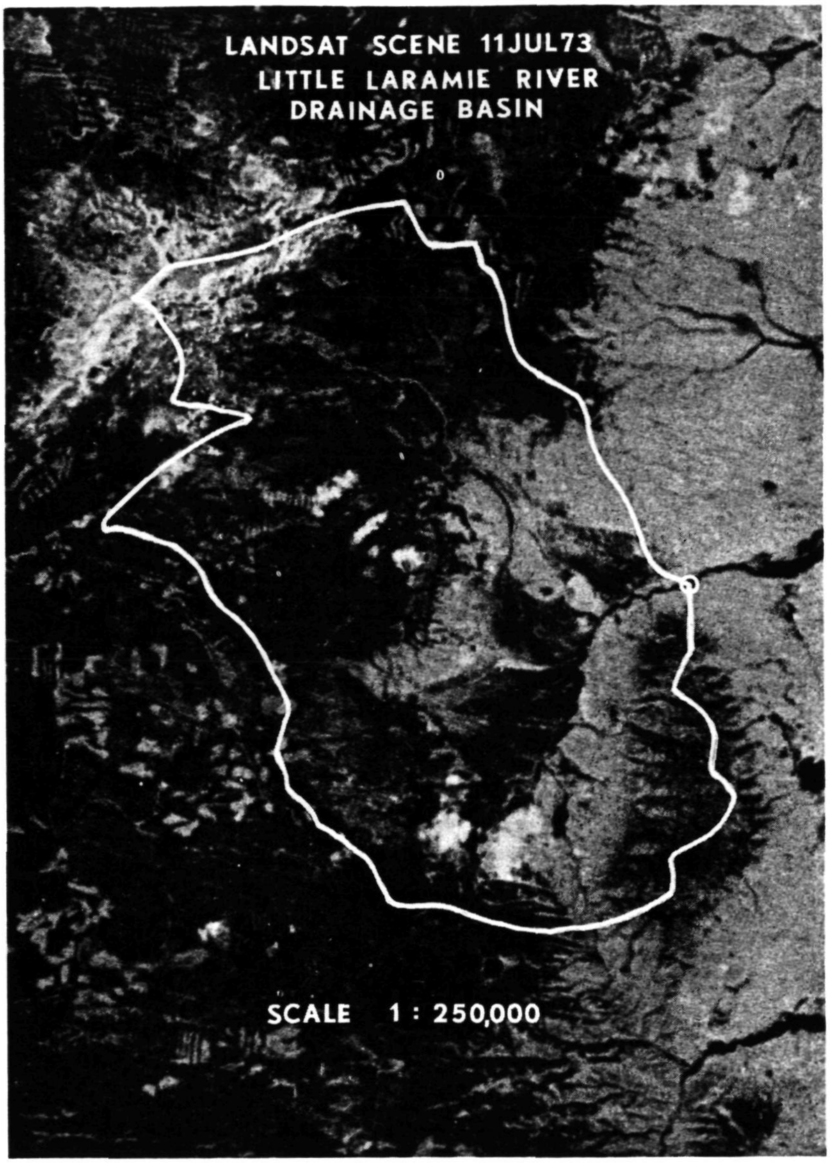
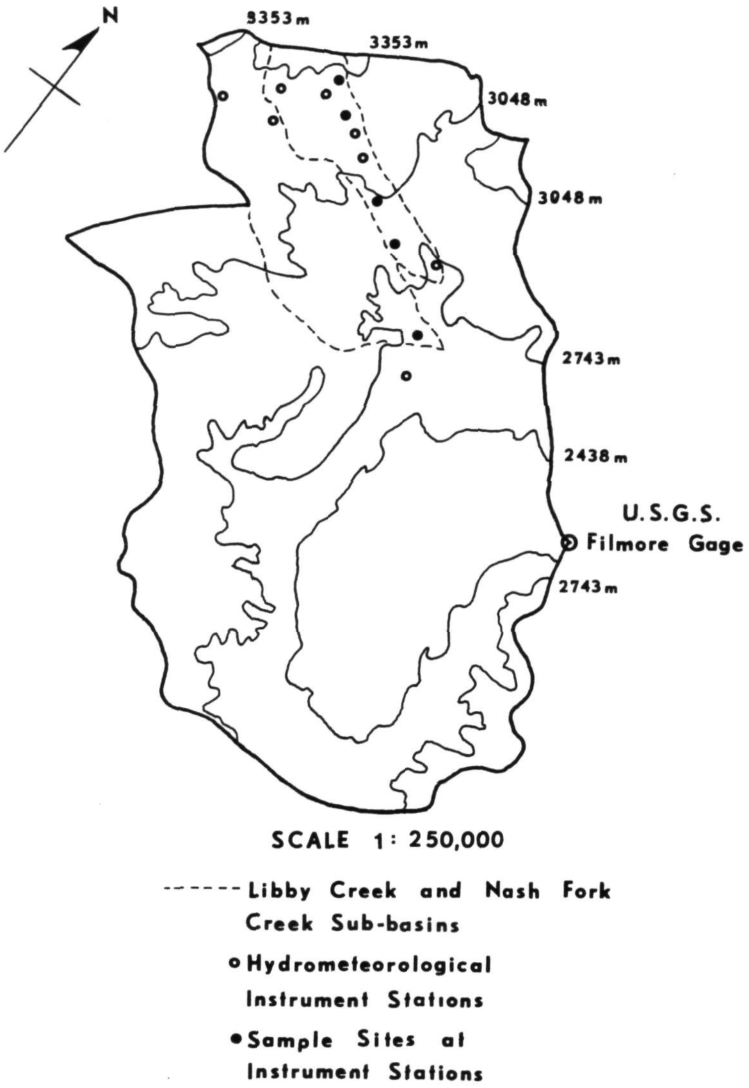
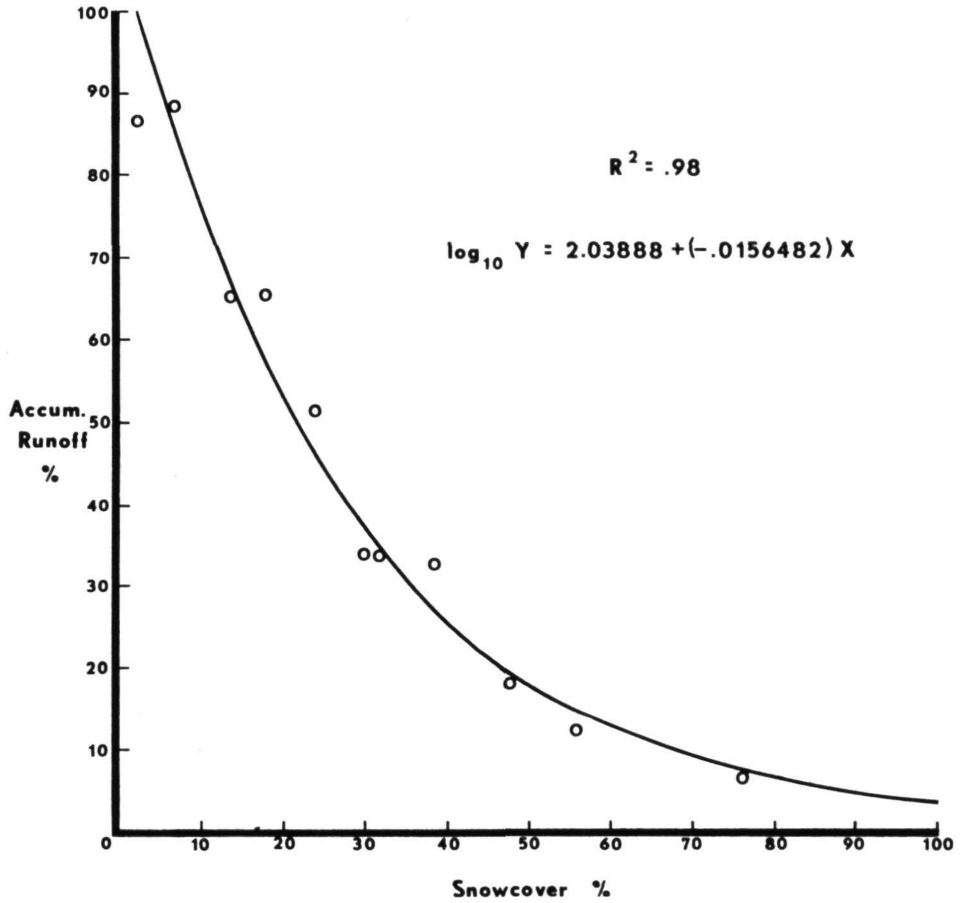

LANDSAT SCENE 11JUL73
LITTLE LARAMIE RIVER
DRAINAGE BASIN
SCALE 1 : 250,000

Figure 2



LITTLE LARAMIE RIVER
DRAINAGE BASIN



PLOTTED DATA

COMPOSITE SNOWCOVER
%
-V-
ACCUMULATED RUNOFF
%

Figure 3