PREDICTION OF RUNOFF PATTERNS IN WYOMING USING LANDSAT IMAGERY TO MEASURE SNOWCOVER AND ESTIMATE RUNOFF FROM SNOWMELT

Ronald W. Marrs

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Department of Geology and Geophysics
College of Arts & Sciences
University of Wyoming

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Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming

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ABSTRACT

Snowpack has been traditionally monitored by on-site recording stations supplemented by periodic sampling for water content. Snowcover estimates from Landsat imagery can be used to effectively augment these measurements and improve water forecasts. The method used is to interpret snowcover area from a sequence of images obtained during several snowmelt seasons. The snowcover measurements are plotted against measured streamflow summed over the melt season. As cumulative runoff increases, snowcover decreases each year. The empirical relationship derived from these data is evaluated and compared to similar curves for other snowmelt seasons to derive a composite relationship that represents the "typical" pattern of snowmelt vs. runoff for each watershed. The curves derived in this fashion can be used to forecast volume and timing of runoff during the spring snowmelt, using the current Landsat imagery to assess the condition of the snowpack in a given watershed. Composite curves were compiled for each Wyoming watershed where adequate data were available for several seasons. Both the annual and composite curves are useful for predicting the expected runoff from the most recent satellite images. Dates for beginning, peak, and end of spring snowmelt can be predicted.

INTRODUCTION

Landsat is the key element in a system that provides a new and broader perspective on many earth resources problems. Among the resources that can be effectively monitored using Landsat is the snowpack that accumulates in mountain watersheds each year. Landsat provides an excellent platform for periodically observing the snowpack so that its accumulation and depletion can be efficiently measured. Researchers have used the capability provided by Landsat to monitor the size and condition of the accumulated snowpack, and have developed methods for relating the satellite snowpack measurements to the annual runoff that is released as the snowpack melts.

We have attempted to build on these efforts in an attempt to apply this new technology to water forecasting on a statewide scale. Our test regions were the mountain watersheds of Wyoming in which snowpack contributes significantly to the annual runoff. The procedures for analysis were tailored to be as simple and economical as possible while maintaining both flexibility and accuracy. We believe that our results represent a first step in the development of an operational system for monitoring snowpack and estimating runoff across much of Wyoming.

ACKNOWLEDGEMENTS

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BACKGROUND

Just one year after the launch of the first Landsat system (ERTS), the first results of applications tests were published detailing the use of Landsat as a tool for periodically mapping snowcover. In October, 1973, Barnes and others reported:

> "...snow extent can be mapped from ERTS imagery in more detail than is depicted on aerial survey snow charts. For the areas tested, the agreement between the percentage snow cover as determined from ERTS data and from aerial survey snow charts is of the order of 5 percent for most cases. Moreover, it appears that although small details in the snowline can be mapped better from higher-resolution aircraft photographs, boundaries of the areas of significant snow cover can be mapped as accurately from the ERTS imagery as from the aircraft photography. Moreover, the costs involved in deriving snow maps from ERTS imagery appear to be very reasonable in comparison with existing data collection methods."

The work continued, and in 1975 a symposium was held (Rango, 1975 (ed.)) to discuss results of a number of studies in which the utility of satellite data for mapping snowcover and for predicting runoff had been demonstrated (Katibah, 1975; Leaf, 1975; Rango and Salomonson, 1975; and Thompson, 1975). Thompson (1975) and Rango and Salomonson (1975) demonstrated the application of snowcover mapping to runoff forecasting in Wyoming watersheds. Even so, the techniques were not immediately accepted as operational procedures, although the test studies indicated potential for efficient and cost-effective application.

Four years later, another conference was held to discuss "Operational Applications of Satellite Snowcover Observations" (Rango and Peterson, 1979 (eds.)). Several newly tested procedures for estimating runoff from satellite snowcover measurements were presented (Schumann and others, 1979; Shafer and Leaf, 1979; Moravec and Danielson, 1979; Brown and others, 1979;

Hannaford and Hall, 1979; Martinec and Rango, 1979). Some workers used Landsat data together with data from meteorlogical satellites (Schumann and others, 1979), others correlated the snowcover data with more sophisticated models for runoff prediction (Dillard and Orwig, 1979; Moravec and Danielson, 1979; Hannaford and Hall, 1979). Rango and Martinec (1982) incorporated daily temperature data into a prediction model. Most studies emphasized the necessity for defining specially tailored snowcover/runoff relationships for each drainage area in order to accommodate variations in pattern due to topography, slope aspect, vegetation cover, elevation and other local conditions. Most workers reported that good results could be obtained using Landsat as a base for estimating snow cover.

METHODS

The methods used were largely those pioneered by Rango and Salomonson (1975), Thompson (1975), and Moravec and Danielson (1979). Every effort has been made to keep interpretation and analysis procedures as simple and cost-effective as possible, without unduly jeopardizing accuracy of results. In this context, the methods used by early investigators have been applied with only minor modification and without embellishments that could produce slightly improved forecasts, but at considerable cost in terms of manpower and data analysis time.

Bulk-processed Landsat image transparencies of spectral band 5 (red band) were selected for interpretation because they provided strong contrast between snow and vegetation even during the late spring snowmelt period. Single-band scenes were preferred to color-composite scenes because of greater availability and lower cost. Transparencies were used because they are more readily input to video analysis and provide better image detail than prints.

Streamflow data from selected gauge stations were obtained from the Wyoming Water Research Center in the form of computer listings of daily discharge values and monthly discharge totals (Table 1). Drainage sub-areas were defined to provide for single-scene coverage of individual regions with consideration made for availability of appropriate streamflow data. Discharge values for most sub-areas are represented by measurements from a single gauge station.

YELLOWSTONE RIVER AT YELLOWSTONE LAKE OUTLET Y.N.P. STATION NO. 061865.00
LATITUDE 44-34-03 LONGITUDE 110-22-48 SECTION 0 TOWNSHIP 0 ,RANGE 0 P.M.
ELEVATION 7727.77 FT DRAINAGE AREA 1006.00 SQ MI NONCONTRIBUTING 0.00 SQ MI BASIN 01030300
YELLOWSTONE PARK DATA FROM USGS (P)

MEAN DAILY FLOW IN CFS BY WATER YEAR
1977

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
1	1180.00	747.00	516.00	300.00	290.00	300.00	444.00	575.00	1020.00	1940.00	1230.00	822.00
2	1170.00	742.00	512.00	290.00	290.00	310.00	444.00	561.00	1070.00	1930.00	1220.00	810.00
3	1170.00	736.00	503.00	280.00	290.00	310.00	444.00	625.00	1120.00	1910.00	1190.00	798.00
4	1140.00	731.00	494.00	280.00	300.00	310.00	440.00	650.00	1200.00	1900.00	1180.00	792.00
5	1140.00	720.00	494.00	280.00	300.00	310.00	440.00	660.00	1290.00	1890.00	1150.00	769.00
6	1100.00	714.00	480.00	280.00	300.00	310.00	440.00	665.00	1410.00	1870.00	1150.00	764.00
7	1090.00	709.00	480.00	280.00	300.00	310.00	440.00	676.00	1500.00	1830.00	1140.00	753.00
8	1070.00	697.00	470.00	280.00	300.00	310.00	432.00	681.00	1610.00	1790.00	1140.00	736.00
9	1040.00	692.00	460.00	280.00	300.00	310.00	432.00	681.00	1720.00	1770.00	1110.00	720.00
10	1040.00	681.00	450.00	280.00	310.00	310.00	432.00	714.00	1860.00	1740.00	1090.00	709.00
11	1030.00	676.00	420.00	280.00	310.00	310.00	432.00	731.00	1940.00	1700.00	1070.00	692.00
12	1020.00	655.00	410.00	290.00	310.00	310.00	432.00	747.00	2000.00	1670.00	1060.00	681.00
13	998.00	655.00	400.00	300.00	310.00	320.00	432.00	753.00	2010.00	1640.00	1040.00	676.00
14	984.00	640.00	400.00	300.00	310.00	320.00	436.00	775.00	2040.00	1610.00	1010.00	665.00
15	963.00	635.00	400.00	300.00	310.00	320.00	440.00	822.00	2060.00	1580.00	998.00	651.00
16	956.00	620.00	400.00	300.00	310.00	330.00	440.00	840.00	2080.00	1550.00	991.00	681.00
17	921.00	615.00	390.00	300.00	310.00	340.00	444.00	876.00	2070.00	1530.00	963.00	681.00
18	900.00	613.00	370.00	300.00	310.00	340.00	444.00	888.00	2070.00	1510.00	949.00	665.00
19	888.00	605.00	350.00	300.00	310.00	350.00	448.00	876.00	2060.00	1490.00	949.00	655.00
20	882.00	590.00	330.00	300.00	310.00	350.00	448.00	921.00	2130.00	1440.00	935.00	645.00
21	870.00	580.00	330.00	300.00	310.00	360.00	452.00	921.00	2110.00	1420.00	928.00	630.00
22	858.00	580.00	310.00	290.00	310.00	360.00	460.00	935.00	2120.00	1420.00	914.00	620.00
23	840.00	570.00	330.00	290.00	310.00	360.00	460.00	935.00	2110.00	1400.00	900.00	615.00
24	834.00	566.00	330.00	290.00	300.00	370.00	464.00	949.00	2090.00	1390.00	900.00	615.00
25	822.00	557.00	330.00	290.00	300.00	380.00	472.00	963.00	2080.00	1410.00	882.00	605.00
26	810.00	539.00	340.00	290.00	300.00	380.00	485.00	998.00	2080.00	1370.00	894.00	600.00
27	798.00	534.00	340.00	290.00	300.00	390.00	507.00	1030.00	2070.00	1360.00	888.00	590.00
28	780.00	530.00	330.00	290.00	300.00	390.00	521.00	1030.00	2040.00	1340.00	886.00	590.00
29	775.00	530.00	330.00	290.00		448.00	539.00	1030.00	2000.00	1330.00	876.00	600.00
30	769.00	525.00	310.00	290.00		456.00	552.00	1020.00	1960.00	1280.00	858.00	605.00
31	764.00		300.00	290.00		448.00		1010.00		1260.00	834.00	
TOTAL	29602.00	18981.00	12319.00	9000.00	8510.00	10722.00	13696.00	25538.00	54940.00	49250.00	31325.00	20465.00
MEAN	954.90	632.70	397.39	290.32	303.93	345.87	456.53	823.81	1831.33	1588.71	1010.48	682.17
AC-FT	58714.71	37648.26	24434.38	17851.23	16879.33	21266.77	27165.61	50653.88	108971.90	97685.95	62132.23	40591.73

TOTAL ANNUAL FLOW IN ACRE-FEET = 563995.98

INSTANTANEOUS PEAK IN CFS = **

Total Annual Runoff (cfs) = 284,348.

** INDICATES MISSING DATA
* INDICATES COMPUTED FROM INCOMPLETE DATA
E INDICATES ESTIMATED VALUE

Table 1. Example of a typical printout of the streamflow data used to compile reference curves for each watershed. Daily discharge values (cfs) for area Y-1. Values were summed for periods preceeding each coverage cycle.

An image mask was constructed for each sub-area so that the region of interest could be isolated on each 1:1,000,000-scale Landsat scene (Fig. 1). Use of the image mask assures that the same area is evaluated on each successive Landsat scene. It also enables the interpreter to easily separate the sub-area to be evaluated from the surrounding areas with the electronic image analyzer.

The Spatial Data Systems model 70 image analyzer was used to make estimation of snowcovered areas more efficient (Fig. 2). This device allows the interpreter to color slice the image of the selected drainage area according to image grey tones (Fig. 3). The density analyzer is adjusted so that a selected color boundary corresponds to the snowline displayed on the image. An electronic planimeter then allows the interpreter to instantaneously estimate the area of basin and the area of snowcover.

Daily discharge volumes measured at appropriate gauge stations (obtained from the digital data base of the Wyoming Water Research Center) are summed to produce cumulative runoff values for dates corresponding to the dates of the Landsat imagery. The cumulative runoff values are plotted against snowcover and against time to yield curves representing the snowmelt/runoff pattern for the drainage area (Appendix A). Runoff versus time data are derived entirely from streamflow measurements and serve only as a guide to help define the snowcover/runoff relationship more accurately. Using the two curves together allows the interpreter to more accurately interpolate snowcover values between the widely spaced samples provided by Landsat images.

Figure 1. Landsat image of the Yellowstone area partially snowcovered and masked for automatic analysis.

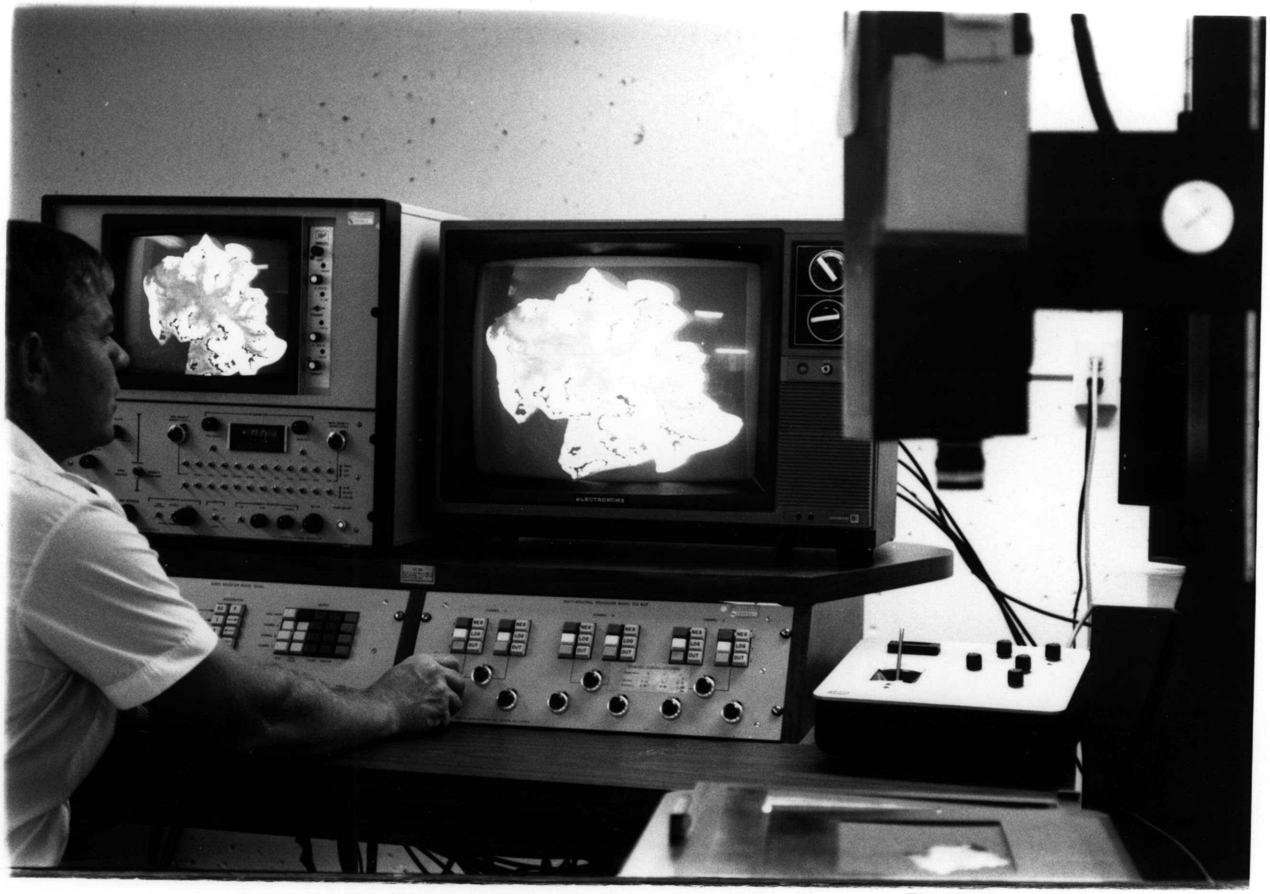


Figure 2. The Spatial Data Systems video image analyzer. The automatic planimeter option was used to quickly estimate the area of snowcover in each watershed for each date of satellite coverage.

Figure 3. Density-sliced version of an image area covering the Yellowstone Lake watershed (compare Fig. 1). The lightest areas are snowcovered.

Separate curves are generated for each season's data; then the curves are combined to produce a composite snowcover/runoff curve for each drainage area. The composite curve is constructed by inversely weighting each season's data relative to its deviation from the long-term average runoff. As a result, the composite curve presents the snowcover/runoff relationship expected for an average year. The composite curve is presented along with curves representing individual seasons so that runoff predictions can be made using the composite curve as a standard and using the individual season curves to adjust for observed conditions indicating unusually heavy or unusually light snowpack or other abnormal conditions.

For each drainage area, a brief discussion was prepared detailing the quality of the data used in constructing the standard curves, critical values determined in the analysis, and other important considerations with regard to interpretation of graphs.

One problem that critically affects analysis in a few areas is that of availability of streamflow data. Gauge stations have not been installed on some drainages; and, for some others, the streamflow data are available only for a few years or only during certain parts of the year. If no streamflow data are available, the snowcover information can provide only a relative estimate of expected runoff. Also, few gauging stations are ideally located for measuring the actual water that results from snowmelt. Often, the gauge stations are below dams or along heavily used portions of the drainage where flows are regulated in one fashion or another. The ideal gauge station for this application would be located along a major drainage, but above the region where large amounts of runoff are removed for storage, agriculture or other uses. The gauge station should, ideally, be located near the point where streams emerge from mountain canyons, so that it records only runoff that originates in that portion of the watershed where the snowpack accumulates. Thus, the recorded data would not be strongly influenced by water management or non-snow precipitation (such as thunderstorms) outside the area of snow accumulation. Some runoff curves used in this work were distorted by changes in flow rates that relate to water management practices or occasional spring storms that occurred during the snowmelt season. These distortions do not preclude the use of the data for correlation with snowcover estimates, but they do complicate the interpretation of the data. During seasons when such distortions are severe (especially during drought years), the accuracy of predictions is greatly diminished; and, in fact, if the distortions are very large, the data may not be adequate for defining a useful runoff/snowcover relationship.

A more severe problem is that of limited satellite coverage due to equipment failures or cloud cover. The 18-day cycle of Landsat satellites 1, 2, and 3 and the 16-day cycle of Landsats 4 and 5 are marginally adequate for runoff forecasts, even if every image acquired during the snowmelt season is cloud-free. Unfortunately, at least half of the imagery acquired during the snowmelt season in the Rocky Mountain region is not useable because of cloud cover. Cloud cover is not a critical limitation in constructing snowcover/runoff reference curves because fourteen years of almost continuous operation of Landsat satellites has produced several seasons of good, cloud-free coverage for most areas. These data can be used to define the reference relationships. But, if forecasts are to be made, the timeliness and availability of cloud-free images are critical, and the imagery should be available for each area every few days. The present Landsat system provides no possibility for solution of this latter problem, but several eventual solutions are possible with later systems.

1. The frequency of satellite data orbits could be increased to provide greater opportunity to image on cloud-free days. This could be accomplished by using more than one satellite in alternating orbit cycles or by using a pointable satellite imaging system (such as the planned SPOT satellite to be launched by the French).

2. Landsat data might be supplemented by images from geostationary weather satellites. The coverage provided by these systems has been used successfully for broad, regional snow surveys; and previous research suggests that it might be possible to effectively combine data from the geostationary satellites with the less frequent, but higher resolution data from Landsat.

3. Cloud-penetrating radar systems could be used instead of the visible and near-IR imaging systems carried by Landsat. Such systems would allow imaging at night and through cloud cover. Seasat and Space Shuttle radar systems have already demonstrated potential for an operational system with radar imaging capability.

One final consideration is that snowcover measurements can not be used to forecast runoff until the snowmelt season is already underway and the snowpack has begun to diminish. This limitation precludes very early projections of expected runoff and necessitates continued use of snow-course measurements and other methods that might provide early estimates of snowpack.

RUNOFF PREDICTIONS: 1985

Preliminary tests were designed to assess the predictive capability of the snowcover/runoff curves for several Wyoming watersheds. Very limited resources were available for conducting the tests; so a single image area was chosen that would cover several watersheds. The area chosen was that of Landsat path 39 row 30 (Landsat 1,2, and 3) covering portions of the Snake River, Wind River, and Green River drainage basins. This single Landsat image covers seven watersheds in which snowpack provides a major portion of the spring runoff. The areas covered are:

S-1, Buffalo Fork of the Snake River

G-1, Green River Bend

G-2, New Fork River

G-5, Big Sandy area

G-6, Little Sandy area

W-., Upper and Middle Wind River

W-2, Popo Agie and Little Wind River

A sequence of six Landsat scenes was obtained for this region spanning the period from 17 March to 21 June, 1985. The March 17 date preceded the beginning of measureable decrease in snowcover, so estimates of expected runoff could not be made until imagery was obtained for April 2 and later dates. With each successive date of coverage,the estimates of expected runoff and peak flow were modified by correlating the observed rate of snowpack depletion with the appropriate snowcover/runoff curve derived from data for previous years. Table 2 summarizes the predictions made for the 1985 snowmelt season. So far, we have been unable to obtain streamflow data for 1985, so we have not yet checked the accuracy of these predictions.

Table 2. Predictions of expected runoff and peak runoff values for the 1985 snowmelt season. These predictions are based entirely on estimates of snowcover derived from the 1985 Landsat images and interpreted using the curves derived from data accumulated during previous seasons.

Area	Date of Coverage	Percent Snowcover	Estimated Runoff	Estimated Peak Flow	Date of Peak Flow
S-1 Buffalo Fork	17 Mar	100%			
	2 Apr	100%			
	18 Apr	82%	123,395cfs	3,080cfs	June 9
	4 May	57%	101,361	2,600	June 8
	20 May	56%	130,482	3,230	June 9
	21 June	28%	126,230	3,140	June 9
(actual)					
G-1 Green River Bend	17 Mar	100%			
	2 Apr	100%			
	18 Apr	79%	144,712cfs	2,307cfs	June 13
	4 May	59%	146,277	2,314	June 14
	20 May	40%	124,650	2,214	June 13
	21 June	12%	90,387	1,983	?
(actual)					
G-2 New Fork	17 Mar	100%			
	2 Apr	92%	202,134cfs	3,638cfs	June 12
	18 Apr	34%	141,569	2,475	June 10
	4 May	28%	198,876	3,578	June 12
	20 May	19%	210,469	3,790	June 12
	21 June	6%	209,672	3,605	June 13
(actual)					
G-5 Big Sandy	17 Mar	100%			
	2 Apr	95%	22,396cfs	400cfs	June 2
	18 Apr	24%	17,881	316	June 5
	4 May	10-14%	17,690	313	June 5
	20 May	8%	18,071	319	June 5
	21 June	0%	18,642	329	June 5
(actual)					
G-6 Little Sandy	17 Mar	100%			
	2 Apr	100%			
	18 Apr	28%	3,500cfs	95cfs	June 9
	4 May	14%	3,866	100	June 9
	20 May	10%(max)	4,386	107	June 8
	21 June	2%	9,223	175	June 17
(actual)					

Table 2. (continued)

Area	Date of Coverage	Percent Snowcover	Estimated Runoff	Estimated Peak Flow	Date of Peak Flow
W-1 Upper & Middle	17 Mar	70%			
Wind River	2 Apr	61%	338,116cfs	3,504cfs	July 1 ?
	18 Apr	43%	246,863	2,666	June 6
	4 May	31%	241,975	2,614	June 6
	20 May	23%	246,863	2,666	June 6
	21 June	11%(max)	244,419	2,640	June 6
(actual)					
W-2 Popo Agie &	17 Mar	60%			
Little Wind	2 Apr	42.5%	113,341cfs	4,000cfs	June 9-10
	18 Apr	24%	113,341	4,000	June 9-10
	4 May	15%	106,257	3,750	June 9-10
	20 May	16%	141,676	5,000	June 9-10
	21 June	4%	80,958	2,857	June 9-10
(actual)					

CONCLUSION

The groundwork is now sufficiently complete and the accumulated data base is minimally adequate for operational application of this technique to water management in Wyoming. The techniques appear to be both effective and practical. Current and proposed tests will establish timeliness and reliability with which these new techniques can provide runoff estimates from satellite data. We are fast approaching the point where we must decide whether or not to implement the technique as a routine part of a statewide water management program. The commitment to use the Landsat estimation procedures in water management will involve data, equipment, and manpower; but the total cost should be very small relative to the potential gains to be realized through even the most modest improvement in runoff forecasts. Total cost for upgrading the data base (imagery and streamflow data), analyzing the data, and issuing forecasts of expected runoff each month during the snowmelt season should be on the order of $20,000-30,000 per year. The investment is certainly appropriate if even one mistake in water management can be averted due to improved forecasting capabilities.

REFERENCES

Barnes, J.C., Clinton, J.G., and Simmes, D.A., 1973, Use of satellite data for mapping snow cover in the western United States: in Anson, A., 1973, Symposium on management and utilization of remote sensing data, American Society of Photogrammetry, Falls Church, VA, pp. 166-176.

Brown, A.J., Hannaford, J.F. and Hall, R.L., 1979, Application of snowcovered area to runoff forecasting in selected basins of the Sierra Nevada, California: in Rango, A., and Peterson, R., 1979, Operational applications of satellite snowcover observations, NASA Conference Pub. 2116, pp. 185-200.

Dillard, J.P. and Orwig, C.E., 1979, Use of satellite data in runoff forecasting in the heavily-forested, cloud-covered Pacific Northwest: in Rango, A., and Peterson, R., 1980, Operational applications of satellite snowcover observations, NASA Conference Pub., 2116, pp. 127-150.

Hannaford, J.F., and Hall, R.L., 1979, Application of satellite imagery to hydrologic modeling snowmelt runoff in the southern Sierra Nevada: in Rango, A., and Peterson, R., 1979, Operational applications of satellite snowcover observations, NASA Conference Pub. 2116, pp. 201-222.

Katibah, E.F., 1975, Operational use of Landsat imagery for the estimation of snow areal extent: in Rango, A., 1975, Operational applications of satellite snowcover observations, NASA SP391, pp. 129-142.

Leaf, C.F., 1975, Applications of satellite snow cover in computerized short-term streamflow forecasting: in Rango, A., 1975, Operational applications of satellite snowcover observations, NASA SP-391, pp. 175-186.

Martinec, J., and Rango, A., 1979, Discharge forecasts in mountain basins based on satellite snow cover mapping: in Rango, A., and Peterson, R., 1979, Operational applications of satellite snowcover observations, NASA Conference Pub. 2116, pp. 223-238.

Moravec, G.F., and Danielson, J.A., 1979, A graphical method of stream run-off prediction from Landsat derived snowcover data for watersheds in the upper Rio Grande Basin of Colorado: in Rango, A., and Peterson, R., 1979, Operational applications of satellite snowcover observations, NASA Conference Pub. 2116, pp. 171-184.

Rango, A., 1975, Operational applications of satellite snowcover observations: NASA SP-391, Washington, D.C., 430 p.

APPENDIX A: SNOWCOVER/RUNOFF RELATIONSHIPS FOR EACH WYOMING WATERSHED

Forty-four drainage areas were selected for evaluation (Fig. A-1). These areas cover essentially all areas of Wyoming in which an annual snowpack accumulates in quantities sufficient to provide significant component of the spring runoff. Each area was evaluated individually and compared to adjacent areas to establish an expected (or average) relationship between diminishing snowcover and runoff augmented by snowmelt during the spring and summer months. The summary of information for each area includes average curves (if data were adequate to define an average) and snowcover/runoff curves for abnormally dry and abnormally wet seasons that reveal the manner in which the runoff pattern shifts with below- or above-normal snowpack. A brief discussion of the significant characteristics of each watershed, the data quality, and considerations made in the interpretation and analysis of each data set accompanies the charts. The charts and summary provide information that will enable a reasonable forecast of expected runoff to be made from the most current Landsat imagery if such imagery is acquired during the onset of the spring snowmelt. In many cases, the data may also assist in forecasting the expected peak and duration of snowmelt runoff.

New data should be added to the data set each year as Landsat continues to provide coverage. The new data may be used to refine the prediction relationships and improve the ability of the interpreters to accurately forecast runoff from snowmelt.

It is important to consider that these data can be used to greatest advantage in situations where they augment data gathered at appropriately located snowcourses. The technique is one that gives a regional perspective of the extent and continuity of the annual snowpack. It does not yield reliable estimates of the variations in runoff typically associated with fluctuations in snow-water content and local variations in snow depth. Snow-course measurements provide this type of information; so the two techniques should yield best results if used together.

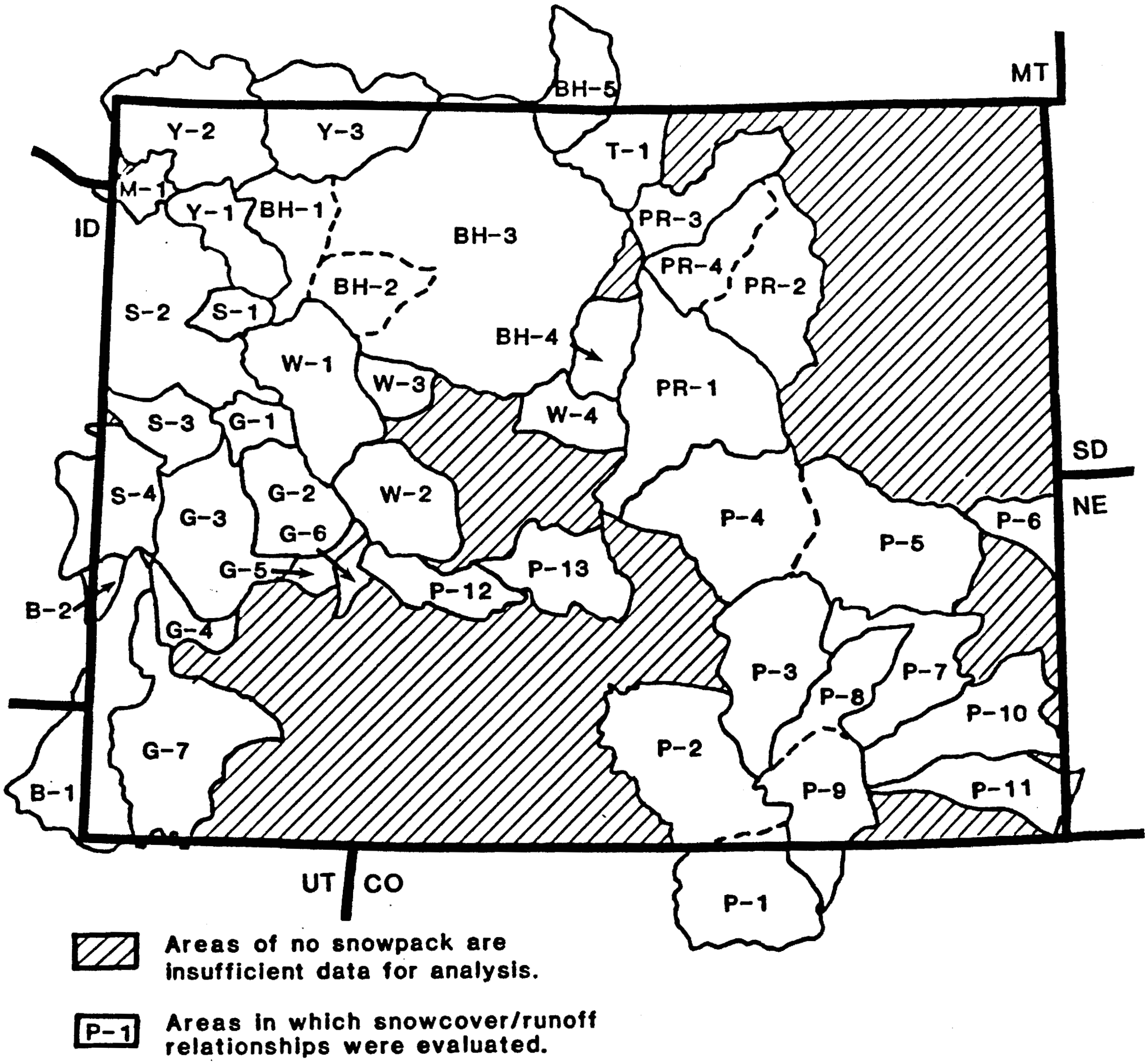


Figure A-1. Index of areas for which analysis of snowcover and runoff were made. Letters designate the major drainage in the region (i.e. BH=Big Horn River).

AREA Y-1

SNOWMELT AND RUNOFF PATTERNS: YELLOWSTONE LAKE DRAINAGE AREA

Landsat imagery for 1973 and 1977 were used to determine the snowmelt/runoff relationship for the Yellowstone Lake drainage. Four dates of coverage were available for each of these years, but the 1973 coverage is somewhat better distributed during the melt season, so the resulting curves developed for the 1973 season are considered more reliable. Streamflow data from station no 61865 on the Yellowstone River at the outlet from Yellowstone Lake were used to determine cumulative runoff values. The flow at this station should show essentially no influence of water management because the outflow from Yellowstone lake is not controlled. Flow data were available each day for the years evaluated.

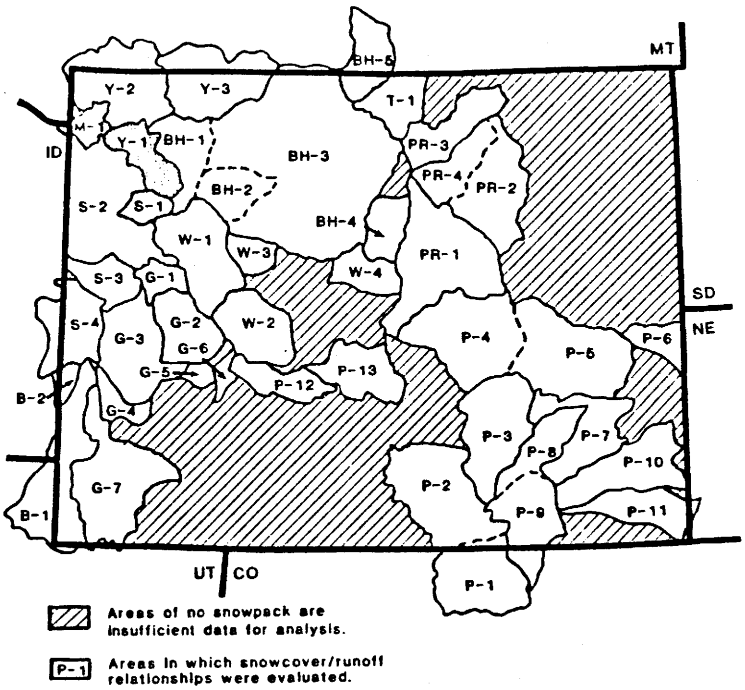
In both the 1973 and 1977 water years, the spring runoff doubles as snowmelt intensifies during the month of May (from approximately 500cfs to 1000cfs). The difference between an average flow rate in January, 1973 of 600cfs and in January, 1977 of 290cfs is probably due both to the extremely light accumulation of snow in 1977 and the perhaps, colder temperatures. Runoff from snowmelt usually begins early in May (between the 5th and 15th) after the snowpack area has diminished to 40-50% of the basin area. Peak runoff occurs in late June or early July (June 22 - July 13) with a strong tendency for larger peak runoff rates to occur at later dates. The 1977 water year shows extreme draught conditions in which peak flow occured on June 22 at only 2120cfs. 1973 was a more typical year with peak flow ocurring on July 1 at 3460cfs. Peak flows as high as high as 9120cfs (June 28-30, 1974) were recorded at this station during the eleven-year period used in this evaluation. A typical peak flow rate at this station would be about 5800cfs and should occur on July 4 or 5. The snowmelt should also peak at this time or just prior.

Discharge from the Yellowstone Lake drainage was below normal for both the 1973 and 1977 water years, but 1973 was only slightly below normal (433,447cfs in 1973 compared to the 11-year average of 475,370cfs). Consequently, we believe that the 1973 snowmelt curve is reasonably representative of the normal snowmelt pattern for this area. We might expect the snowmelt curve for a truly average year to be slightly steeper during the period of maximum snowmelt than the curve derived from the 1973 satellite data. The average snowmelt curve given is our best estimate of the configuration of the snowmelt vs. runoff curve for an "average" year.

The 1973 data suggest the water supplied from the melting of the snowpack represents about one third of the total discharge from the Yellowstone Lake drainage, yet peak flow rates can be increased by a factor of ten or twenty times during the relatively brief period of rapid snowmelt that occurs between late May and early August.

CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: May 10
Peak of runoff augmented by snowmelt: July 3
Snowmelt complete (no visible snow): August 1
Percent runoff provided by snowpack: 33%
Peak runoff volume (normal year): 5800 cfs
Guage number used in estimating runoff: #61865 at Yellowstone Lake outlet.


MT
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CO
Y-2
Y-3
BH-5
T-1
M-1
Y-1
BH-1
BH-3
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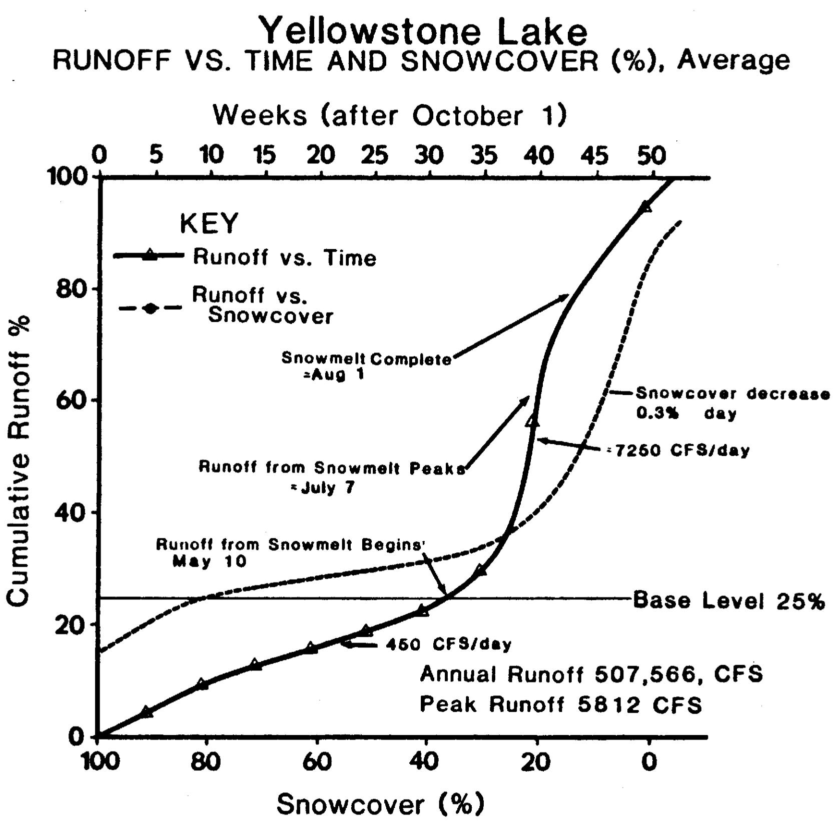
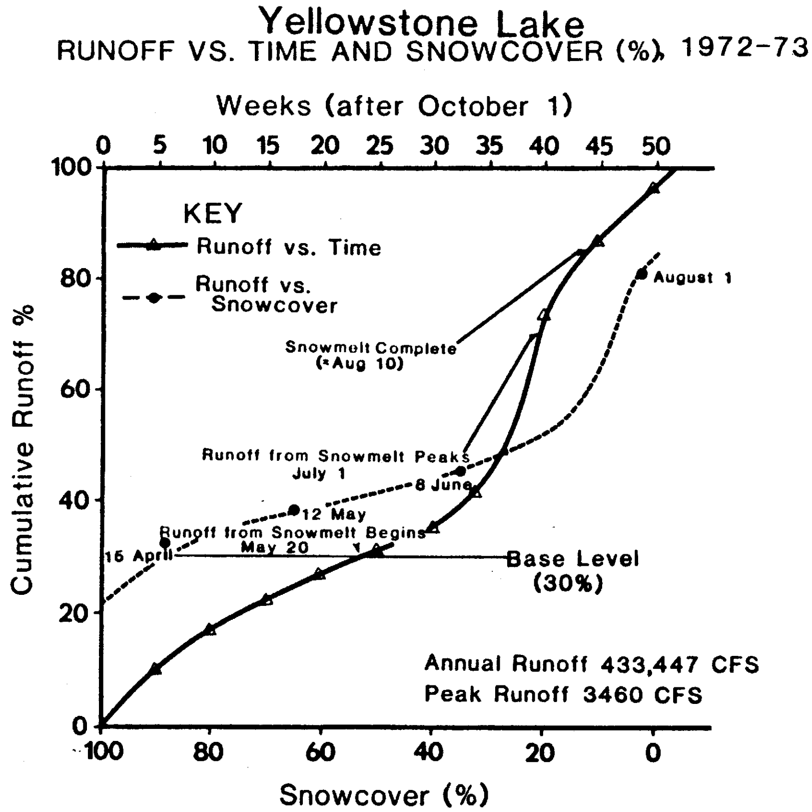
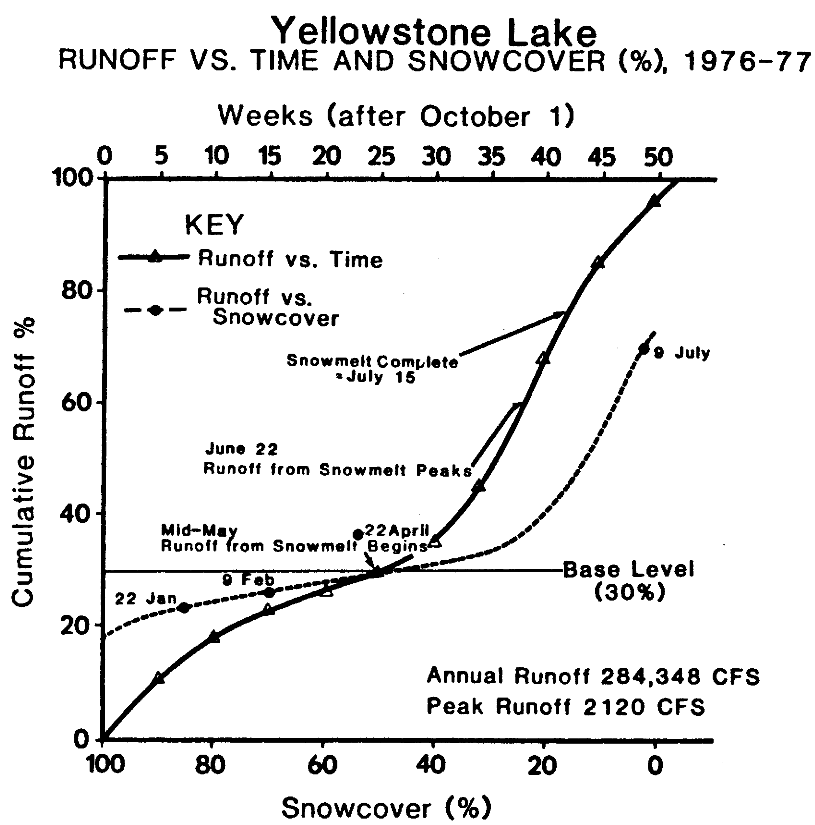
PR-4
PR-2
BH-2
S-2
S-1
BH-4
W-1
W-3
PR-1
W-4
S-3
G-1
S-4
G-3
G-2
W-2
P-4
P-5
P-6
G-6
G-5
P-13
P-12
B-2
G-4
P-3
P-8
P-7
P-10
G-7
P-2
B-1
P-9
P-11
P-1
Areas of no snowpack are insufficient data for analysis.
Areas in which snowcover/runoff relationships were evaluated.


Yellowstone Lake
RUNOFF VS. TIME AND SNOWCOVER (%), Average
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
Snowmelt Complete ≈Aug 1
Snowcover decrease 0.3% day
≈7250 CFS/day
Runoff from Snowmelt Peaks ≈July 7
Runoff from Snowmelt Begins May 10
Base Level 25%
450 CFS/day
Annual Runoff 507,566, CFS
Peak Runoff 5812 CFS
Cumulative Runoff %
100 80 60 40 20 0
Snowcover (%)


Yellowstone Lake
RUNOFF VS. TIME AND SNOWCOVER (%), 1972-73
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
August 1
Snowmelt Complete (≈Aug 10)
Runoff from Snowmelt Peaks July 1
8 June
12 May
Runoff from Snowmelt Begins May 20
15 April
Base Level (30%)
Annual Runoff 433,447 CFS
Peak Runoff 3460 CFS
100 80 60 40 20 0
Snowcover (%)


Yellowstone Lake
RUNOFF VS. TIME AND SNOWCOVER (%), 1976-77
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
Snowmelt Complete ≈July 15
9 July
June 22
Runoff from Snowmelt Peaks
Mid-May
Runoff from Snowmelt Begins
22April
9 Feb
22 Jan
Base Level (30%)
Annual Runoff 284,348 CFS
Peak Runoff 2120 CFS
100 80 60 40 20 0
Snowcover (%)

AREA Y-2

SNOWMELT AND RUNOFF PATTERNS: UPPER YELLOWSTONE RIVER (below Yellowstone Lake)

Landsat imagery for 1973 and 1977 was used to determine the snowmelt-runoff relationship for the upper Yellowstone River. Five dates of coverage are available for 1973 and 1977. Each data set is equally well distributed and, therefore, both the 1973 and 1977 snowmelt curves are equally reliable.

Discharge for 1973 was 14% below the 11-year average of 1,184,181 cfs, and represents a drier than normal year. This estimate of drier climate for 1973 is confirmed by a snow course at elevation of 7380 feet on the Yellowstone Plateau. In fact, the 14% below normal discharge of 1973 coincides exactly with the 14% below normal water equivalent of snow in the Lupine Creek Snow course. However, the Parker's Creek Snow course at an elevation of 9400 feet in the glaciated area of the Lamar River, shows 1973 to be 46% below the 20 year average water equivalent values.

For 1977, the water equivalent values in the Lupine Creek and Parker's Peak Snow courses also indicate two different climates. In the lower elevation Lupine Creek Snow course, 1977 is a drought year because the water equivalent values are only 29% of the 20 year average. However, the shape of the 1977 discharge curve is not the typical straight line curve characteristic of extreme drought in most areas.

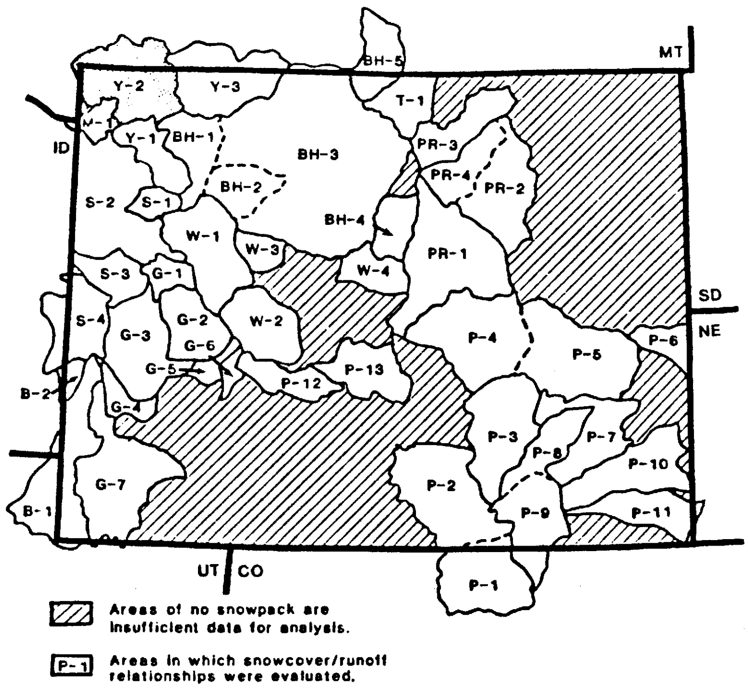
In the high elevation Parker's Peak Snow course, 1977 appears as a very dry year. This climate estimate is consistent with discharge values. Also, the slight degree of difference between water equivalents values for 1973 and 1977 in the Parker's Peak Snow course is consistent with the slight depression of base level between the 1973 and 1977 discharge curves.

Of course, it is possible that even extreme drought conditions in this drainage would not produce straight line discharge curves typical of other drainages. If this is true, then the above arguments regarding change in curve shape and correlation with water equivalent values are irrelevant.

The average discharge curve for this area was constructed by averaging the 11 years of discharge data for each month. The average snowmelt curve is our best guess. It is a modified 1973 snowmelt curve.

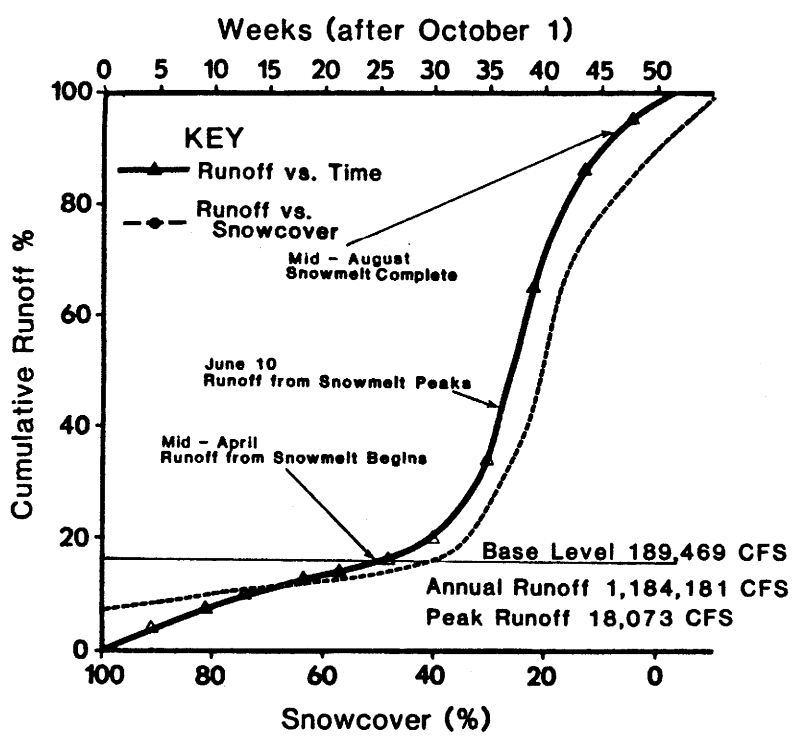
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: mid-April
Peak of runoff: June 10
Snowmelt complete (no visible snow): mid-August
Percent runoff provided by snowpack: 57% (?)
Peak runoff value (average): 18,073 cfs
Gauge Station used: #061915 Yellowstone River at Corwin Springs



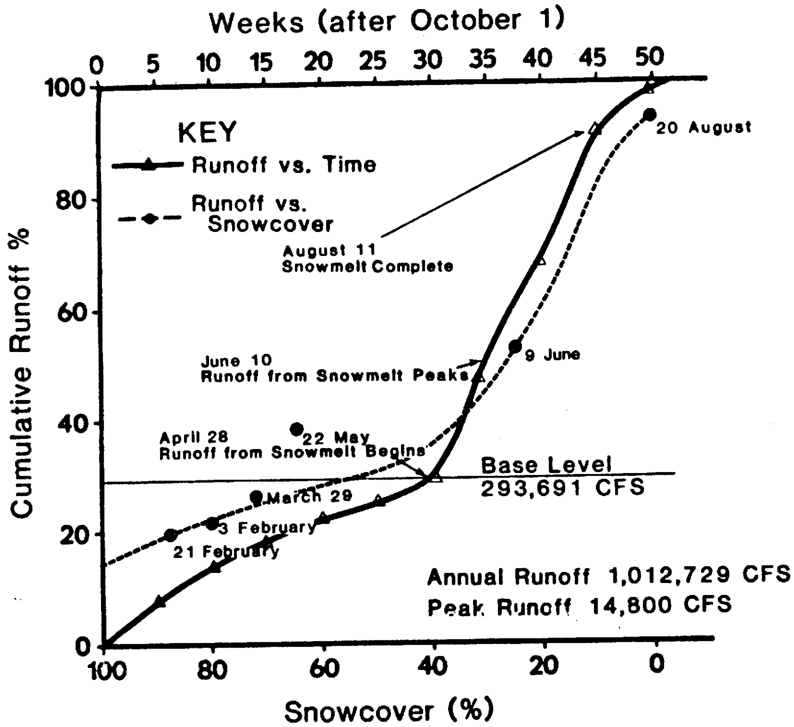
Yellowstone River

RUNOFF VS. TIME AND SNOWCOVER (%), Average



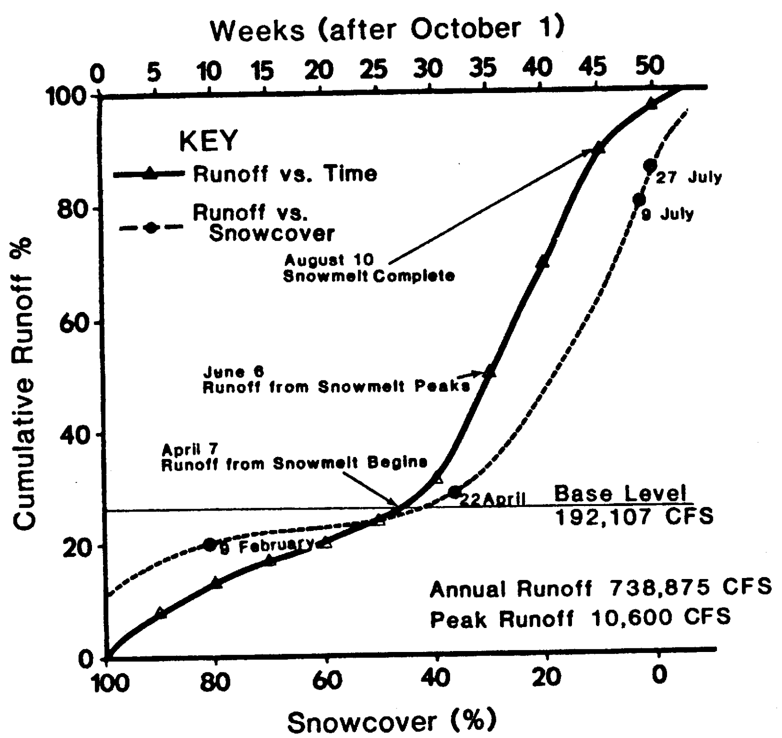
Yellowstone River

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)



Yellowstone River

RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)



AREA Y-3

SNOWMELT AND RUNOFF PATTERNS: CLARK'S FORK DRAINAGE AREA

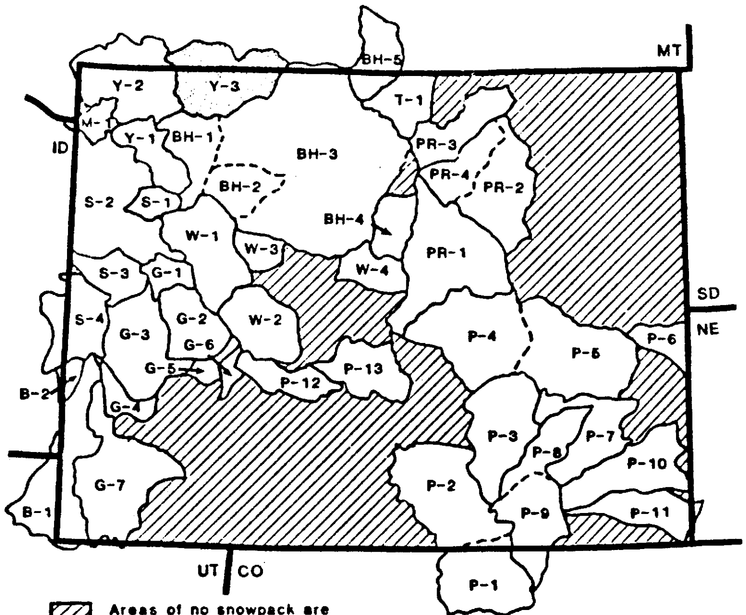
Satellite data from four different snowmelt seasons were used to determine snowmelt-runoff patterns for the Clark's Fork drainage in northwest Wyoming; but only a few dates of useful coverage were available for each of the four seasons. Of the four years' coverage, 1981 appears to best represent an average year. In the several years since Landsat was first launched (in 1972), average annual discharge at the Belfry, Montana gauge station has been 371,433 cfs. Discharge was below average for all four seasons for which useable satellite coverage was available (cloud cover was more frequent in wetter years). 1977 was a particularly dry year, so data for 1977 were not used in constructing the composite snowcover-runoff curve for the Clark's Fork drainage area.

Snowmelt usually begins in late April on the Clark's Fork and continues through the spring and summer months, ending in late August. Peak runoff varies greatly from year to year and is expected in early June (June 11). Annual runoff volume is highly dependent on the annual snowpack, with about 70% of the total discharge occurring during the May, June, July snowmelt season. The pattern of runoff is fairly consistent for the sample years, so the snowcover-runoff curves should provide reliable runoff forecasts. In the Clark's Fork area, cloud cover is a frequent problem in making estimates of snowcover from the Landsat imagery; so opportunity is limited for obtaining the critical April-May coverage needed for water-supply forecasts.

Snow course data do not correlate well with runoff. For example: 1981 has highest discharge of all charts; yet, according to snow course data, it was a dry year. 1979 shows below normal snowpack at high-elevation snow courses and above normal snowpack at low-elevation snow courses.

CRITICAL VALUES

Beginning of runoff from snowmelt: April 24
Peak of runoff augmented by snowmelt: June 11
Snowmelt complete (no visible snow remaining): August 27
Percent runoff expected from snowpack: 70%
Gauge station used in estimating runoff: #62075, Clark's Fork of the Yellowstone River near Belfry, Montana

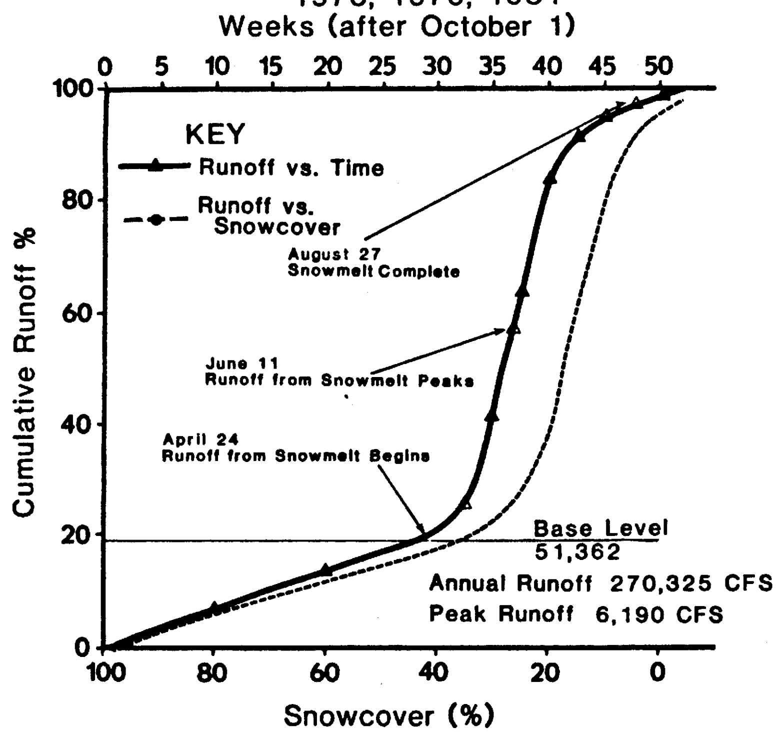


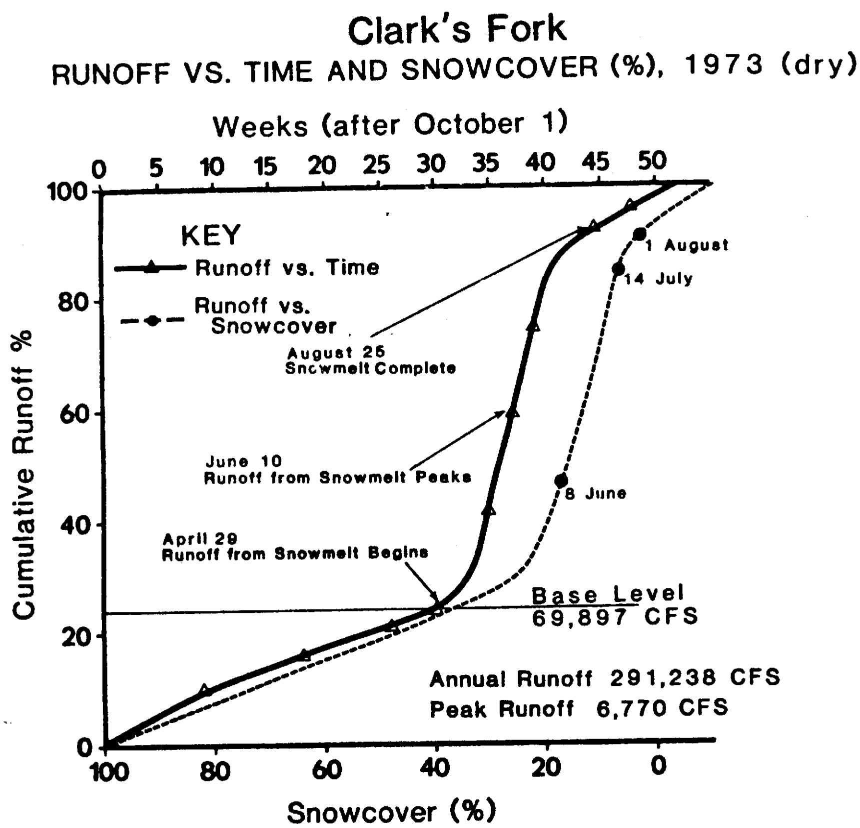
Areas of no snowpack are insufficient data for analysis.

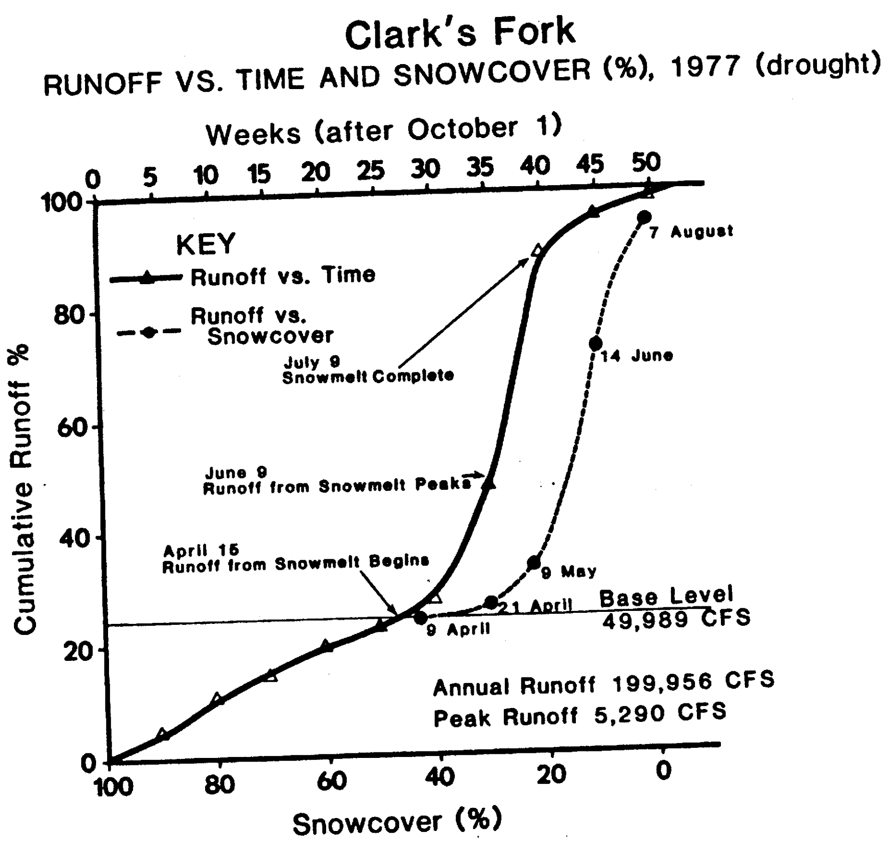
P-1 Areas in which snowcover/runoff relationships were evaluated.

Clark's Fork

RUNOFF VS. TIME AND SNOWCOVER (%), (composite)
1973, 1979, 1981

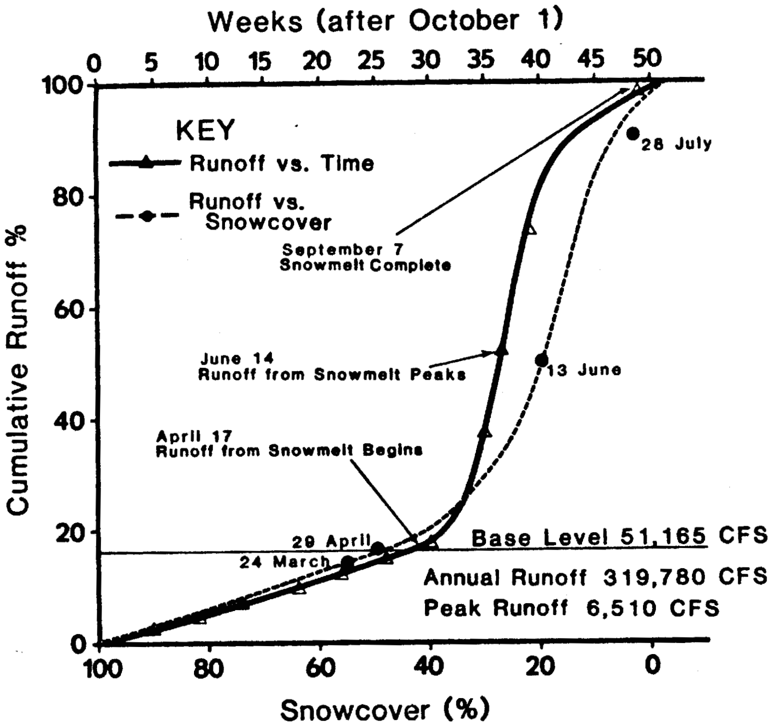



Clark's Fork
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
August 25
Snowmelt Complete
June 10
Runoff from Snowmelt Peaks
April 29
Runoff from Snowmelt Begins
1 August
14 July
8 June
Base Level
69,897 CFS
Annual Runoff 291,238 CFS
Peak Runoff 6,770 CFS
Cumulative Runoff %
Snowcover (%)


Clark's Fork
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
July 9
Snowmelt Complete
June 9
Runoff from Snowmelt Peaks
April 15
Runoff from Snowmelt Begins
7 August
14 June
9 May
21 April
9 April
Base Level
49,989 CFS
Annual Runoff 199,956 CFS
Peak Runoff 5,290 CFS
Cumulative Runoff %
Snowcover (%)

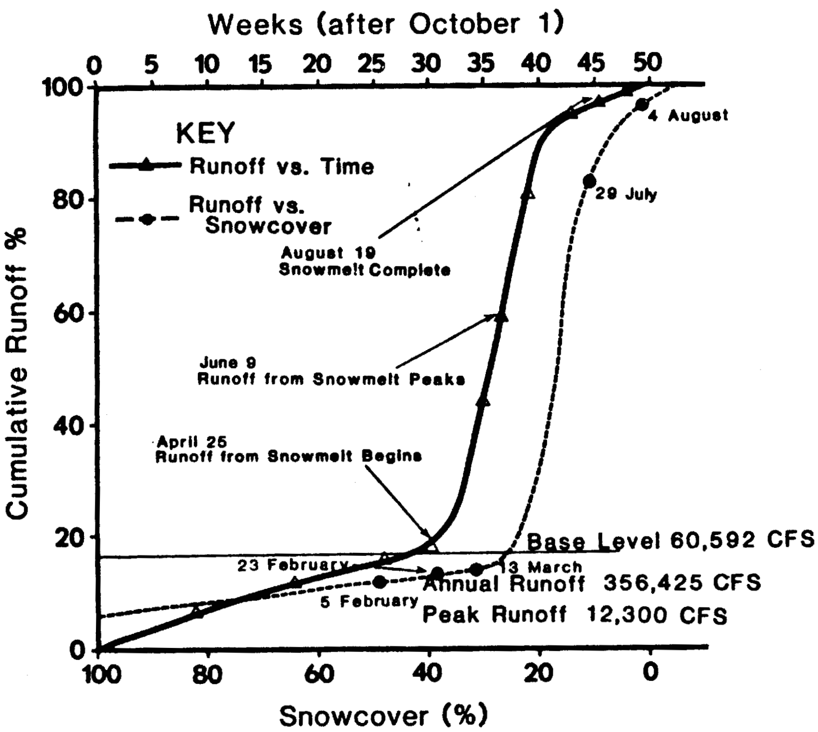
Clark's Fork

RUNOFF VS. TIME AND SNOWCOVER (%), 1979 (dry)



Clark's Fork

RUNOFF VS. TIME AND SNOWCOVER (%), 1981



SNOWMELT AND RUNOFF PATTERNS: MADISON RIVER DRAINAGE

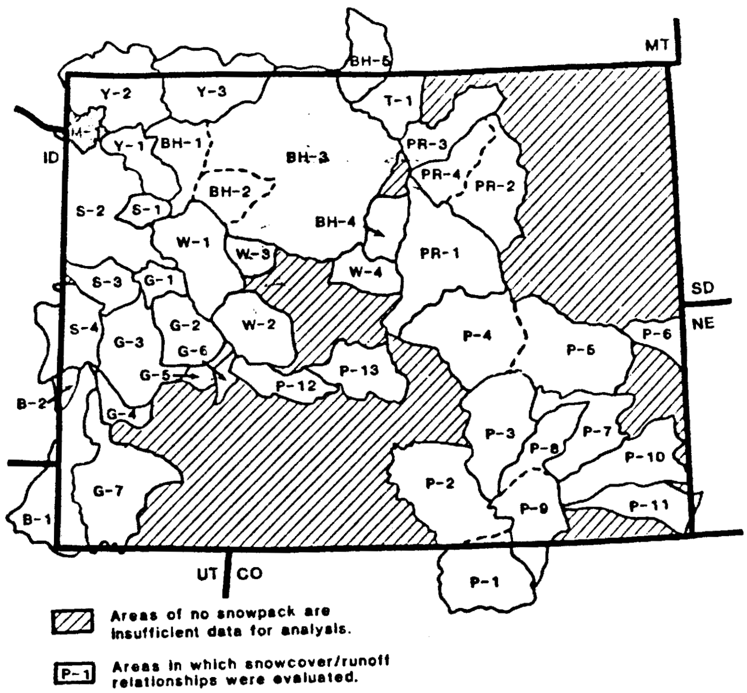
The data set for the Madison River drainage is severely limited because only two years of discharge data were available. Because Landsat data is only available for one of the two years of discharge data, we could only construct one snowmelt and runoff curve for this area. Also, the available Landsat data for the 1973 water year is not well distributed over the season of snowmelt. Therefore, the snowmelt-runoff curve for the Madison River drainage is a very preliminary one.

The nearly straight-line discharge curve for 1973 resembles the "drought" curves of 1977 for the Bear, Salt and Greys rivers. Yet, according to estimates of climate, based upon 11 year average discharge values and snow course data in adjacent areas, 1973 is drier than the average year, but not a drought. A snow course in the Madison river drainage confirms that the water content of the snow was 25% below the 20 year average during the winter snowmelt months (Jan-May).

Better snowmelt-runoff curves might be derived by using data from a gauge station further downstream in Montana. By enlarging the drainage area, snowmelt-runoff curves might be based upon more reliable data.

CRITICAL VALUES (based upon 1973 data only)

Beginning of runoff from snowmelt: May 6
Peak of runoff: May 21
Snowmelt complete (no visible snow): July 15
Percent of runoff provided by snowpack: 10%
Peak runoff volume: 1280 cfs
Gauge station used in estimating runoff: #060375 Madison River near West Yellowstone


MT
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PR-4
PR-2
BH-2
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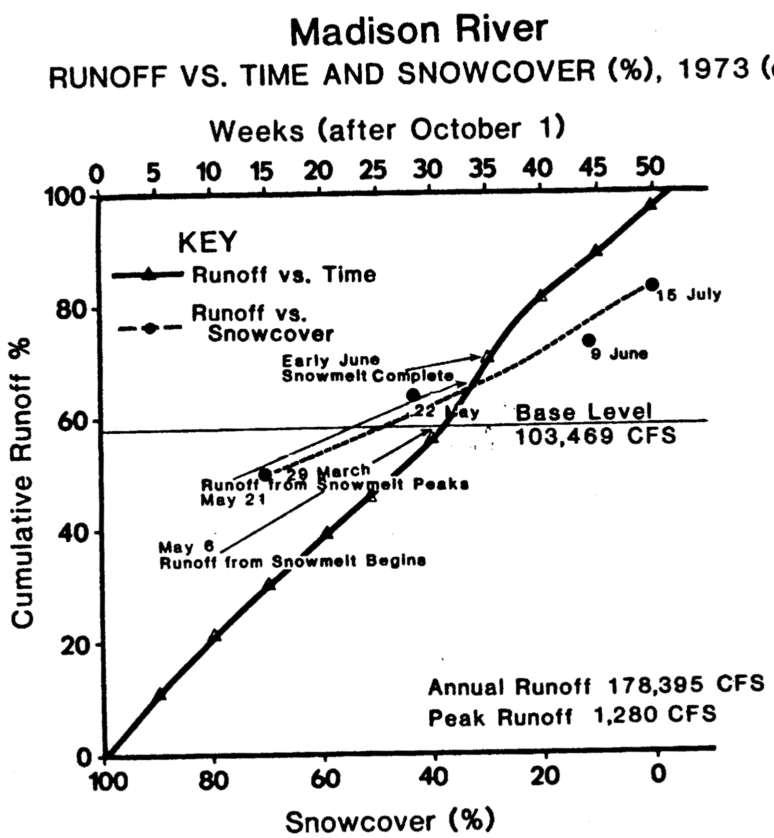
G-4
P-3
P-8
P-7
P-10
G-7
P-2
P-9
P-11
B-1
P-1
Areas of no snowpack are insufficient data for analysis.
Areas in which snowcover/runoff relationships were evaluated.


Madison River
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
Cumulative Runoff %
100
80
60
40
20
0
15 July
9 June
Early June Snowmelt Complete
22 May
Base Level 103,469 CFS
29 March
Runoff from Snowmelt Peaks May 21
May 6 Runoff from Snowmelt Begins
Annual Runoff 178,395 CFS
Peak Runoff 1,280 CFS
100 80 60 40 20 0
Snowcover (%)

AREA S-1

SNOWMELT AND RUNOFF PATTERNS: BUFFALO FORK OF SNAKE RIVER

Landsat imagery for 1973, 1977 and 1978 were used to determine the snowmelt-runoff relationship for the Buffalo Fork of the Snake River. The dates of coverage are well-distributed over the season of snowmelt for all three years. Because each year represents a different climatic regime, we have been able to confidently define the snowmelt-runoff relationship in this drainage for a dry year, wet year and drought year.

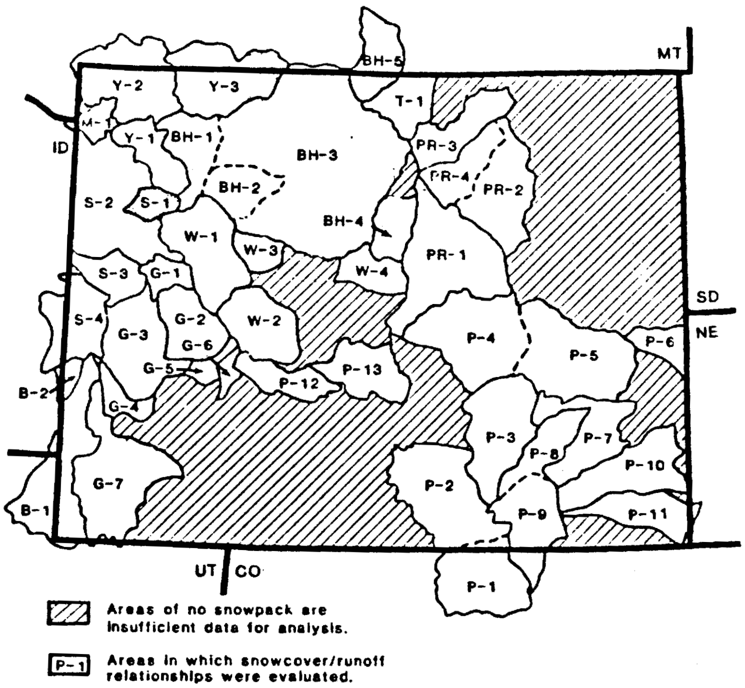
Consequently, the average snowmelt-runoff relationship was easily computed by averaging the 1973 (dry season) and 1978 (wet season) graphs. The 1972-82 average annual flow of 205,154 cfs is within five percent of the averaged 1973 and 1978 values. In a "normal" year, snowmelt begins in late April, peaks in mid-June and ends in July. The discharge recorded during the period of peak snowmelt is substantially augmented by rains. The range of snowmelt peaks varies between 2700 and 5900 cfs in the 11 year period from 1972-82. Timing of runoff peaks and the range of values are fairly consistent in this drainage area.

Discharge values should correlate best with the water-equivalent snow course data from the Blackrock site; but estimates of expected runoff from snowcover data do not correlate well with estimates based upon water equivalent content of snow at the Blackrock snowcourse. The lower Yount's Peak yields water equivalent values indicating that 1973 is much drier than 1977 and is contradictory to all regional estimates of climate.

A similar disparity between discharge and water equivalent data was noted in the Upper Yellowstone River drainage. The chosen sites in both the Yellowstone River and Buffalo Fork drainages were at different elevations. Our best correlation of discharge and water equivalent values should occur at higher elevation sites because the permanent snowpack is the dominant factor at higher elevations.

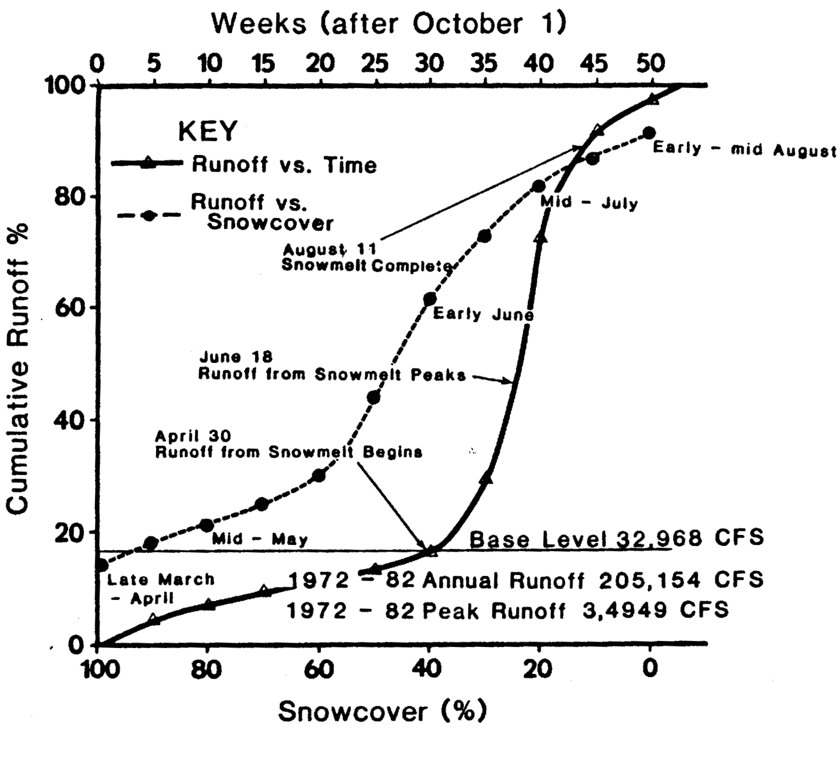
CRITICAL VALUES (for a normal year):

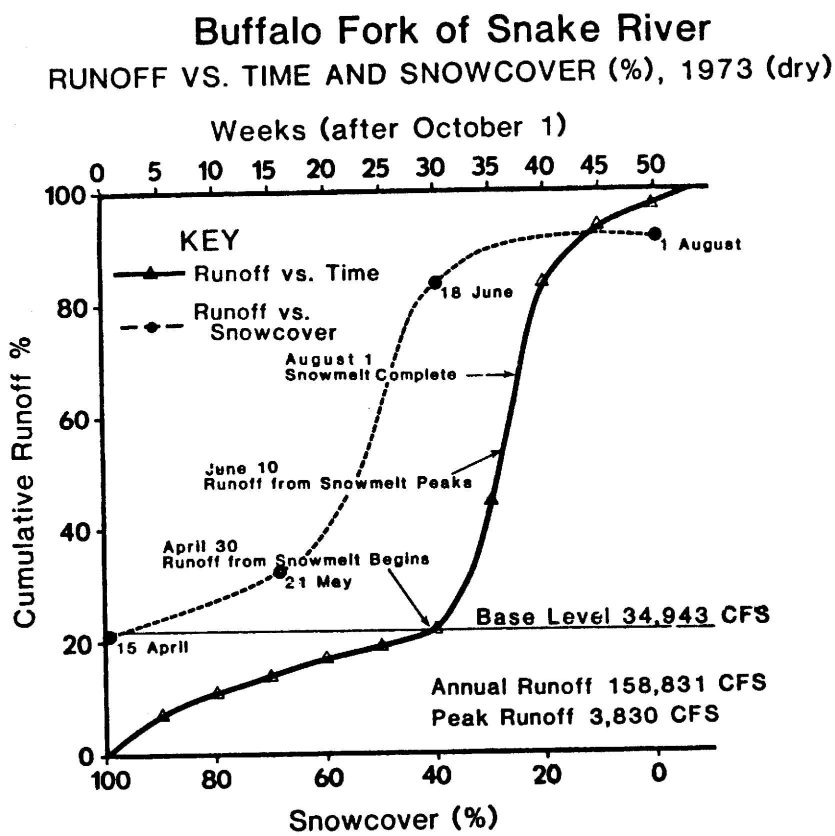
Beginning of runoff from snowmelt: April 30
Peak of runoff (augmented by rains?): June 18
Snowmelt complete (no visible snow): August 4
Percent of runoff provided by snowpack: 57% (approximately)
Peak runoff volume (normal year): 3949 cfs
Gauge station used in estimating runoff: #130119 Buffalo Fork above Lava Creek, near Moran

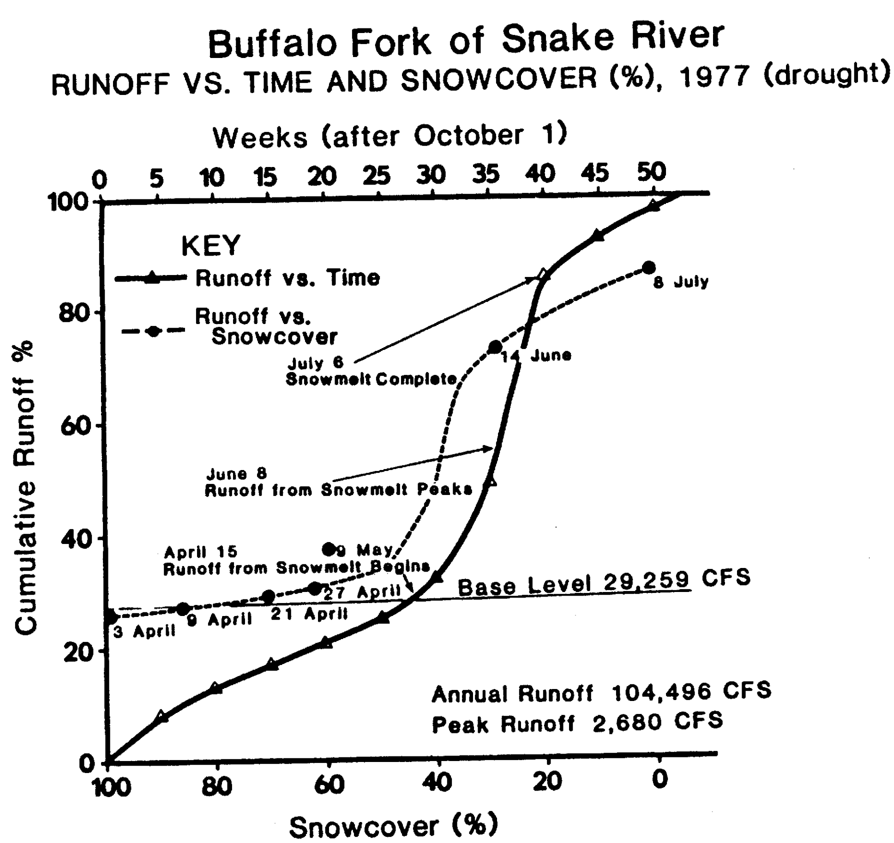


Buffalo Fork of Snake River

RUNOFF VS. TIME AND SNOWCOVER (%), Average

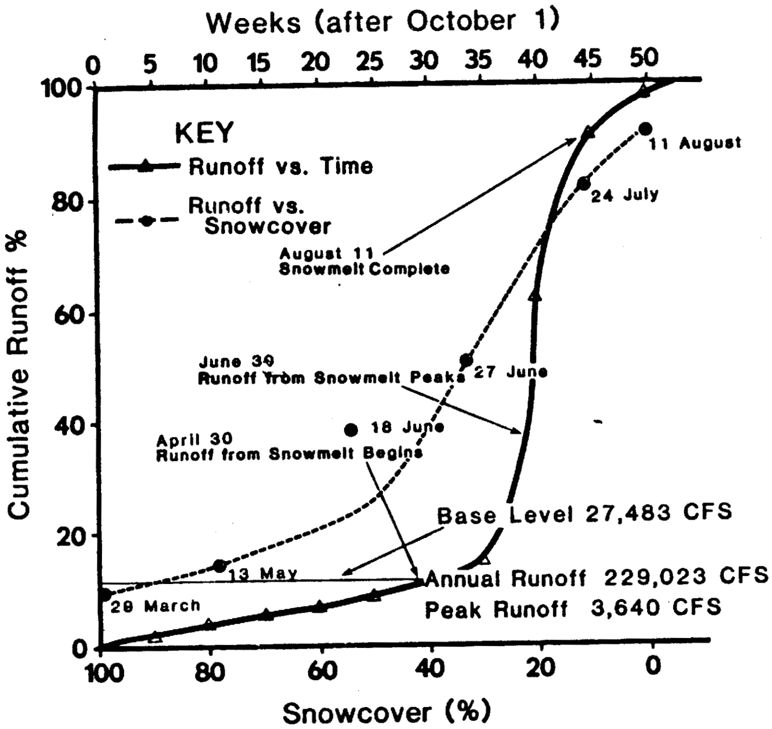



Buffalo Fork of Snake River
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
18 June
1 August
August 1
Snowmelt Complete
June 10
Runoff from Snowmelt Peaks
April 30
Runoff from Snowmelt Begins
21 May
15 April
Base Level 34,943 CFS
Annual Runoff 158,831 CFS
Peak Runoff 3,830 CFS
100 80 60 40 20 0
Snowcover (%)


Buffalo Fork of Snake River
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
8 July
July 6
Snowmelt Complete
14 June
June 8
Runoff from Snowmelt Peaks
April 15
Runoff from Snowmelt Begins
9 May
27 April
3 April
9 April
21 April
Base Level 29,259 CFS
Annual Runoff 104,496 CFS
Peak Runoff 2,680 CFS
100 80 60 40 20 0
Snowcover (%)

Buffalo Fork of Snake River

RUNOFF VS. TIME AND SNOWCOVER (%), 1978 (wet)



AREA S-2

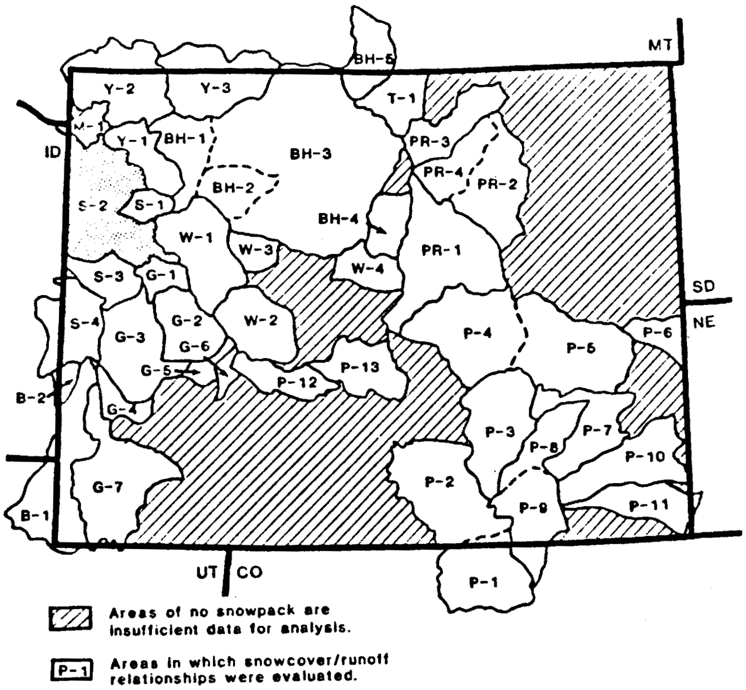
SNOWMELT AND RUNOFF PATTERNS: UPPER SNAKE RIVER

Unfortunately, Landsat imagery was available only for 1977 (a dry year). The seven dates of available coverage are well-distributed throughout the season, but one year of snowcover and discharge data cannot adequately define the snowmelt-runoff relationship for an area. Drainages containing 3 years or more of well-distributed coverage and complete discharge data are the ones that best define the snowmelt-runoff relationship. Therefore, it is best to use the 1977 curves for the Upper Snake River in conjunction with yearly curves for the Buffalo Fork of the Snake to approximate the snowmelt-runoff relationship for the drainage of the Upper Snake. The well-defined variations in snowfall and runoff for the Buffalo Fork of the Snake River should most closely match those of the Upper Snake. (See discussion of regional climatic variations in the Buffalo Fork area for the 1972-82 period)

The seven years of complete discharge data allowed the determination of average annual flow (1,168,063 cfs), the average peak flow (11,730 cfs) and the construction of an average discharge curve for the Upper Snake River. On the average, snowmelt appears to begin gradually in April and to end in mid-July. The average time of peak snowmelt is mid-June. Peak flows range from approximately 10,000 to 15,000 cfs. Thus, the pattern of flow vs. time for the Upper Snake River is very similar to that of the Buffalo Fork of the Snake.

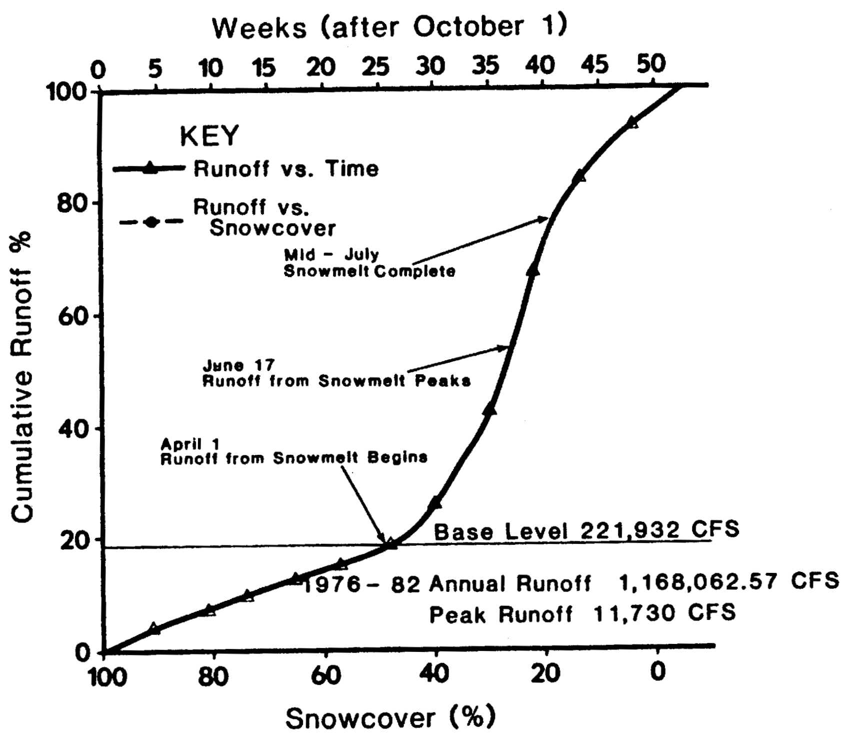
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: mid-April
Peak of runoff augmented by snowmelt: mid-June
Snowmelt complete (no visible snow): late July
Percent runoff provided by snowpack: 49% (approximate)
Peak runoff volume (normal year): 11,730 cfs
Gauge stations used in estimating runoff: #130110 (South Fork) Snake River at Moran, less flow values measured at station #130187.5 Snake River below Flat Creek near Jackson



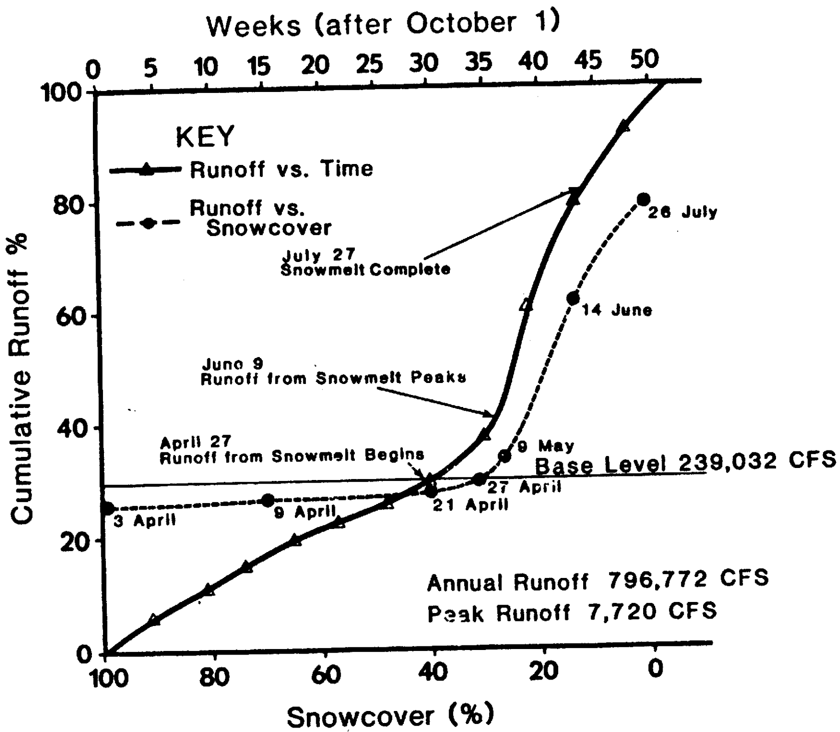
Upper Snake River

RUNOFF VS. TIME AND SNOWCOVER (%), Average



Upper Snake River

RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)



AREA S-3

SNOWMELT AND RUNOFF PATTERNS: HOBACK RIVER

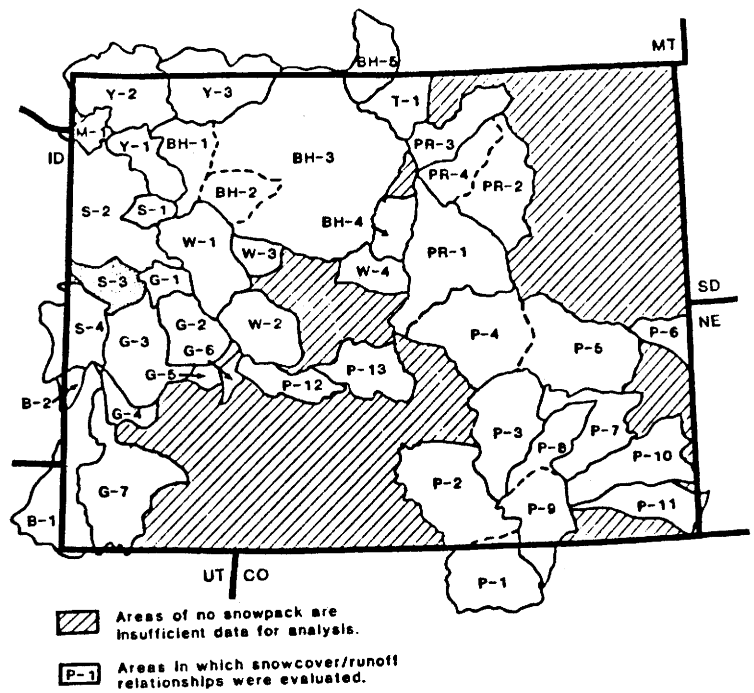
Landsat images for 1973, 1977 and 1978 were used to determine the snowmelt pattern in the drainage area of the Hoback River. Seven or eight dates of coverage are well-distributed through the season of snow accumulation and snowmelt for each of the three water years.

The annual discharge measured in 1978 is approximately normal, so we expect that the snowmelt pattern for 1978 was also near normal. Snow course measurements show the water equivalent of snowpack for 1978 to be about normal or slightly greater than normal. The 1973 and 1977 water years were dry years. Both the average discharge values and water equivalent snowpack data confirm these lower than normal snowpack estimates.

If 1978 is considered as a normal year, then, on the average, snowmelt should begin in late March, should peak about June 10, and end in early July. For the 11 water years of record (1972-82) the peak volume of runoff ranges from 11,000 to 29,000 cfs. Snowmelt generally peaks in early June.

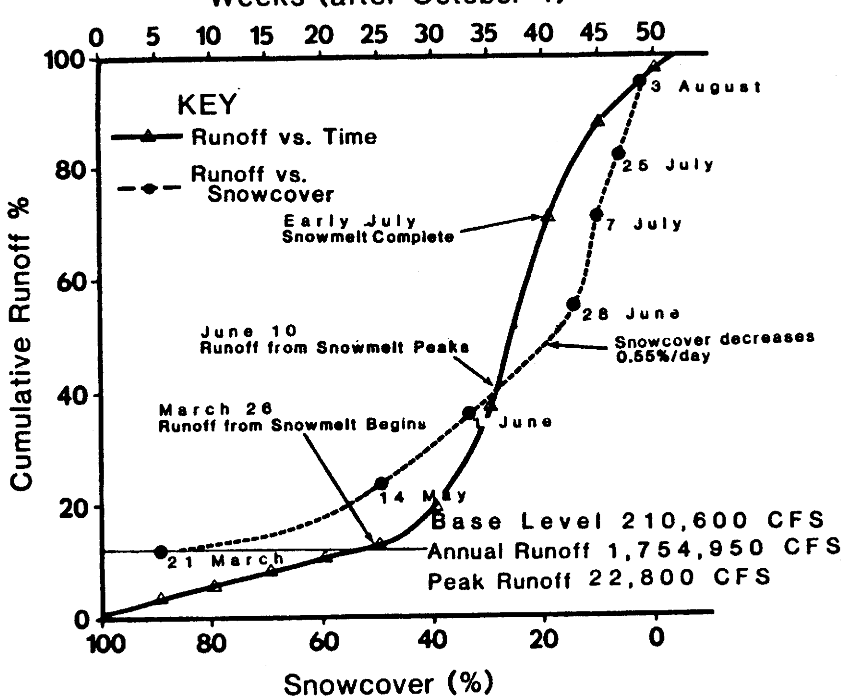
CRITICAL VALUES (normal year):

Beginning of runoff from snowmelt: March 26
Peak of runoff augmented by snowmelt: June 10
Snowmelt complete (no measureable snow): July 4
Percent runoff provided by snowpack: 58%
Peak runoff volume: 20,246 cfs
Gauge station used in estimating runoff: #130225 Snake River above Greys Reservoir, near Alpine



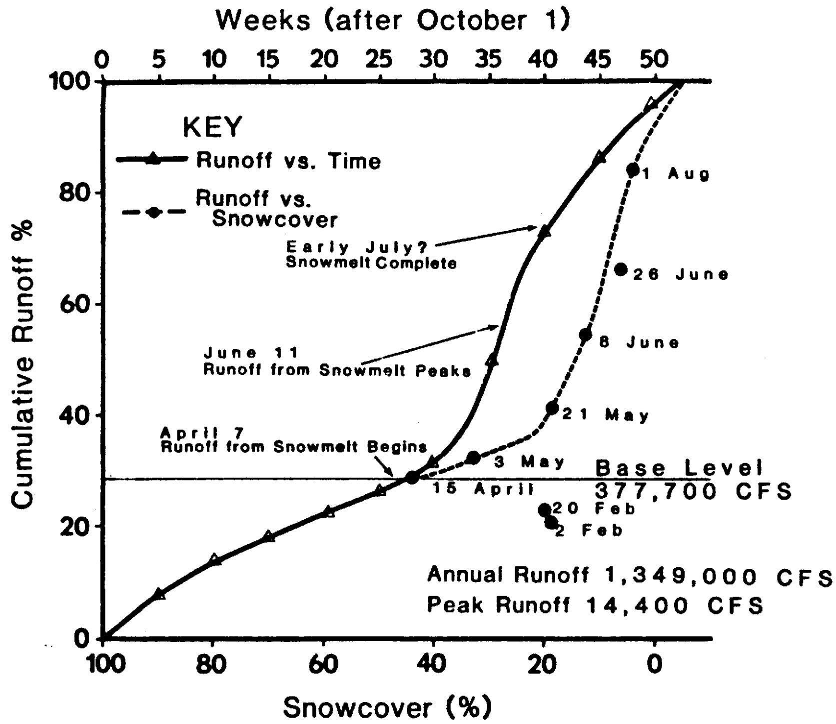
Hoback River

RUNOFF VS. TIME AND SNOWCOVER (%), 1978 (average)



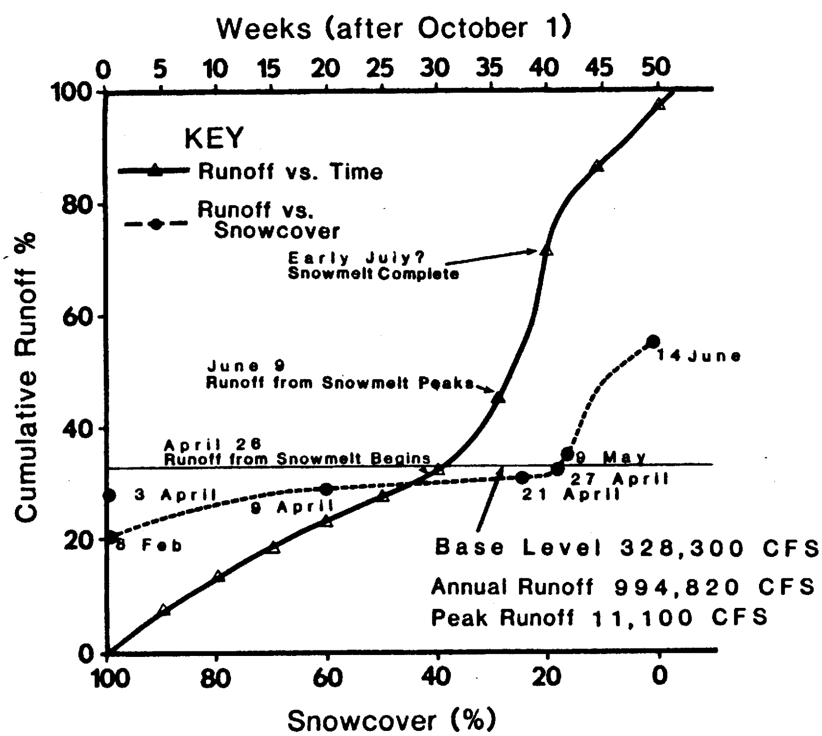
Hoback River

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)



Hoback River

RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)



AREA S-4

SNOWMELT AND RUNOFF PATTERNS: SALT AND GREYS RIVERS

Landsat imagery for the 1973, 1977 and 1978 water years was used to determine the snowmelt-runoff relationship for the Salt and Greys Rivers. Only four dates of coverage were available for 1973. The snowmelt curve derived from these data is not as reliable as the 1977 or 1978 snowmelt patterns because of the lack of adequate coverage during the time of snowmelt. In contrast, both the 1977 and 1978 snowmelt curves were derived from seven dates of coverage that were well-distributed through the season of snowmelt.

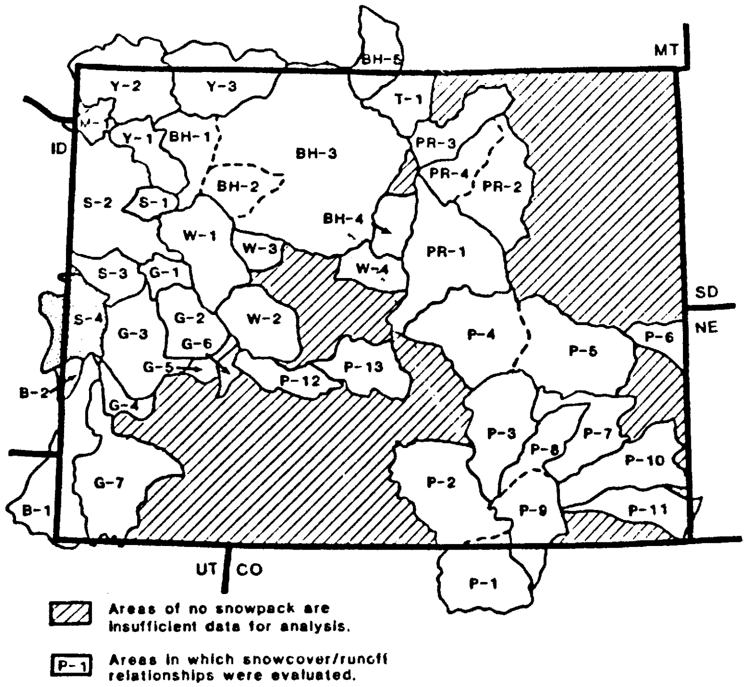
The average discharge values for the Greys and Salt Rivers correlate well with the average water equivalent snowpack data from snow courses. However, the 1973 water equivalent values for the Salt River do not agree with the dry year estimate based upon discharge values. The average to above average snow-course measurements for the Salt River in 1973 contrast with the below average measurements for the Greys River. It is possible that the Salt River experienced average to above average snowfall while snowfall in the Greys River drainage was below average. The net effect when the discharge from the Salt and Greys are combined is a slightly below normal water year for 1973.

The average snowmelt-runoff curve was derived by combining the dry year data of 1973 with the wet year curve of 1978. We expect that this average snowmelt-runoff relationship approximates a normal year because the averaged 1973 and 1978 discharge is actually 3% above the 1972-82 average annual discharge of 276,280 cfs.

The peak discharge normally occurs in late May. Peak flow is normally between 1500 to 3800 cfs. The 1972-82 average peak flow is 2600 cfs.

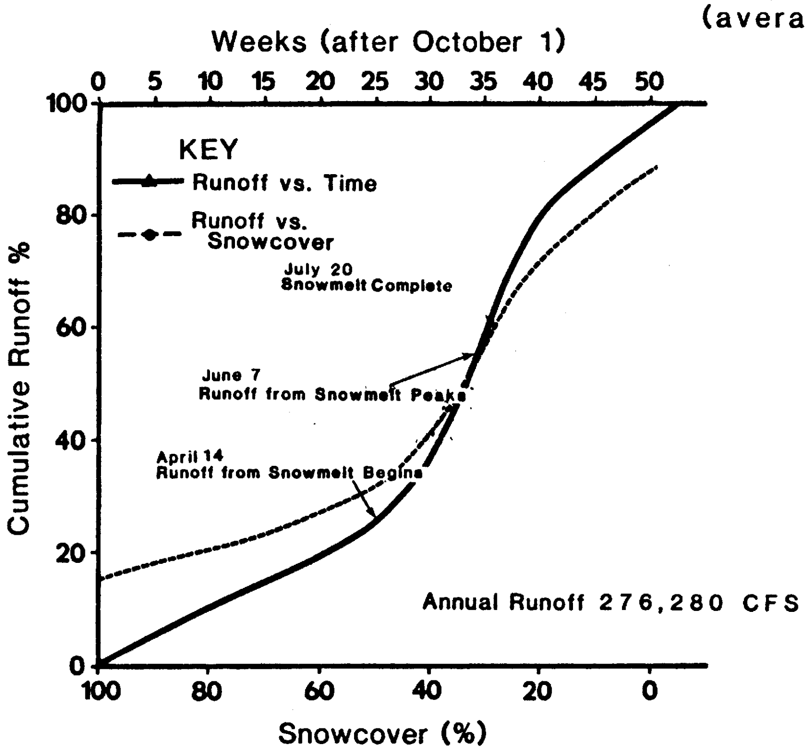
CRITICAL VALUES (normal year):

Beginning of runoff from snowmelt: April 15
Peak of runoff augmented by snowmelt: May 23-June 21
Snowmelt complete (no measureable snow): August 2
Percent runoff provided by snowpack: 50%
Peak runoff volume (normal year): 2600 cfs
Gauge stations used in estimating runoff:
#130275 Salt River above reservoir near Elna
#130230 Greys River above reservoir near Alpine

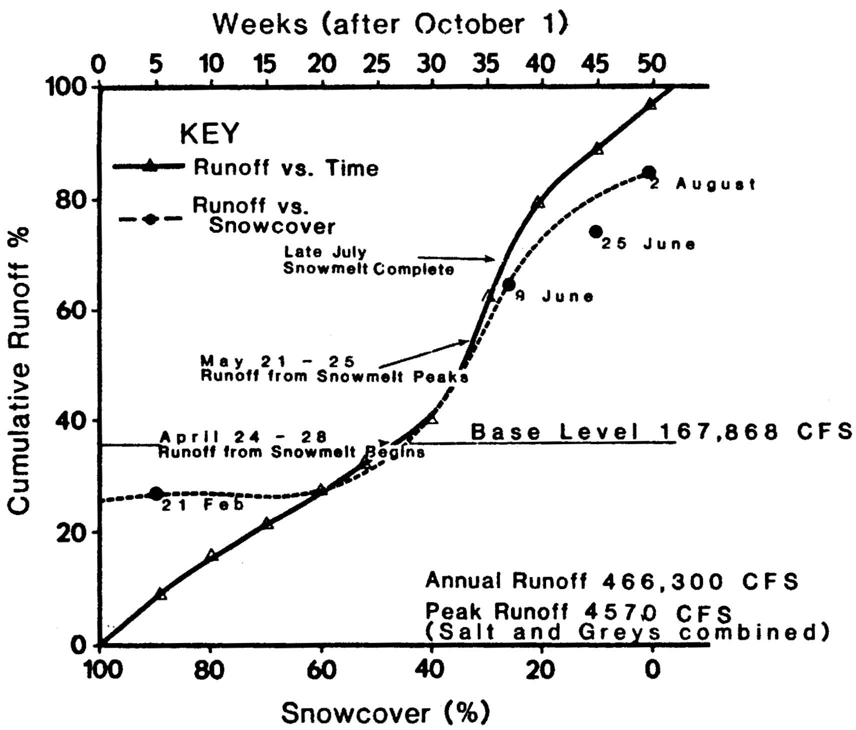


Salt and Greys Rivers

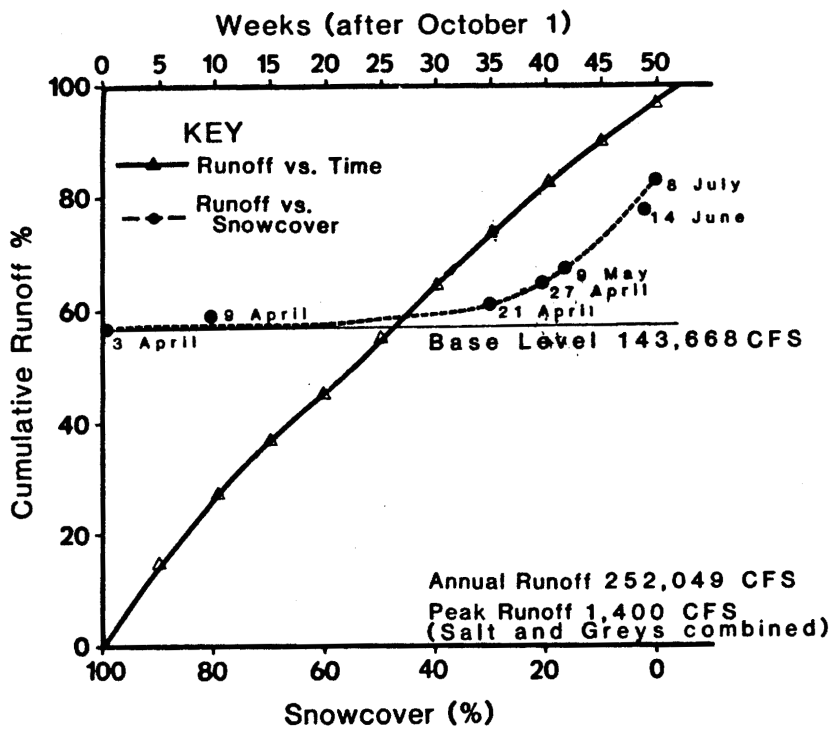
RUNOFF VS. TIME AND SNOWCOVER (%), 1973, 1978 (averaged)

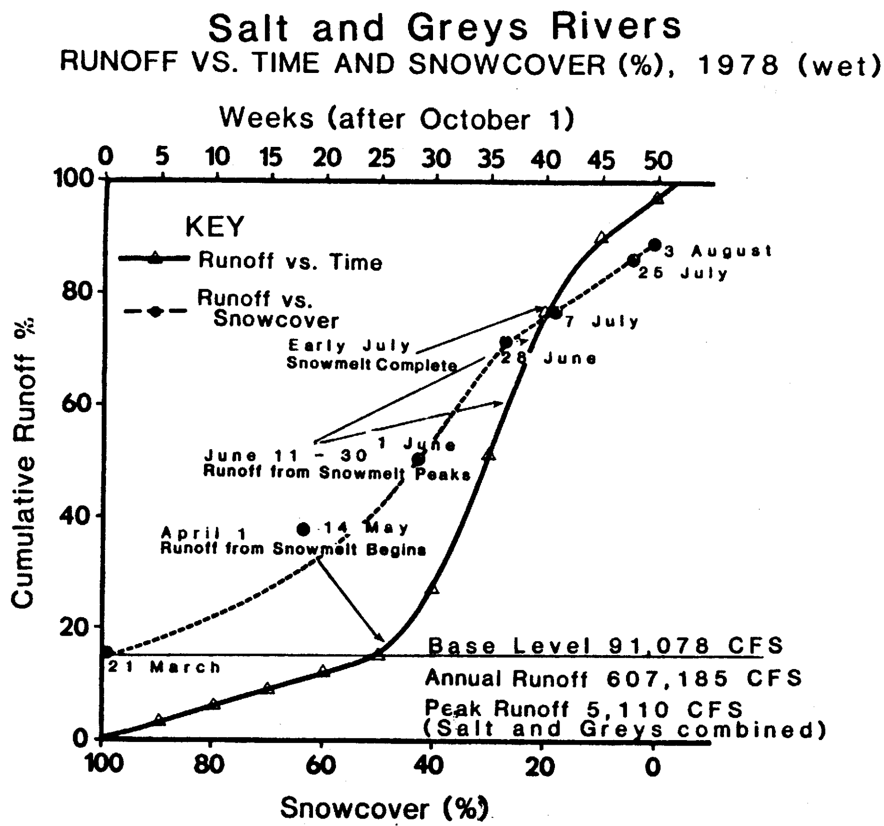


Salt and Greys Rivers
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)



Salt and Greys Rivers
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)





Salt and Greys Rivers
RUNOFF VS. TIME AND SNOWCOVER (%), 1978 (wet)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
3 August
25 July
7 July
Early July Snowmelt Complete
28 June
1 June
June 11 - 30 Runoff from Snowmelt Peaks
14 May
April 1 Runoff from Snowmelt Begins
21 March
Base Level 91,078 CFS
Annual Runoff 607,185 CFS
Peak Runoff 5,110 CFS
(Salt and Greys combined)
100 80 60 40 20 0
Snowcover (%)

AREA B-1

SNOWMELT AND RUNOFF PATTERNS: NORTH AND SOUTH FORKS OF BEAR RIVER

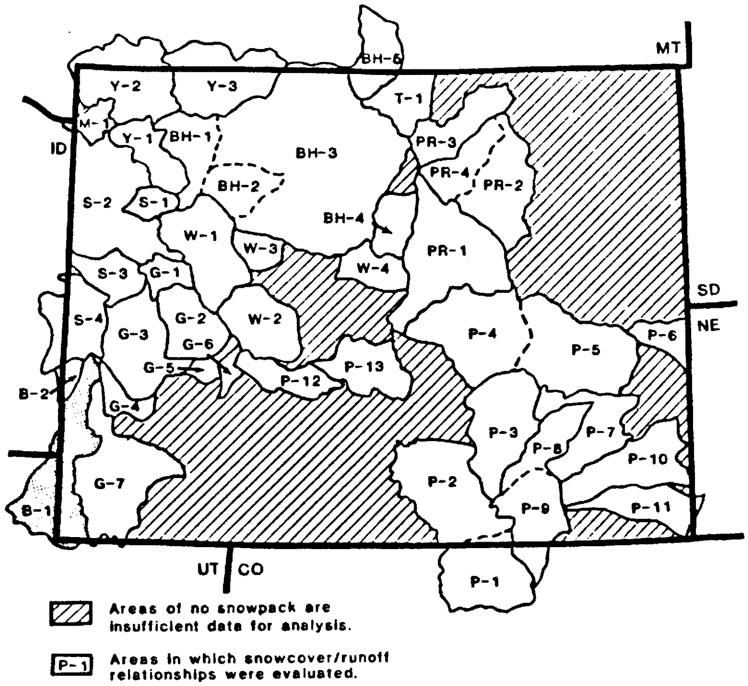
Landsat imagery for the water years 1973 and 1977 were used to assess the snowmelt pattern in the Bear River drainage. The four dates of coverage available for 1973 enable the construction of a fairly reliable average curve. 1973 was a year of near normal discharge in the Bear River drainage, and the 1973 snowmelt pattern is considered fairly representative of a normal year. Snowcover on four of the five dates of coverage for 1977 reveal the unusually low snow accumulation for this drought year. The April 3 date for 1977 probably represents a spring storm which offered a temporary break in the drought pattern, but did not significantly increase the snowpack. Thus, the 1977 snowmelt curve honors the data from the February 8, April 9, April 21, and May 15 coverage dates and is considered representative of the snowmelt pattern for a very dry year.

No snow course data is available for this drainage or the adjacent Black's Fork drainage. Therefore, we must rely on runoff estimates from discharge and snowcover values.

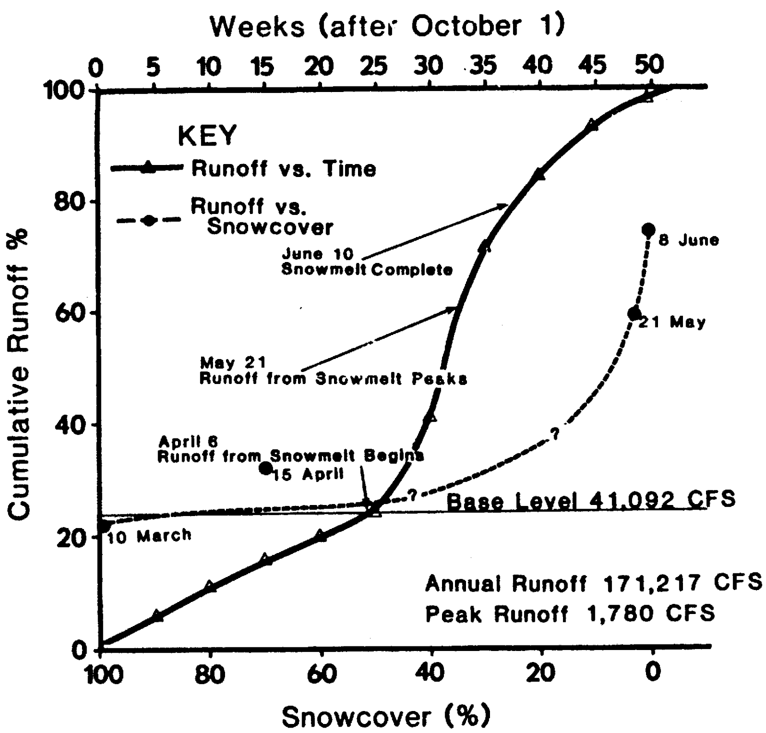
Drastic changes in shapes of curves were noticed between near normal and drought years in this drainage as well as the Thomas Fork and Salt River areas. The change from the normal S-shaped curve to the almost straight line curve of a drought year is probably most pronounced in southeast Wyoming where the drought was most severe (North and South Bear River, 78% less than average; Salt River area, 61% less than average; Thomas Fork of Bear River, 79% less than average).

CRITICAL VALUES (for a normal year):

Beginning of runoff from snowmelt: April 6
Peak of runoff augmented by snowmelt: May 21
Snowmelt complete (no measureable snow): June 8
Percent of runoff provided by snowpack: 47%
Peak runoff volume: 1,752 cfs
Gauge station used in estimating runoff: #100395 Bear River at Border, Wyoming

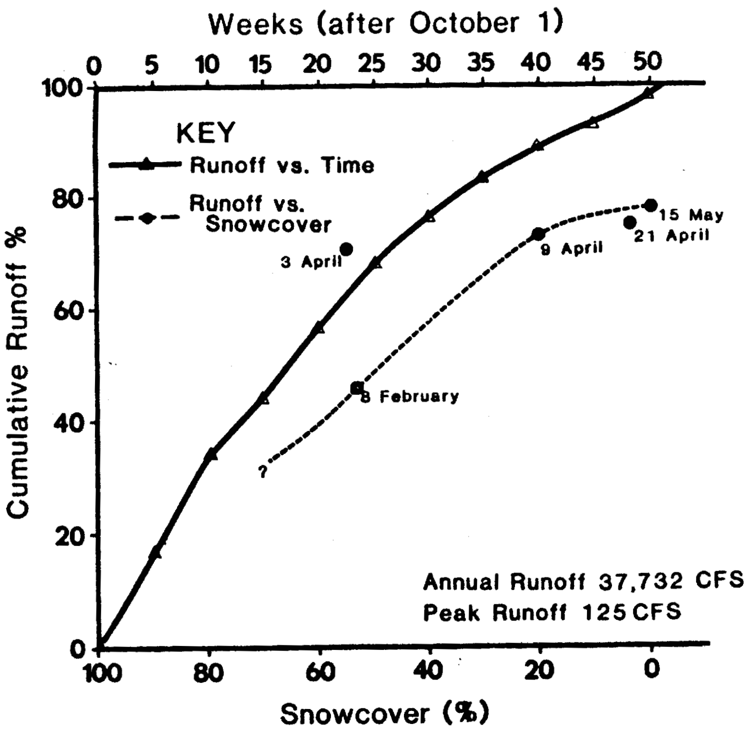


North and South Fork of Bear River
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (≈ Average)



North and South Forks of Bear River

RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)



AREA B-2

SNOWMELT AND RUNOFF PATTERNS: THOMAS FORK OF BEAR RIVER

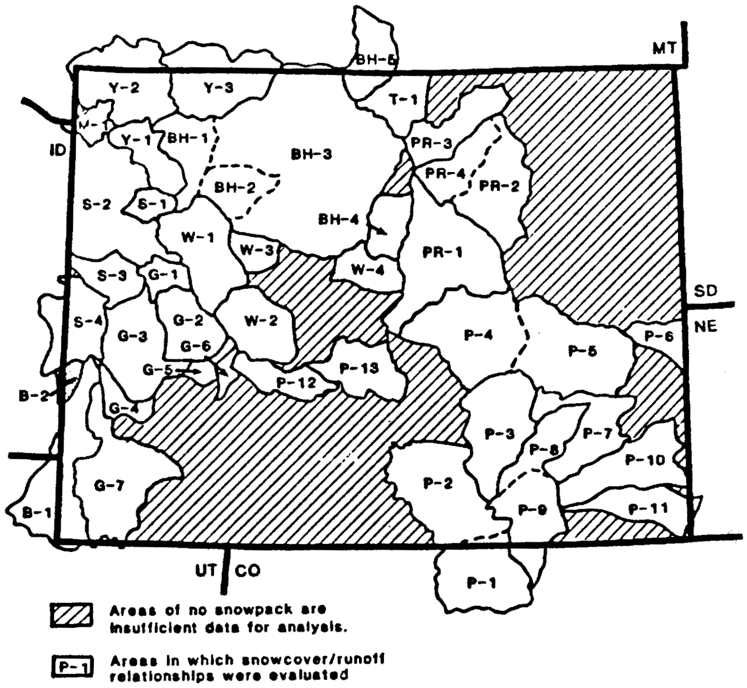
Landsat imagery for the 1973 and 1977 water years were used to construct snowmelt curves for the Thomas Fork drainage. Four irregularly distributed dates of coverage were available for 1973. Unfortunately, the April and May coverage necessary to reliably map the pattern of snowmelt was very sparse. Therefore, the 1973 snowmelt curve is not very reliable. However, the five dates of coverage for 1977 provide a very good snowmelt curve for a drought year, but the snowpack amounts to only about 5% of the total runoff in 1977.

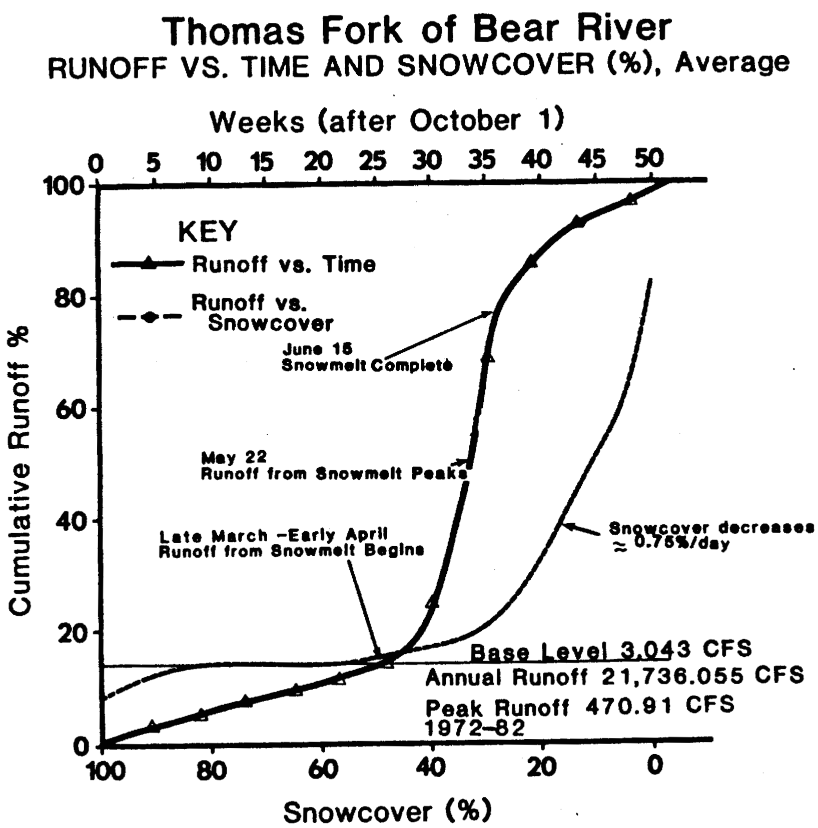
According to average discharge values and snow course data, 1973 and 1977 are both dry years. An average discharge curve for this drainage was constructed by averaging 11 years of discharge data. The average snowmelt curve is based upon the 1973 imagery because it is more nearly a "normal" year than 1977. However, as noted in the preceeding paragraph, the 1973 data set is of limited utility.

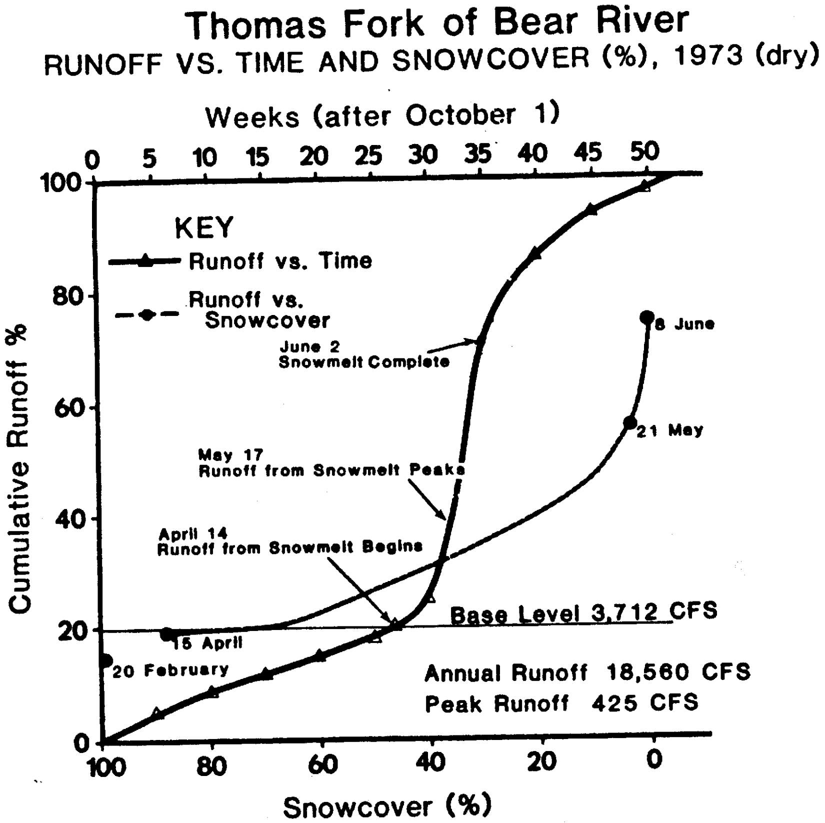
The beginning of snowmelt varies from late March to early April. Peak flows generally occur in early May. The values of peak flow range from 275 to 730 cfs, with 471 cfs being the 1972-82 average value. The peak flow of the Thomas Fork drainage usually occurs within a few days of May 22.

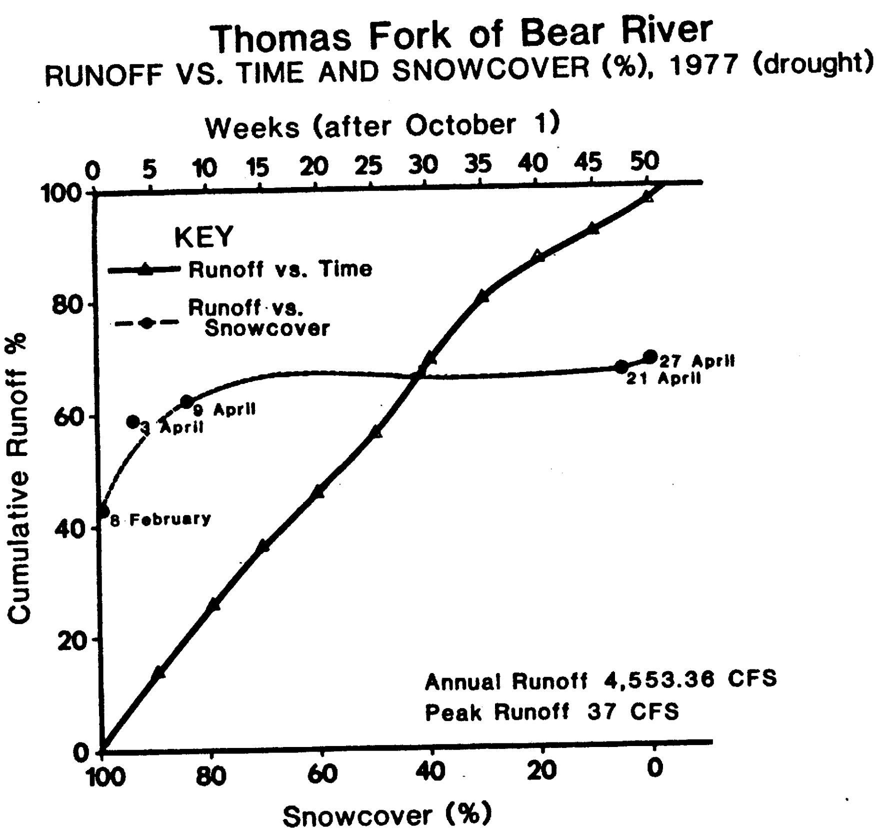
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: Late March - early April (April 1)
Peak of runoff augmented by snowmelt: May 22
Snowmelt complete (no measureable snowpack): June 15
Percent of runoff provided by snowpack: 64%
Peak runoff volume: 471 cfs
Gauge station used in estimating runoff: #100410 Thomas Fork near Wyoming - Idaho State line


MT
SD
NE
ID
UT
CO
Y-2
Y-3
BH-5
T-1
Y-1
BH-1
BH-3
PR-3
PR-4
PR-2
S-2
S-1
BH-2
BH-4
W-1
W-3
PR-1
S-3
G-1
W-4
S-4
G-3
G-2
W-2
P-4
P-5
P-6
G-6
G-5
P-12
P-13
B-2
G-4
P-3
P-8
P-7
P-10
G-7
P-2
B-1
P-9
P-11
P-1
Areas of no snowpack are insufficient data for analysis.
P-1
Areas in which snowcover/runoff relationships were evaluated


Thomas Fork of Bear River
RUNOFF VS. TIME AND SNOWCOVER (%), Average
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
June 15 Snowmelt Complete
May 22 Runoff from Snowmelt Peaks
Late March –Early April Runoff from Snowmelt Begins
Snowcover decreases ≈ 0.75%/day
Base Level 3,043 CFS
Annual Runoff 21,736.055 CFS
Peak Runoff 470.91 CFS
1972–82
100 80 60 40 20 0
Snowcover (%)


Thomas Fork of Bear River
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
Cumulative Runoff %
June 2 Snowmelt Complete
8 June
21 May
May 17 Runoff from Snowmelt Peaks
April 14 Runoff from Snowmelt Begins
Base Level 3,712 CFS
15 April
20 February
Annual Runoff 18,560 CFS
Peak Runoff 425 CFS
100 80 60 40 20 0
Snowcover (%)


Thomas Fork of Bear River
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
Cumulative Runoff %
27 April
21 April
9 April
3 April
8 February
Annual Runoff 4,553.36 CFS
Peak Runoff 37 CFS
100 80 60 40 20 0
Snowcover (%)

AREA G-1

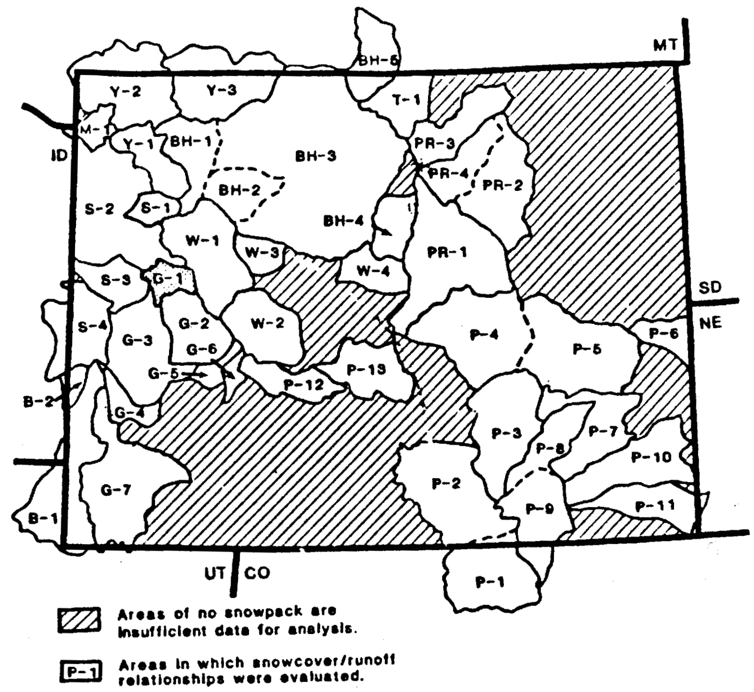
SNOWMELT AND RUNOFF PATTERNS: GREEN RIVER IN THE GREEN RIVER BEND AREA

Imagery for the snowmelt seasons of 1973, 1977, and 1978 were used to estimate snowcover depletion for the Green River Bend watershed. 1977 was a year of extremely light snowpack, so the data from 1973 and 1978 were averaged together to yield a composite snowcover-runoff relationship. The 1973 snowpack was slightly below normal and the 1978 snowpack was above normal in the Green River Bend area. The curves demonstrate the typical snowcover-runoff relationship, with peak of runoff occurring later when the snowpack is large and the slope of the snowcover-runoff curve becomes steeper for seasons of lighter snowpack.

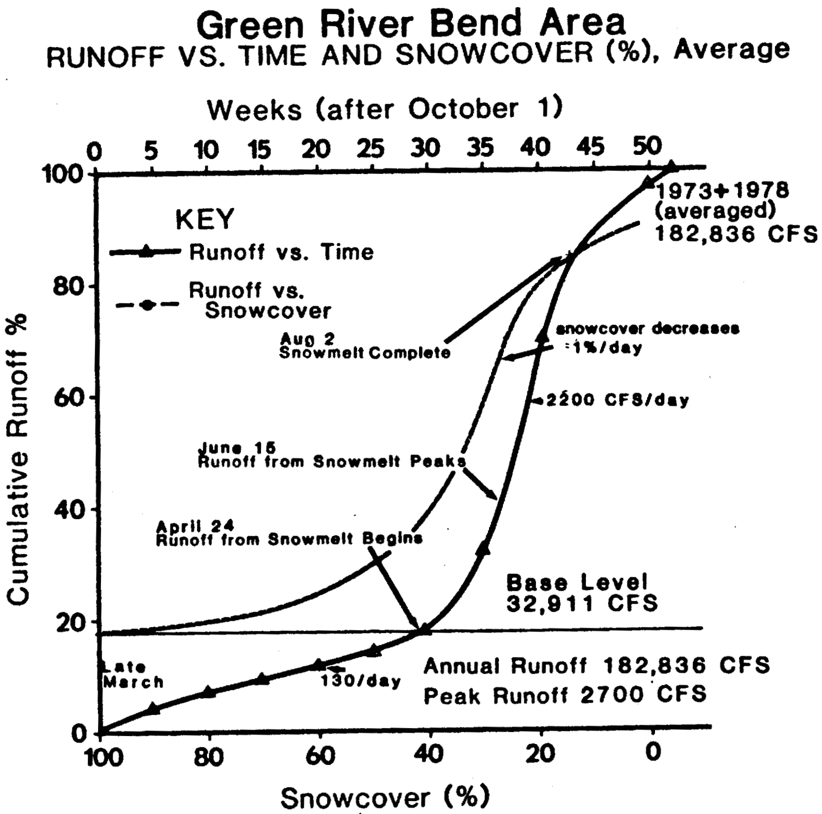
Snowpack in the Green River Bend area supplies 70-75% of the annual runoff for the area. Discharge at the Warren Bridge gauge station on the Green River increases from near 130 cfs just prior to the onset of snowmelt to an average daily discharge of nearly 2000 cfs during the main snowmelt period in June. The greatest volume recorded since 1972 was 4760 cfs on June 9, 1972. Peak volumes in this range require both a large snowpack and favorable melt conditions augmented by rainfall. Peak runoff for a typical melt season is about 2200 cfs.

CRITICAL VALUES (normal year):

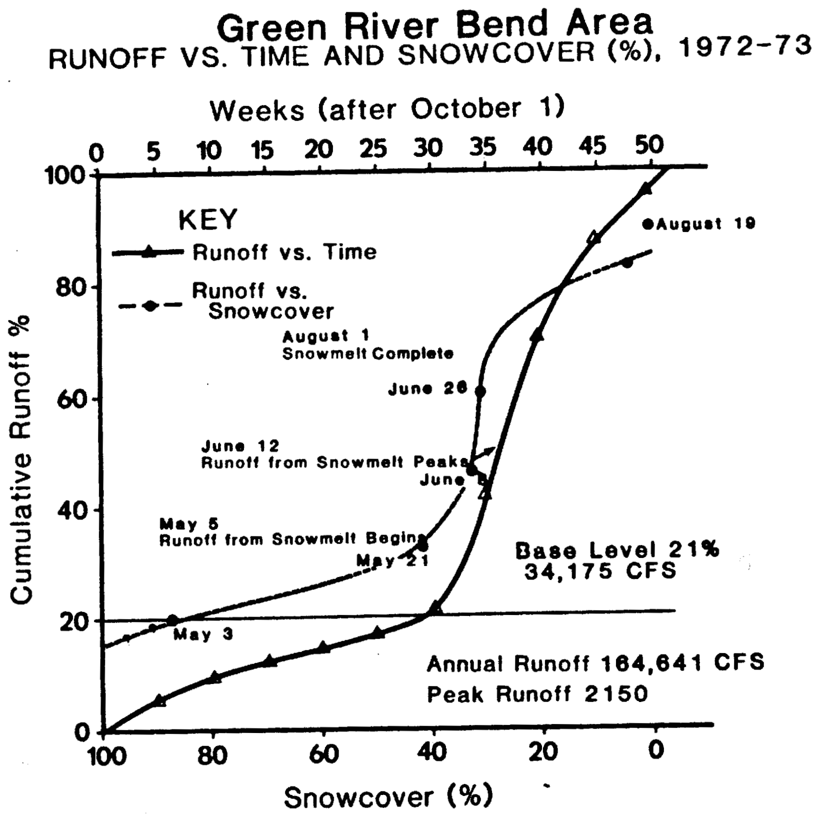
Beginning of runoff from snowmelt: April 24
Peak of runoff augmented by snowmelt: June 15
Snowmelt complete (no visible snow): August 2
Percent runoff provided by snowpack: 75%
Peak runoff volume: 2200 cfs
Average annual discharge: 183,000
Gauge station used in estimating runoff: #91885, Green River at Warren Bridge, near Daniel, Wyoming

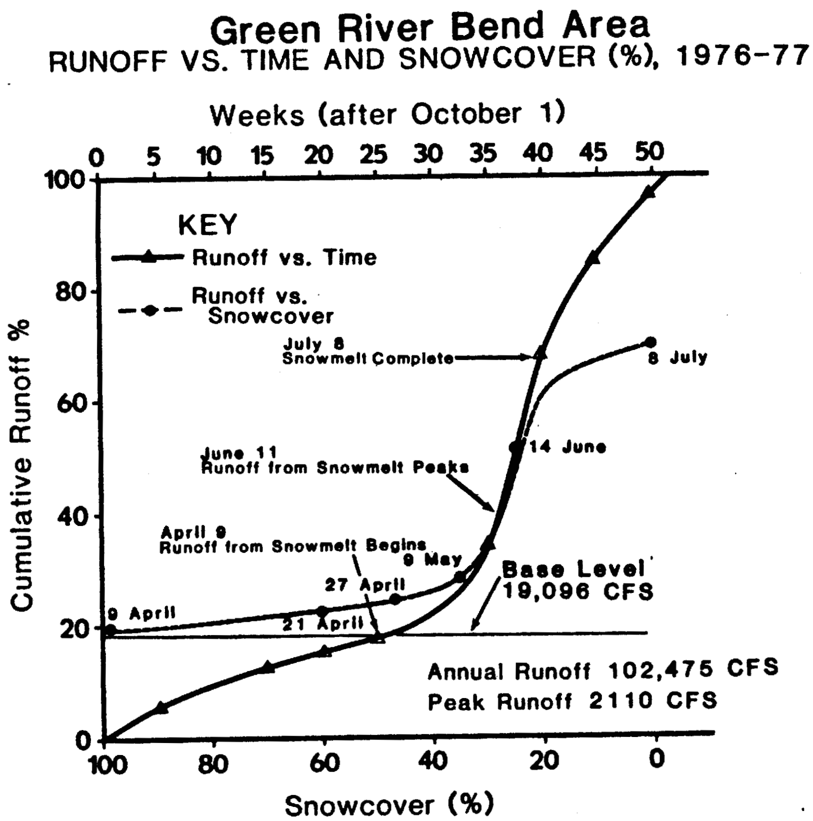


MT
Y-2
Y-3
BH-5
T-1
M-1
Y-1
BH-1
BH-3
PR-3
ID
BH-2
PR-4
PR-2
S-2
S-1
BH-4
W-1
W-3
PR-1
S-3
G-1
W-4
SD
S-4
G-2
W-2
P-4
P-5
P-6
NE
G-3
G-6
G-5
P-12
P-13
B-2
G-4
P-3
P-8
P-7
P-10
G-7
P-2
P-9
P-11
B-1
UT
CO
P-1
Areas of no snowpack are insufficient data for analysis.
P-1
Areas in which snowcover/runoff relationships were evaluated.

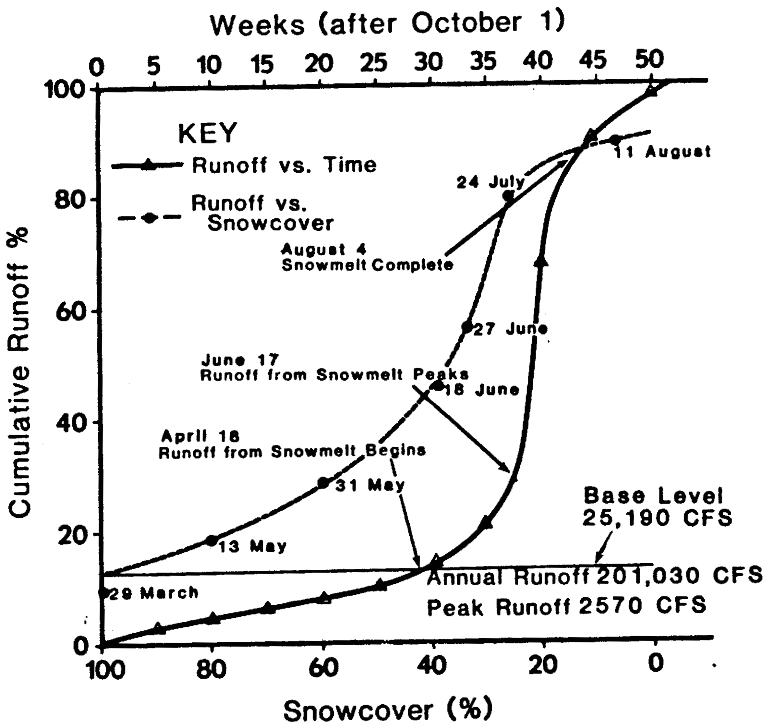


Green River Bend Area
RUNOFF VS. TIME AND SNOWCOVER (%), Average
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
1973+1978 (averaged) 182,836 CFS
Aug 2 Snowmelt Complete
snowcover decreases ~1%/day
2200 CFS/day
June 15 Runoff from Snowmelt Peaks
April 24 Runoff from Snowmelt Begins
Base Level 32,911 CFS
Late March
130/day
Annual Runoff 182,836 CFS
Peak Runoff 2700 CFS
Cumulative Runoff %
0 20 40 60 80 100
100 80 60 40 20 0
Snowcover (%)


Green River Bend Area
RUNOFF VS. TIME AND SNOWCOVER (%), 1972-73
Weeks (after October 1)
Cumulative Runoff %
Snowcover (%)
KEY
Runoff vs. Time
Runoff vs. Snowcover
August 19
August 1
Snowmelt Complete
June 26
June 12
Runoff from Snowmelt Peaks
June 5
May 5
Runoff from Snowmelt Begins
May 21
May 3
Base Level 21%
34,175 CFS
Annual Runoff 164,641 CFS
Peak Runoff 2150


Green River Bend Area
RUNOFF VS. TIME AND SNOWCOVER (%), 1976-77
Weeks (after October 1)
Cumulative Runoff %
Snowcover (%)
KEY
Runoff vs. Time
Runoff vs. Snowcover
July 8
Snowmelt Complete
8 July
June 11
Runoff from Snowmelt Peaks
14 June
April 9
Runoff from Snowmelt Begins
9 May
27 April
9 April
21 April
Base Level
19,096 CFS
Annual Runoff 102,475 CFS
Peak Runoff 2110 CFS

Green River Bend Area
RUNOFF VS. TIME AND SNOWCOVER (%), 1977-78



AREA G-2

SNOWMELT AND RUNOFF PATTERNS: NEW FORK RIVER DRAINAGE

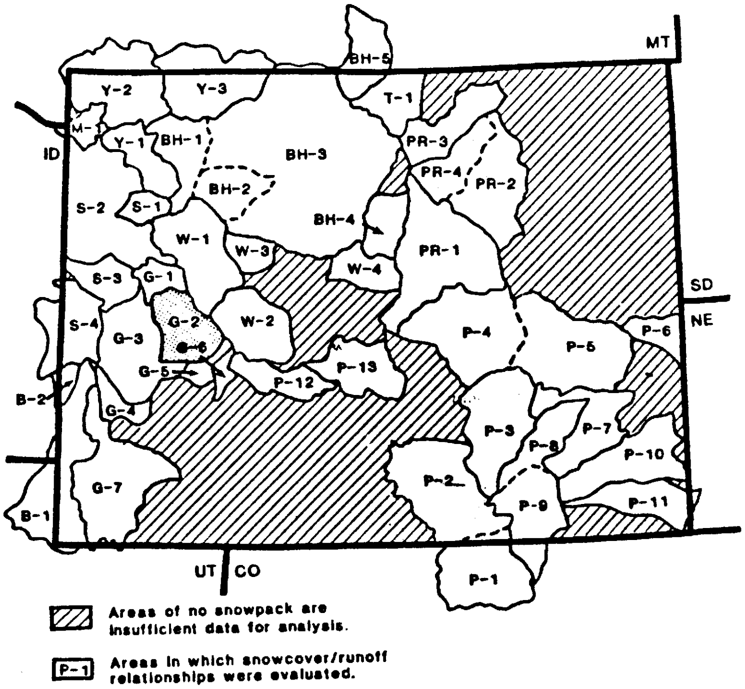
Three snowcover-runoff curves were compiled for the New Fork drainage. The 1973 snowmelt season proved to be near-average in the New Fork drainage basin and data representing the 1973 snowmelt season is considered fairly representative of a "typical" year. Runoff in spring 1977 was very low and that in the spring of 1978 was abnormally high. The three curves (1973, 1977, and 1978) span the expected range of snowcover-runoff conditions for the New Fork drainage. The three curves indicate a fairly normal runoff pattern except that the increase in rate of snowpack depletion usually apparent in dry years is not suggested in the curves for the New Fork area.

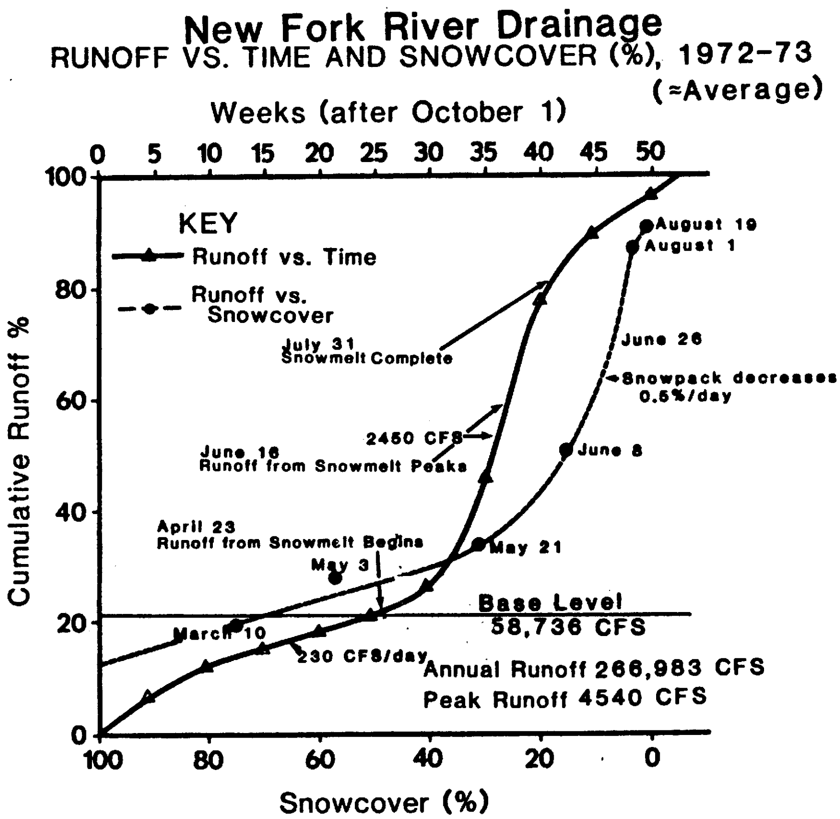
Rate of runoff is fairly constant for the non-snowmelt season, regardless of volume of accumulated snowpack. In 1977, the snowpack produced only 25% of the annual discharge; but, in 1978, about 65% of the total discharge was due to snowmelt. An average year produces about 55-60% of the annual discharge from snowmelt. The flow rate usually increases from near 230 cfs to about 2500 cfs during the snowmelt season on the New Fork. A peak flow of 4540 cfs can be expected during a normal year, but rates as high as 9100 cfs have been recorded (1972).

The consistency of the snowmelt and runoff data for the New Fork drainage are such that the 1972-73 curve can be considered an "average" curve and the 1977 and 1978 melt season provide examples of changes to be expected for abnormally low or high accumulations of snow. The three curves together provide an excellent data base for predicting runoff from Landsat-derived snowcover estimates.

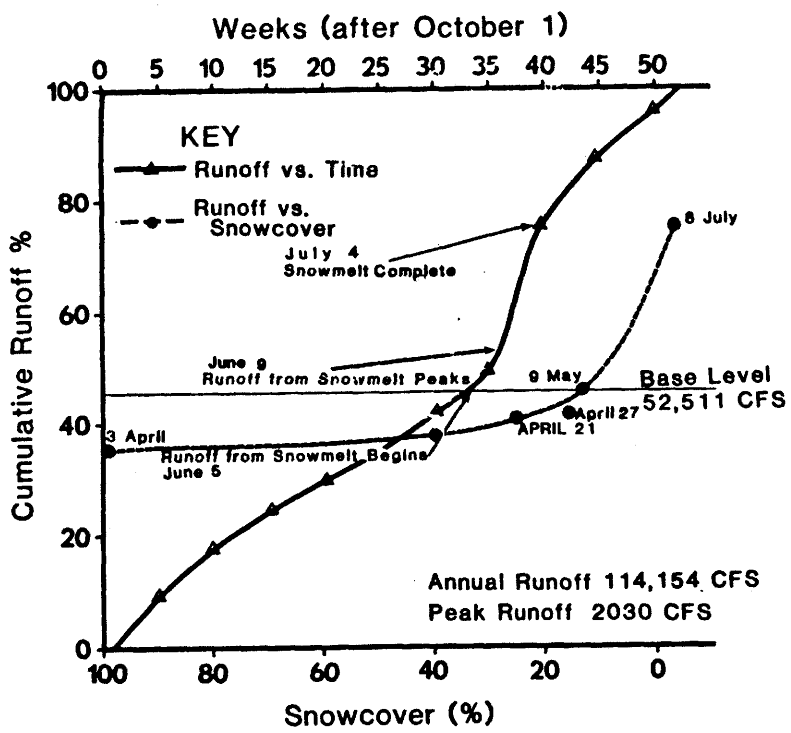
CRITICAL VALUES:

Beginning of runoff from snowmelt: April 1
Peak of runoff augmented by snowmelt: June 16 or 17
Snowmelt complete (no visible snow remaining): August 15
Percent runoff provided by snowpack: 55-60%
Peak runoff volume (normal year): 4550 cfs
Gauge station used in estimating runoff: #92050, New Fork River near Big Piney, Wyoming

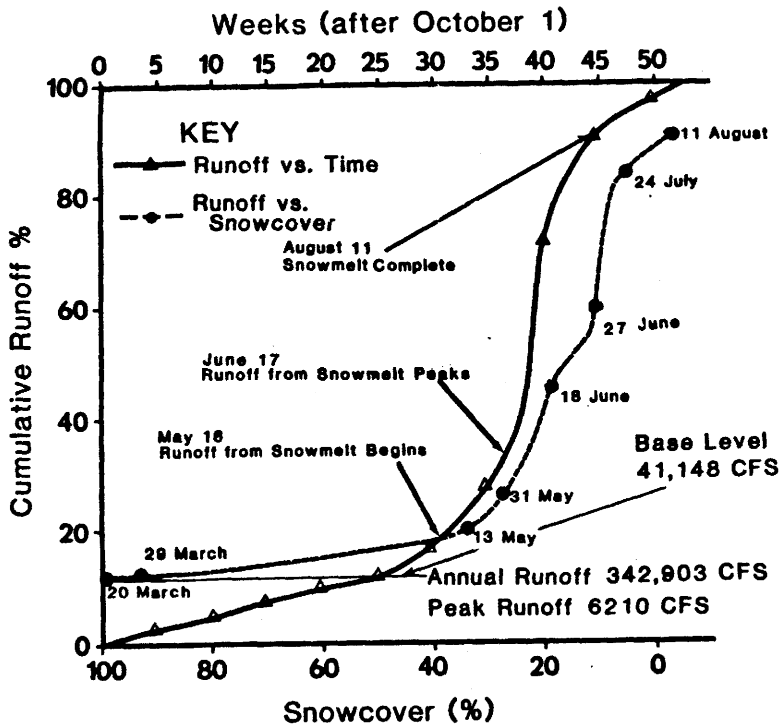

MT
SD
NE
ID
UT
CO
Y-2
Y-3
Y-1
M-1
BH-1
BH-2
BH-3
BH-4
BH-5
T-1
PR-1
PR-2
PR-3
PR-4
S-1
S-2
S-3
S-4
W-1
W-2
W-3
W-4
G-1
G-2
G-3
G-4
G-5
G-6
G-7
B-1
B-2
P-1
P-2
P-3
P-4
P-5
P-6
P-7
P-8
P-9
P-10
P-11
P-12
P-13
Areas of no snowpack are insufficient data for analysis.
Areas in which snowcover/runoff relationships were evaluated.


New Fork River Drainage
RUNOFF VS. TIME AND SNOWCOVER (%), 1972-73
(≈Average)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
Cumulative Runoff %
August 19
August 1
June 26
Snowpack decreases 0.5%/day
July 31 Snowmelt Complete
2450 CFS
June 16 Runoff from Snowmelt Peaks
June 8
April 23 Runoff from Snowmelt Begins
May 3
May 21
Base Level 58,736 CFS
March 10
230 CFS/day
Annual Runoff 266,983 CFS
Peak Runoff 4540 CFS
100 80 60 40 20 0
Snowcover (%)

New Fork River Drainage
RUNOFF VS. TIME AND SNOWCOVER (%), 1976-77 (drought)



New Fork River Drainage
RUNOFF VS. TIME AND SNOWCOVER (%), 1977-78 (wet)



AREA G-3

SNOWMELT AND RUNOFF PATTERNS: UPPER GREEN RIVER (above LaBarge)

Landsat imagery for the 1973, 1977 and 1978 water years were used to determine the snowmelt-runoff relationship for the Upper Green River drainage. Five or six coverage cycles were available for each of the three water years. The well-distributed dates of coverage allow the construction of relatively reliable snowmelt curves.

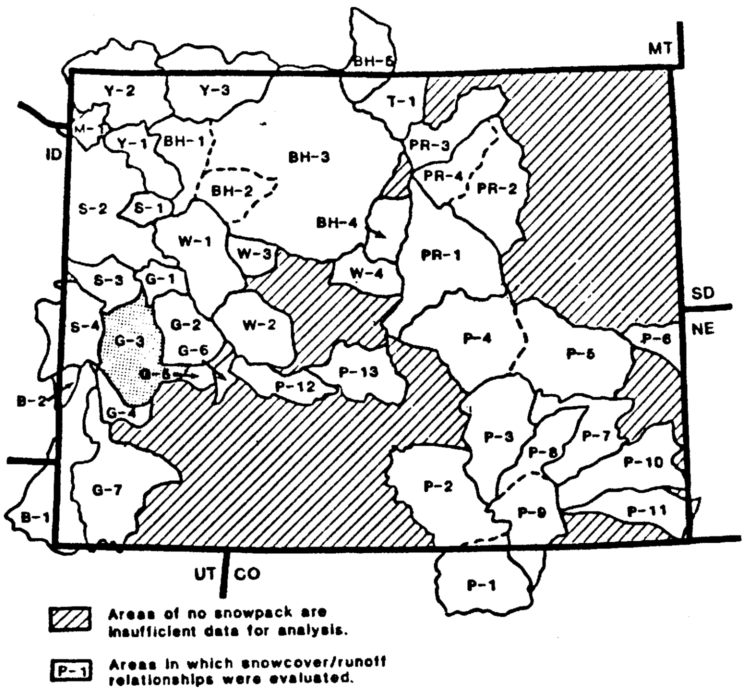
Climate estimates based upon average discharge values correlate well with those based upon water content of snow. This drainage is unique in the very close agreement between discharge and data from six snow courses.

The normal snowmelt-runoff graph was constructed by averaging the dry year curves of 1973 with the wet year curves of 1978. The 1973 and 1978 average discharge of 634,170 cfs is actually 4% above the 1972-82 average discharge of 610,629.73 cfs.

Peak discharge values as high as 17,800 cfs and 13,200 cfs were recorded in the wet years of 1972 and 1982, respectively. The lowest peak flow of 3,640 cfs occurred in the extreme drought year of 1977. On the average, the peak flow is about 10,000 cfs and should occur about June 12.

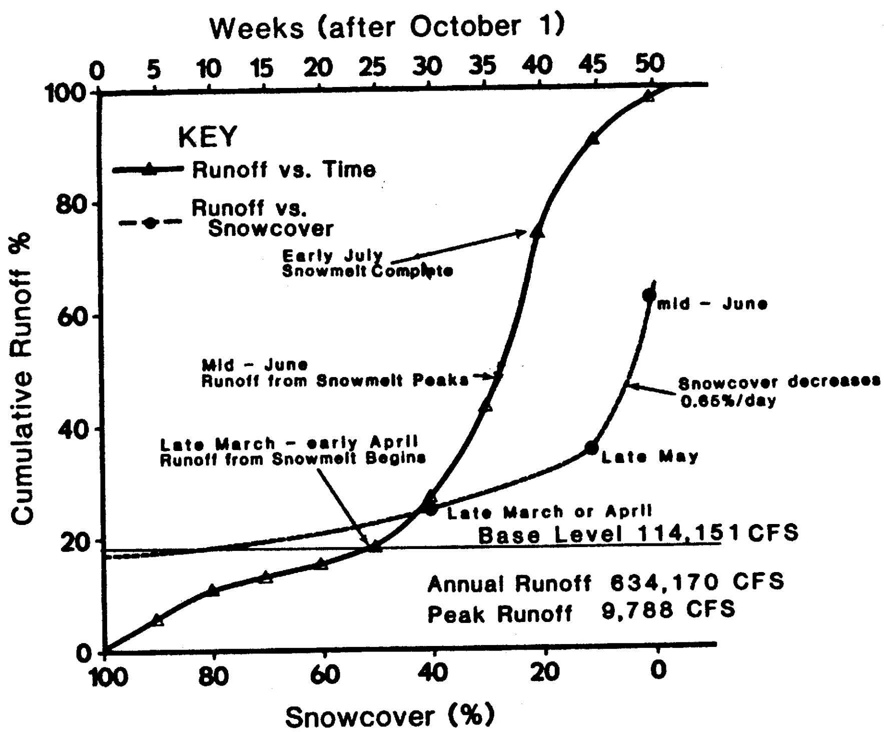
CRITICAL VALUES (normal year):

Beginning of runoff from snowmelt: April 1
Peak of runoff augmented by snowmelt: June 12
Snowmelt complete (no measureable snowcover): late June
Percent of runoff provided by snowpack: 57%
Peak runoff volume: 9,788 cfs
Gauge station used in estimating runoff: #92094 Green River near La Barge



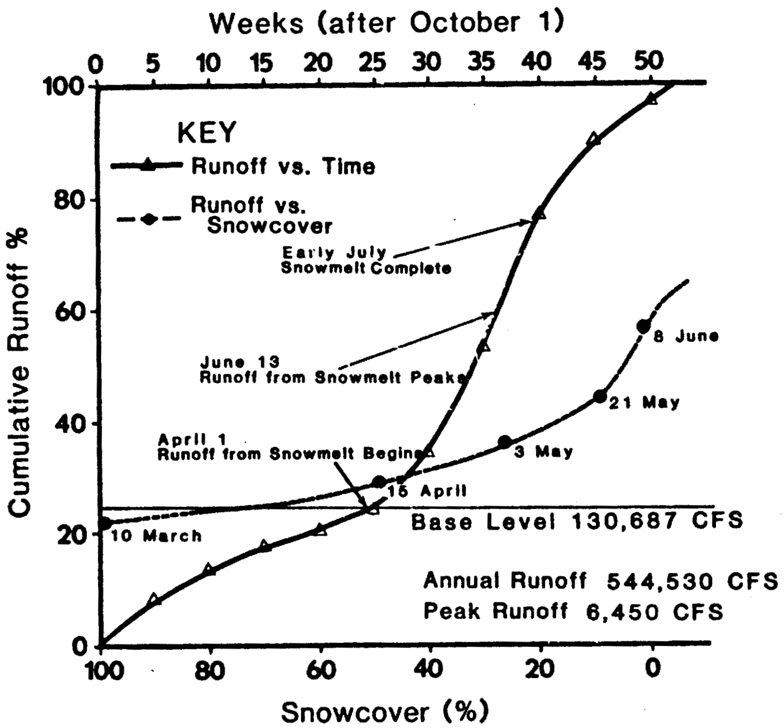
Green River above La Barge

RUNOFF VS. TIME AND SNOWCOVER (%), Average



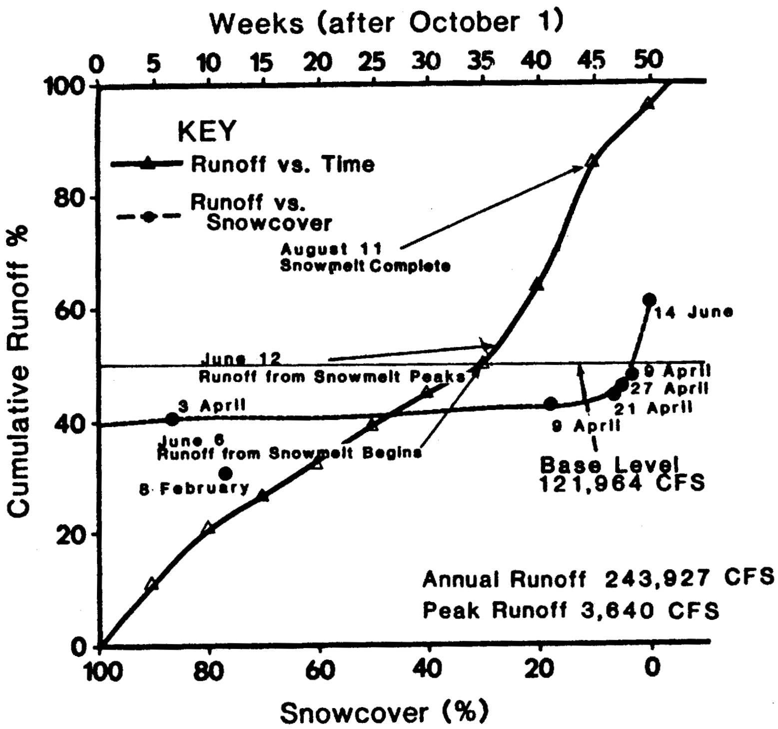
Green River above La Barge

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)



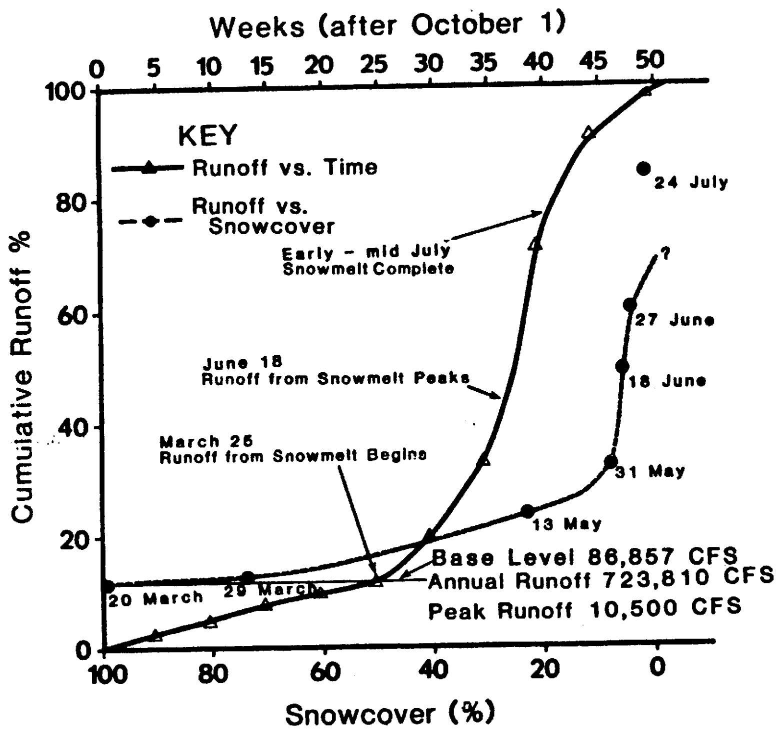
Green River above La Barge

RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)



Green River above La Barge

RUNOFF VS. TIME AND SNOWCOVER (%), 1978 (wet)



AREA G-4

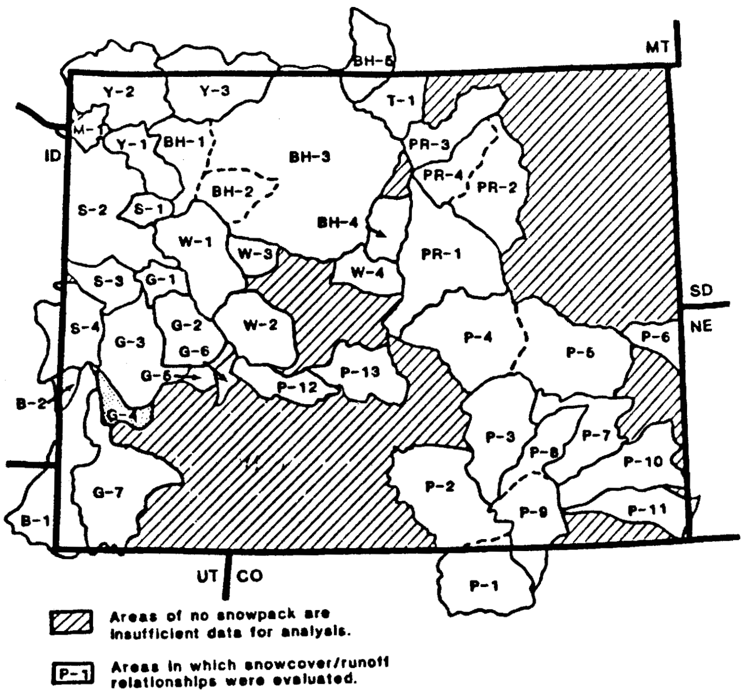
SNOWMELT AND RUNOFF PATTERNS: FONTENELLE CREEK

Landsat imagery for the water years 1973 and 1977 were used to construct snowmelt curves for the Fontenelle drainage area. The four dates of coverage for 1973 define a fairly reliable dry year snowmelt curve. Six dates of coverage for 1977 define a reliable snowmelt curve for a very dry year.

Because both 1973 and 1977 water years were below the 1972-82 11-year average discharge of 28,863 cfs, a normal discharge curve was constructed by averaging the 11 years of discharge data. The average snowmelt curve is a modification of the dry year curve of 1973. Because of the limited Landsat imagery, we can only estimate an average snowmelt curve. Estimates of expected runoff from snowcover measurements will, undoubtedly, be improved in this area as data for years of normal and above normal precipitation are added to the data base.

CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: early-mid-April (April 6)
Peak of runoff augmented by snowmelt: early June (June 12)
Snowmelt complete (no measureable snow): late June (June 25)
Percent of runoff provided by snowpack: 63%
Peak runoff volume: 426 cfs
Gauge station used in estimating runoff: #92105 Fontenelle Creek near Herschler Ranch near Fontenelle



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BH-4
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W-3
PR-1
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G-1
S-4
G-3
G-2
W-2
P-4
P-5
P-6
G-6
G-5
P-13
P-12
B-2
G-4
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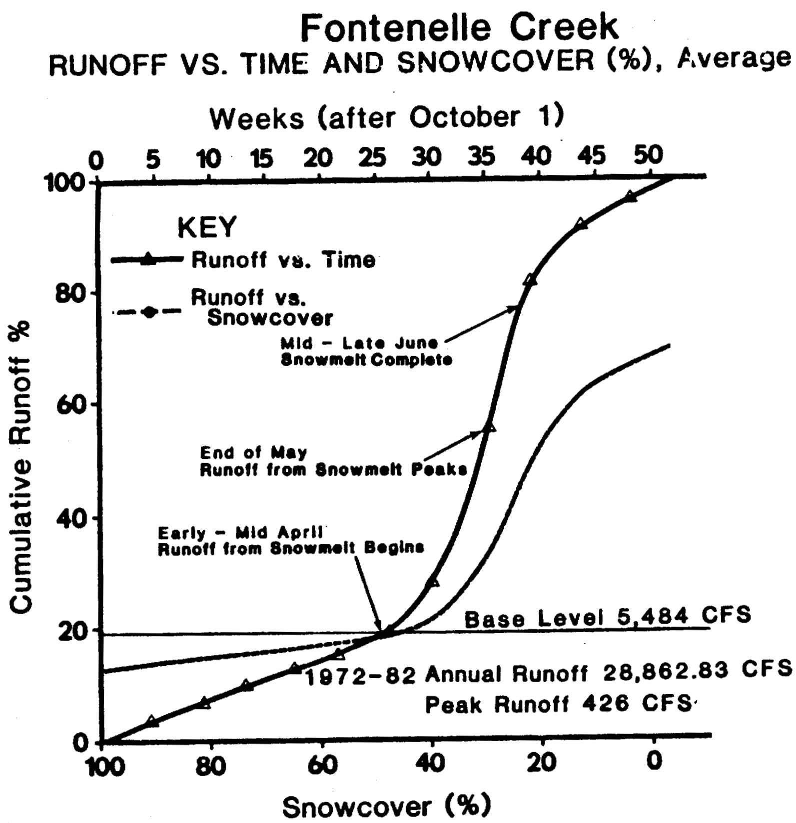
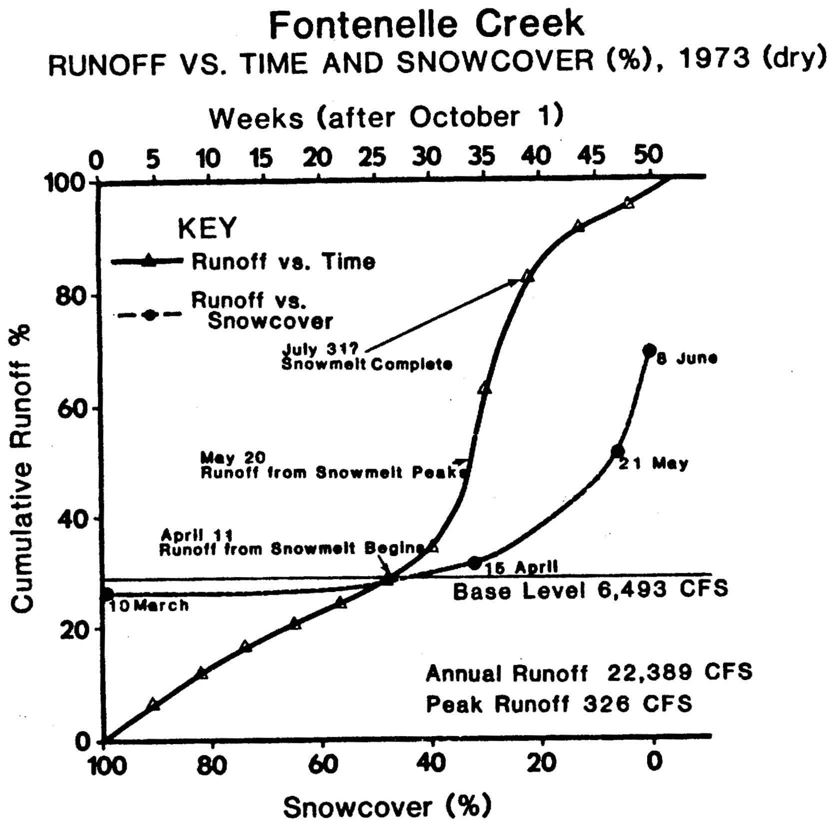
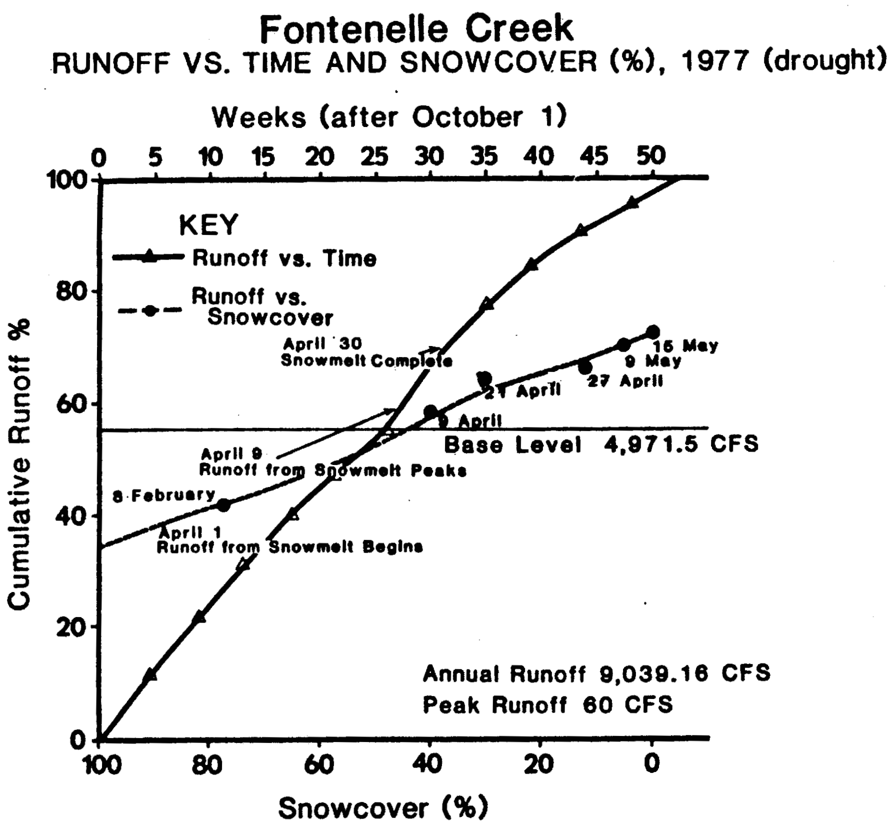
Areas of no snowpack are insufficient data for analysis.
P-1 Areas in which snowcover/runoff relationships were evaluated.



Fontenelle Creek
RUNOFF VS. TIME AND SNOWCOVER (%), Average
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
Mid - Late June Snowmelt Complete
End of May Runoff from Snowmelt Peaks
Early - Mid April Runoff from Snowmelt Begins
Base Level 5,484 CFS
1972-82 Annual Runoff 28,862.83 CFS
Peak Runoff 426 CFS
Cumulative Runoff %
100 80 60 40 20 0
Snowcover (%)


Fontenelle Creek
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (dry)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
July 31? Snowmelt Complete
8 June
May 20 Runoff from Snowmelt Peaks
21 May
April 11 Runoff from Snowmelt Begins
15 April
10 March
Base Level 6,493 CFS
Annual Runoff 22,389 CFS
Peak Runoff 326 CFS
100 80 60 40 20 0
Snowcover (%)


Fontenelle Creek
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
April 30 Snowmelt Complete
15 May
9 May
27 April
21 April
9 April
Base Level 4,971.5 CFS
April 9 Runoff from Snowmelt Peaks
8 February
April 1 Runoff from Snowmelt Begins
Annual Runoff 9,039.16 CFS
Peak Runoff 60 CFS
100 80 60 40 20 0
Snowcover (%)

AREA G-5

SNOWMELT AND RUNOFF PATTERNS: BIG SANDY DRAINAGE AREA

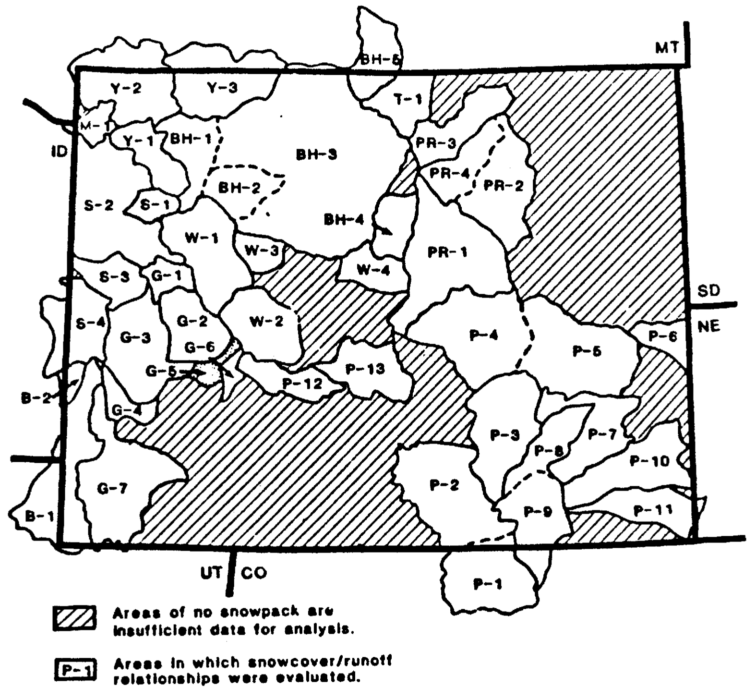
Three snowmelt seasons were used to determine the average snowmelt-runoff relationship for the Big Sandy drainage area. The 1972-73 season compares very favorably to the 11-year average, and is very close to the "average" curve constructed from the three years' data for which satellite imagery were available. Discharge was below average in 1976-77 and above average for the 1977-78 snowmelt season. Together, these three data sets represent a very good base from which to determine a "typical" snowcover-runoff relationship, and for water-supply forecasting in future years. The three curves demonstrate a consistent pattern from year to year and should allow reasonably accurate forecasts to be made.

Only one major problem was encountered in the evaluation of the Big Sandy area: stream flow data were not recorded for the October through March portion of each year. Consequently, runoff values for October through March of each year were interpolated from average discharge rates recorded in September and April. An average value of 33 cfs/day was estimated for these periods of no data. Accordingly, the annual runoff values for each year are also affected by this estimate. Fortunately, during periods of snowmelt, discharge values were measured; so the derived relationships should be accurate, even if the estimates for the remainder of the year are incorrect.

The snowcover-runoff curves for the Big Sandy area show no apparent affect of water management, probably because runoff was not recorded when management practices would have been in effect (during summer months). Peak discharge due to snowmelt usually occurs near the first week of June, but tends to shift to a few days earlier in years of low snowpack and a few days later in years of abnormally large snowpack. Of course, daily temperature variations produce somewhat unpredictable fluctuations in the amount and timing of the peak discharge each year. Snowpack in the Big Sandy drainage provides nearly 70% of the annual runoff (for a normal year), so it is a very important quantity for effective water management in the Big Sandy region.

CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: April 29
Peak of runoff augmented by snowmelt: June 8
Snowmelt complete (no visible snow): July 7
Percent runoff provided by snowpack: 67%
Peak runoff volume (normal year): 7850 cfs
Gauge station used in estimating runoff: #92135, Big Sandy River at Farson, Wyoming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S-2
S-1
BH-2
BH-4
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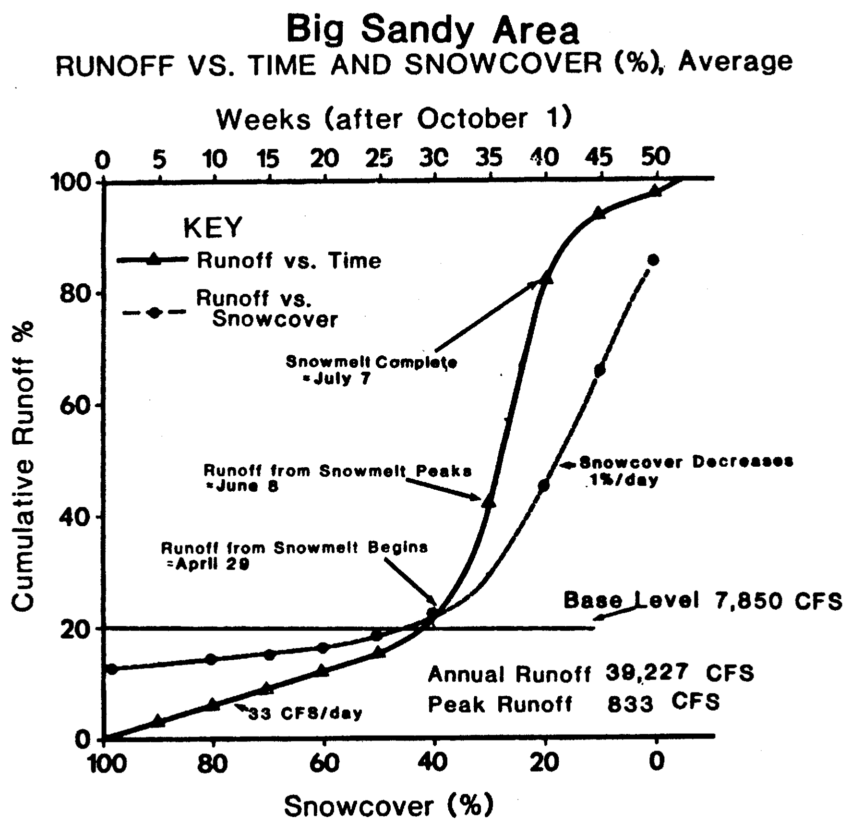
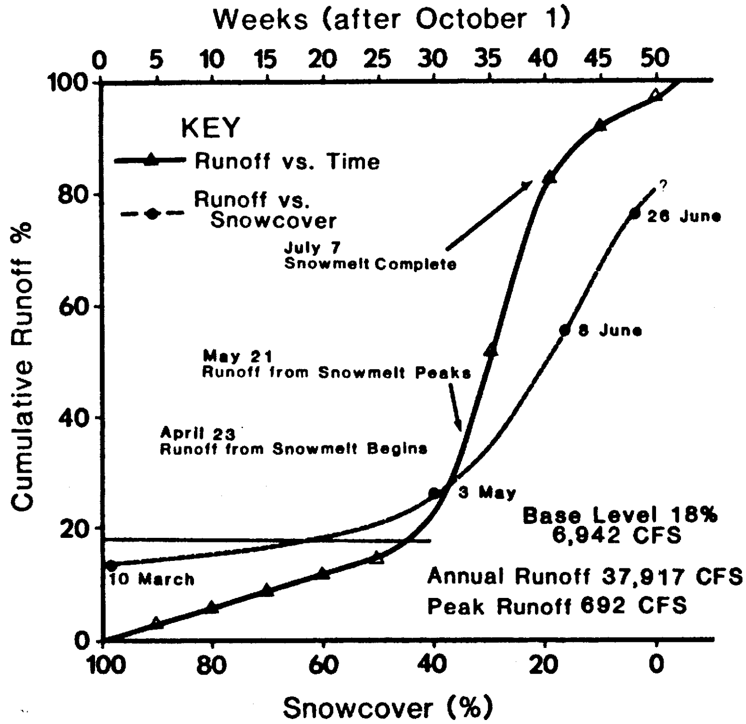
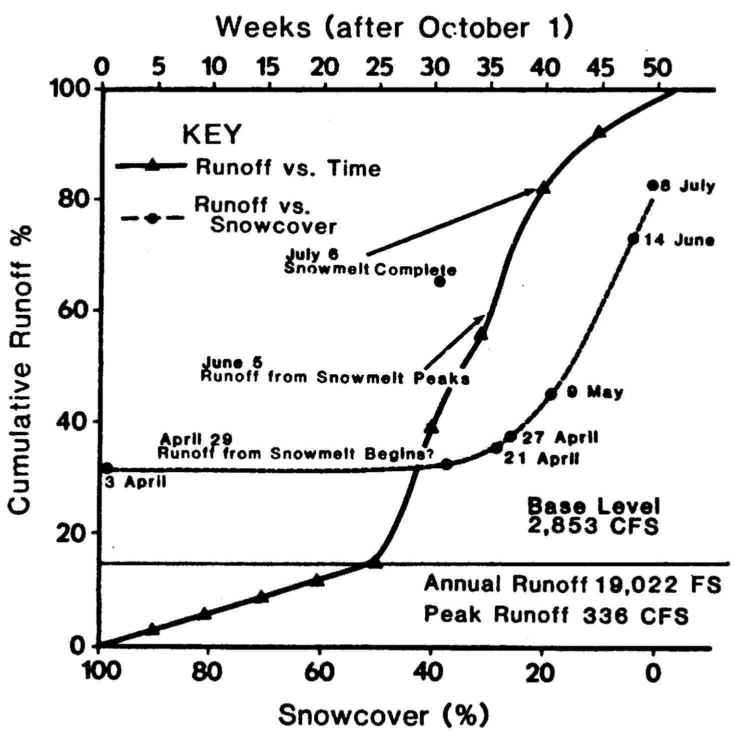
G-6
W-2
P-4
P-5
P-6
G-5
P-12
P-13
B-2
G-4
P-3
P-8
P-7
P-10
G-7
P-2
P-9
P-11
B-1
P-1
Areas of no snowpack are insufficient data for analysis.
P-1 Areas in which snowcover/runoff relationships were evaluated.


Big Sandy Area
RUNOFF VS. TIME AND SNOWCOVER (%), Average
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
Snowmelt Complete =July 7
Runoff from Snowmelt Peaks =June 8
Snowcover Decreases 1%/day
Runoff from Snowmelt Begins =April 29
Base Level 7,850 CFS
Annual Runoff 39,227 CFS
Peak Runoff 833 CFS
33 CFS/day
100 80 60 40 20 0
Snowcover (%)

Big Sandy Area
RUNOFF VS. TIME AND SNOWCOVER (%), 1972-73

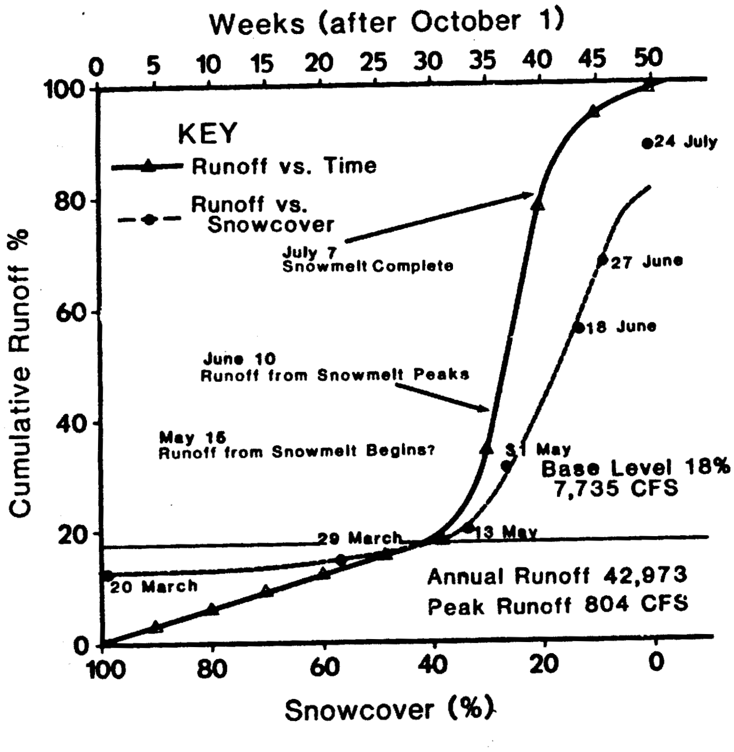


Big Sandy Area
RUNOFF VS. TIME AND SNOWCOVER (%), 1976-77 (drought)



Big Sandy Area

RUNOFF VS. TIME AND SNOWCOVER (%), 1977–78 (Wet)



AREA G-6

SNOWMELT AND RUNOFF PATTERNS: LITTLE SANDY CREEK

Landsat imagery for the 1973, 1977 and 1978 snowmelt seasons was used to determine the snowmelt-runoff pattern in the Little Sandy Creek drainage. The dates of imagery are well distributed throughout the season of snowmelt for all three water years. All three snowmelt curves are considered reliable.

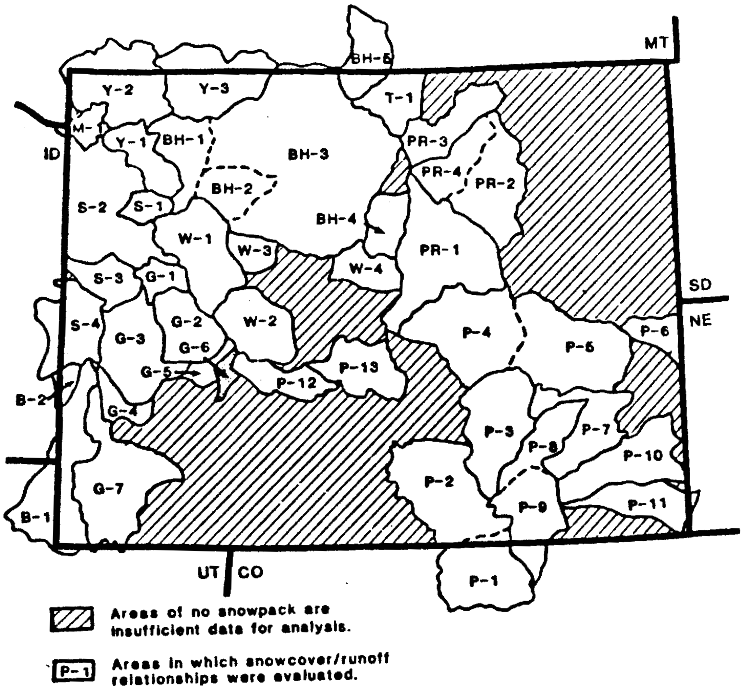
By comparing the 1973, 1977 and 1978 annual discharge to the average annual discharge (8,399 cfs), the 1973, 1977 and 1978 water years represent wet, drought and wet years respectively. However, analysis of water content of snowpack for these years from a nearby snowcourse indicates that only 1978 was a year of above-average snow accumulation. 1973 was slightly below average and 1977 snow accumulation was much below average.

The average discharge curve for this area was constructed by averaging total monthly values over the 10 years of record. The average snowmelt curve is somewhat harder to define because none of the years for which imagery was available was near average. Averaging of the 1973 and 1978, 1973 and 1977 or 1977 and 1978 snowmelt curves may not provide a reliable average curve; but if the climate estimates of dry and wet years for 1973 and 1978 are factual, then an average of these snowmelt curves may provide a fairly representative pattern.

We elected to consider the 1978 snowmelt-runoff pattern most nearly representative of a typical year, but constructed the "average" curve using the 1973 data as a reference for modifying the curve to represent a somewhat dryer season than the 1978 snowmelt season.

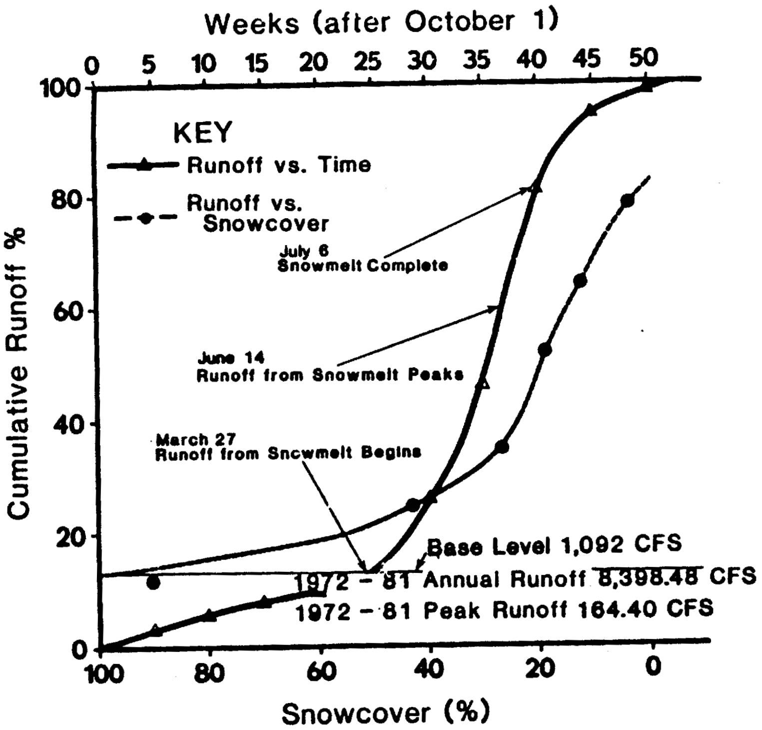
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: March 27
Peak of runoff augmented by snowmelt: June 14
Snowmelt complete (no measureable snowcover): July 6
Percent of runoff provided by snowpack: 68%
Peak runoff volume (normal year): 164 cfs/day
Gauge station used in estimating runoff: #092145 on Little Sandy Creek above Eden, Wyoming



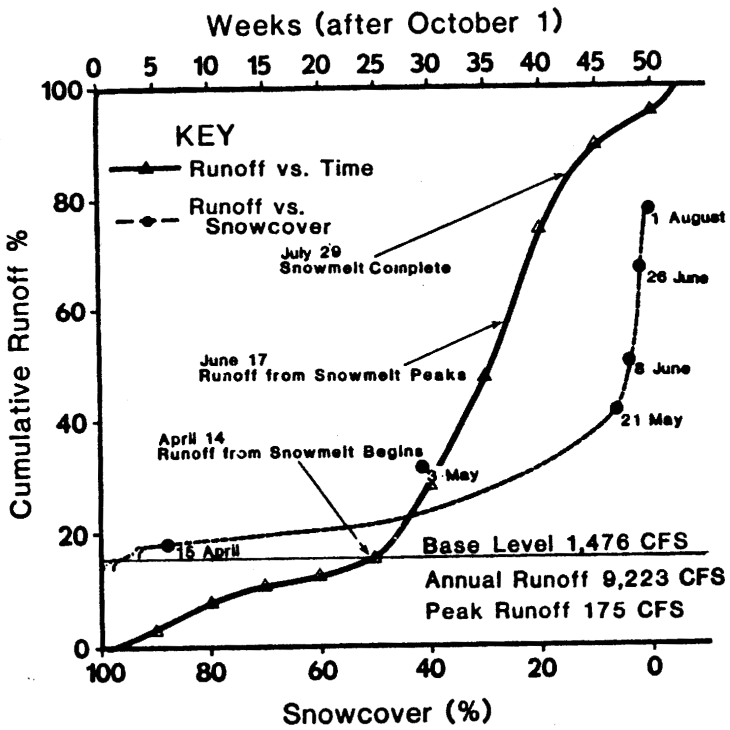
Little Sandy Creek

RUNOFF VS. TIME AND SNOWCOVER (%), Average



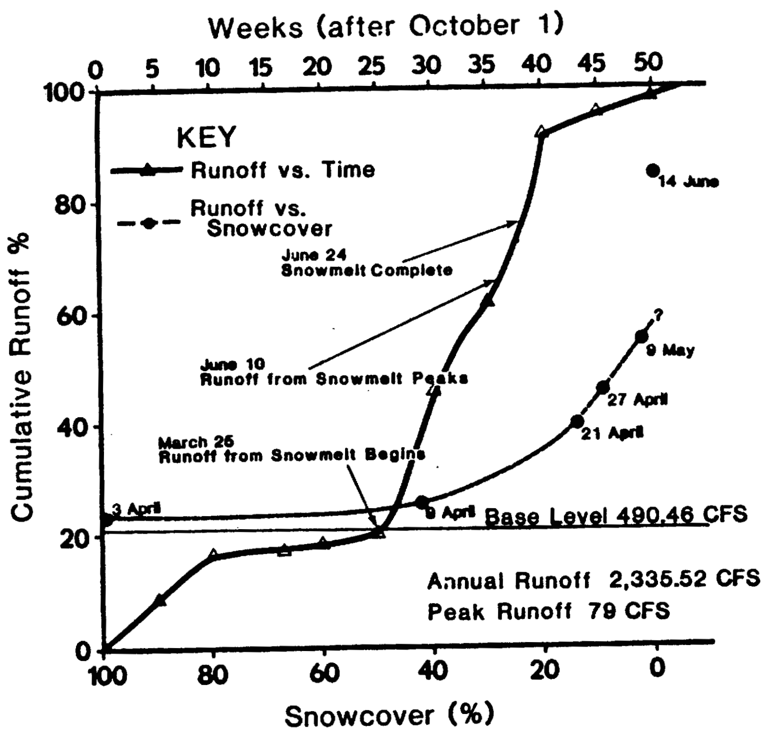
Little Sandy Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



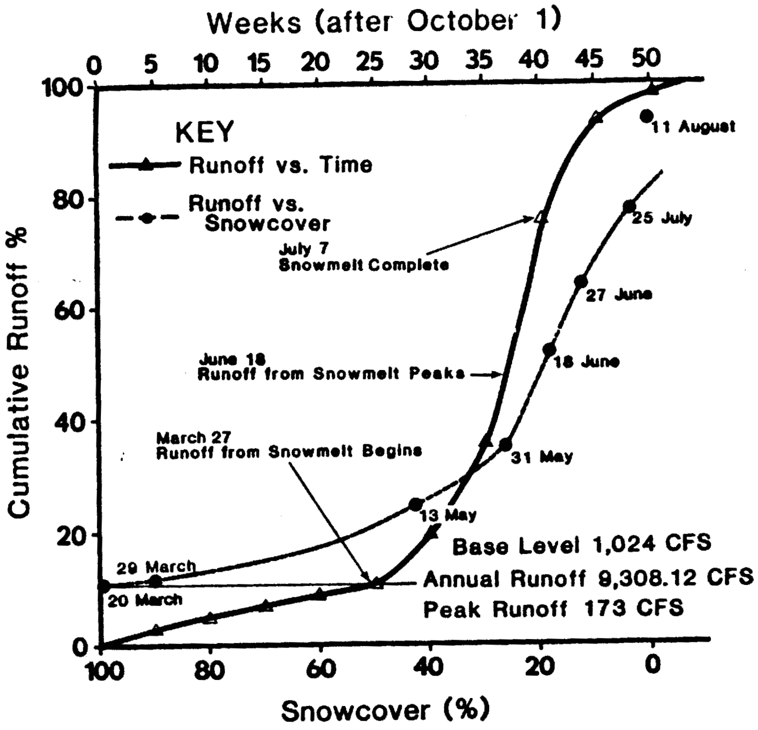
Little Sandy Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)



Little Sandy Creek

RUNOFF VS. TIME AND SNOWCOVER (%) 1978 (wet)



SNOWMELT AND RUNOFF PATTERNS: BLACK'S FORK OF GREEN RIVER

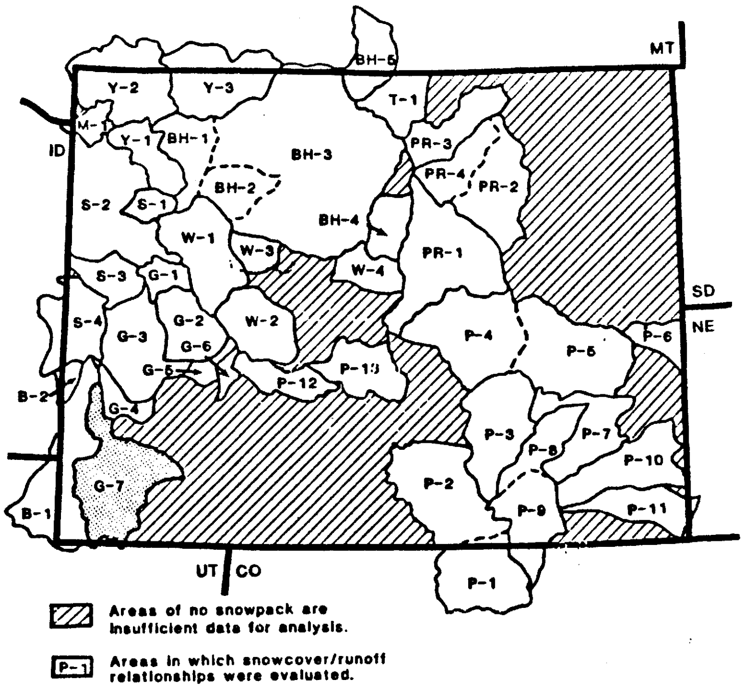
Landsat imagery for the 1973 and 1977 water years were used to construct snowmelt curves for the Black's Fork drainage. Only four dates of coverage were available for 1973. Additional coverage in late April to mid-May would be needed to make the 1973 data more reliable. Five dates of coverage are available for the 1977 water year. However, the April 3 date reflects the increased snowcover immediately following a spring storm. Spring storms generally blanket the drainage area with a thin cover of snow and do not significantly add to the permanent snowpack. The 1977 snowmelt curve is probably most reliable because it shows a pattern similar to that of the discharge curve if the April 3 data are disregarded. However, the 1977 data are not considered near typical, because 1977 was a very dry year.

In 1977, the Black's Fork discharge was 91% below the 11-year average of 113,178 cfs. Of the 28 western drainages, this area was the most severely affected by the 1977 drought. Yet, the 1977 discharge curve is not nearly as straight as the 1977 discharge curve of the Thomas Fork of the Bear River (79% less than average discharge). No snow-course data are available for comparison with runoff-snowcover estimates in the Black's Fork drainage.

The average snowmelt-runoff curves for the Black's Fork are a best guess. Because the 1976 total discharge is approximately normal, the 1976 runoff data were used to construct an average discharge curve. The average snowmelt curve is a modified 1973 (wet year) curve. We feel that the average snowmelt pattern would be better represented by the 1973 data than by the data obtained during the extreme drought of 1977.

CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: March 10
Peak of runoff augmented by snowmelt: May 17
Snowmelt complete (no measureable snow): June 6
Percent runoff provided by snowpack: 57%
Peak runoff volume: 1,907 cfs
Gauge station used in estimating runoff: #92247 Black's Fork near Little America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G-5
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P-13
B-2
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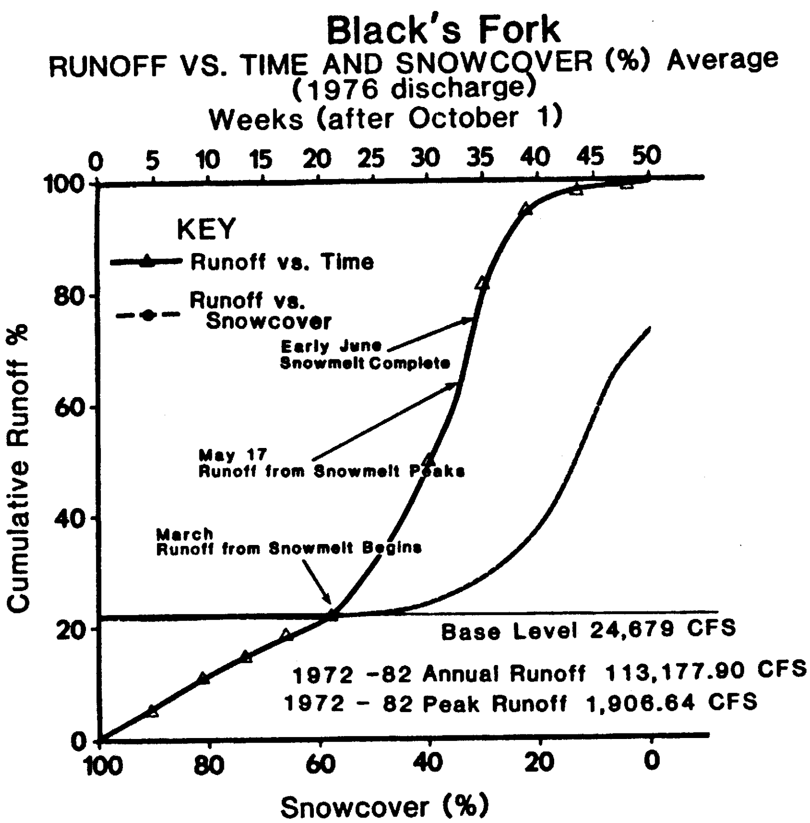
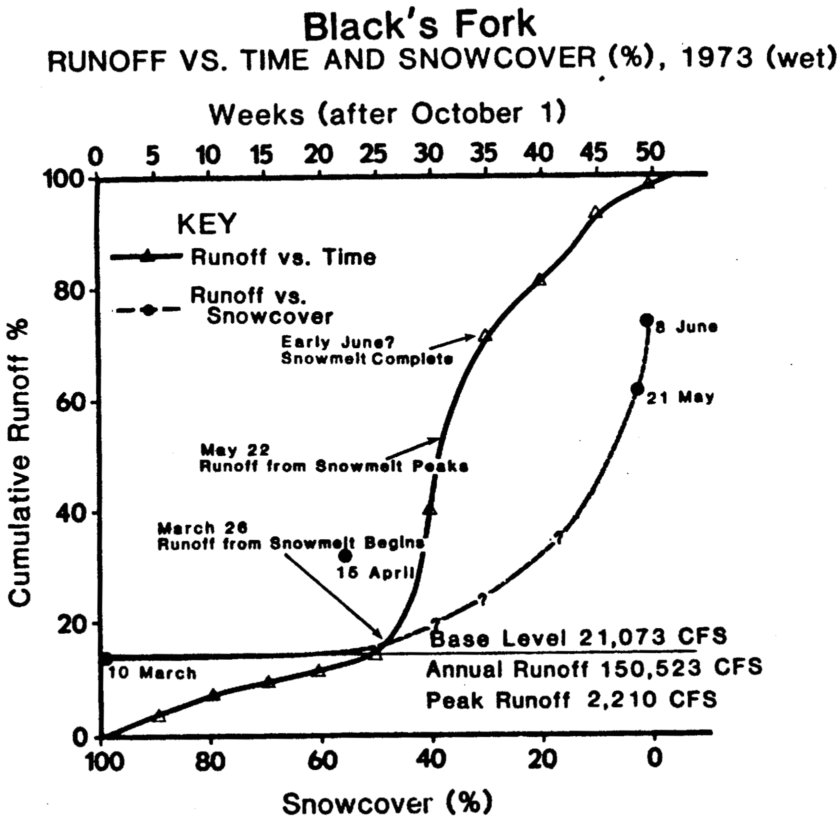
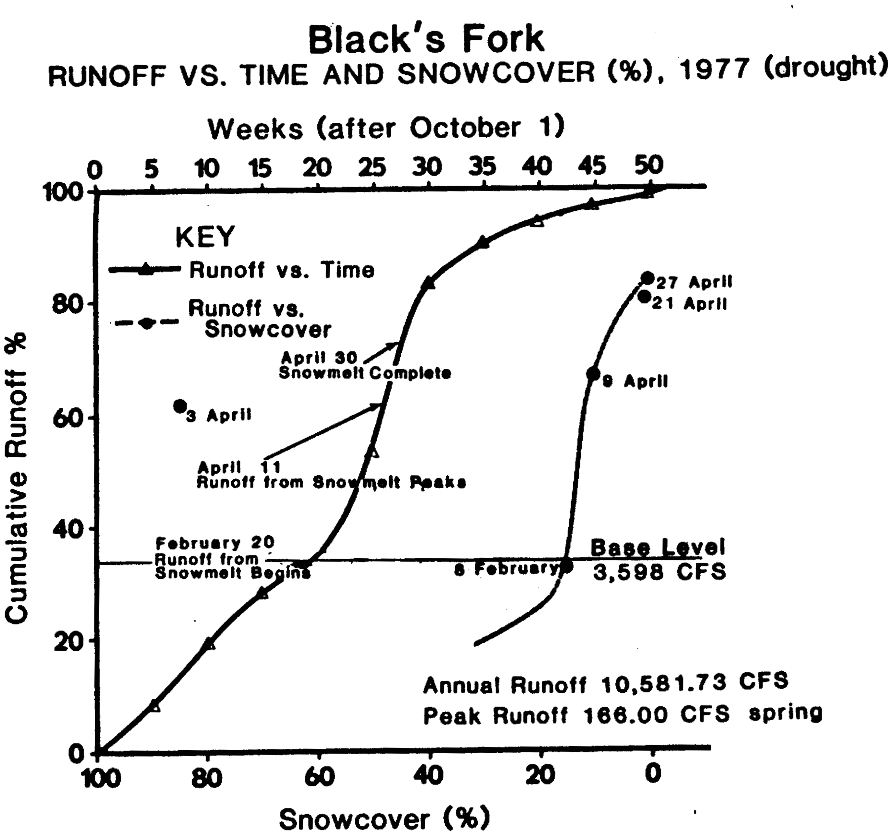
P-1
Areas of no snowpack are insufficient data for analysis.
Areas in which snowcover/runoff relationships were evaluated.


Black's Fork
RUNOFF VS. TIME AND SNOWCOVER (%) Average
(1976 discharge)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
Early June Snowmelt Complete
May 17 Runoff from Snowmelt Peaks
March Runoff from Snowmelt Begins
Base Level 24,679 CFS
1972 -82 Annual Runoff 113,177.90 CFS
1972 - 82 Peak Runoff 1,906.64 CFS
100 80 60 40 20 0
Snowcover (%)


Black's Fork
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
Early June?
Snowmelt Complete
8 June
21 May
May 22
Runoff from Snowmelt Peaks
March 26
Runoff from Snowmelt Begins
15 April
10 March
Base Level 21,073 CFS
Annual Runoff 150,523 CFS
Peak Runoff 2,210 CFS
Cumulative Runoff %
100 80 60 40 20 0
Snowcover (%)


Black's Fork
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (drought)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
27 April
21 April
April 30
Snowmelt Complete
9 April
3 April
April 11
Runoff from Snowmelt Peaks
February 20
Runoff from
Snowmelt Begins
8 February
Base Level
3,598 CFS
Annual Runoff 10,581.73 CFS
Peak Runoff 166.00 CFS spring
Cumulative Runoff %
100 80 60 40 20 0
Snowcover (%)

SNOWMELT AND RUNOFF PATTERNS: UPPER AND MIDDLE WIND RIVER DRAINAGE AREA

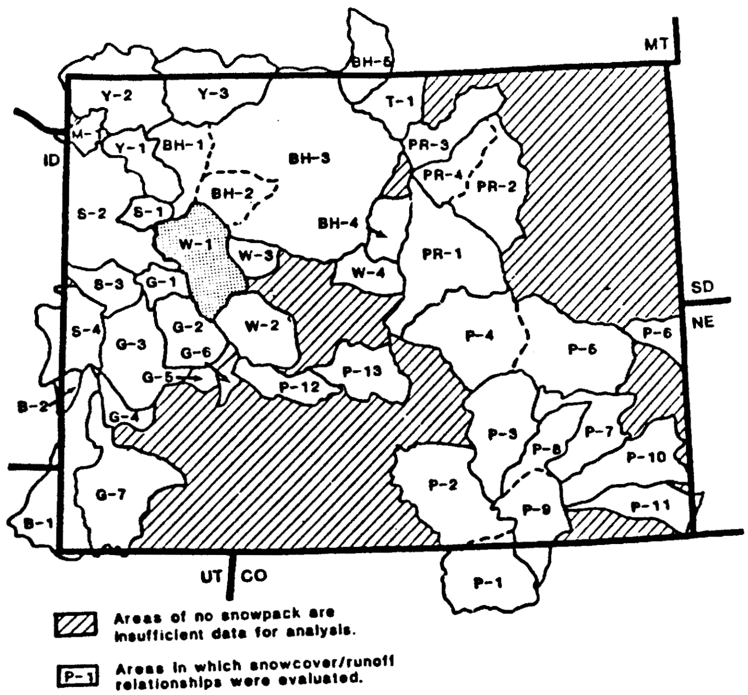
Landsat imagery for the 1973, 1977, and 1978 water years were used to assess the snowmelt pattern in the upper and middle Wind River drainage. In this area runoff procedes in a nearly linear fashion during the winter and early spring while the snowpack accumulates. The runoff rate during this period is normally in the range of 300 cfs per day. Snowmelt increases in late April (about April 25) and the daily runoff increases accordingly to approximately 4500 cfs per day. Base level values (%) are larger for years of low snowpack mainly because the lower contribution of snowmelt to the total runoff results in higher percentage values even though the actual rate of runoff for this period may be lower. Peak runoff occurs in late June or early July (average - July, 1) at approximately 6880 cfs, although runoff volumes as high as 8200 cfs have been recorded in the past ten years.

The snowmelt pattern is somewhat difficult to define in this area because of wide fluctuations in snowcover associated with the spring storms. These storms increase the snowpack by only a minor amount but strongly influence the snowcover pattern for a few days following the storm. The snowcover values estimated for these periods tend to fall above the normal snowcover/runoff curve in an irregular pattern. Such values must be largely ignored in interpreting the relationship of the winter snowpack to runoff.

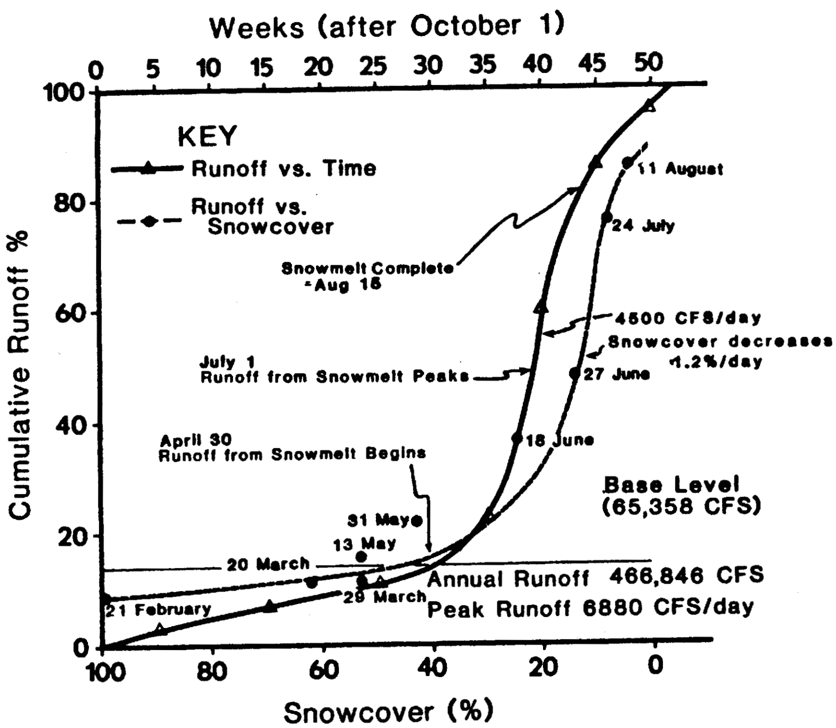
Snowpacks for the 1976-77 and 1972-73 seasons were appreciably below average and the snowmelt patterns were likewise somewhat abnormal. However, the 1977,78 data appear to represent a near-normal year. The total runoff was only 6% above the 10-year annual average for that season. Consequently, we feel that the snowcover/runoff curve derived for the 1978 snowmelt season give us the best available representation of a typical pattern. Variations from this pattern can be interpreted from the 1973 and 1977 data. Most prominent are the tendency for peak of runoff to occur earlier in the year when the snowpack is below normal and for the snowpack to be exhausted at an earlier date. Both of these variations are consistent with expected patterns and should be predictable.

CRITICAL VALUES (approximate for a normal year):

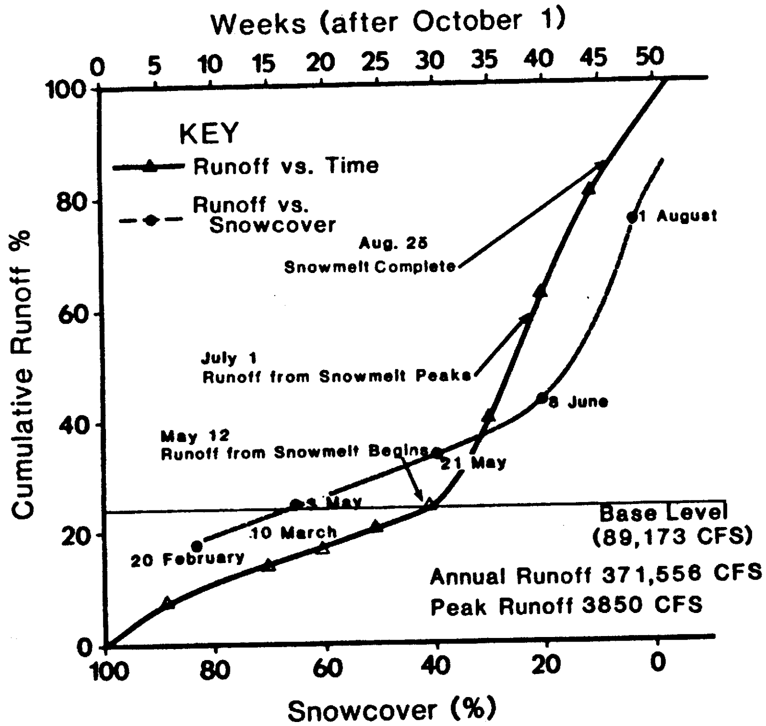
Beginning of runoff from snomelt: April 25
Peak of runoff augmented by snowmelt: July 1
Snowmelt complete (no measureable snowcover): August 12
Percent runoff provided by snowpack: 55%
Peak runoff volume (normal year): 6500 cfs/day
Guage number used in estimating runoff: #62255 on the Wind River near Crowheart



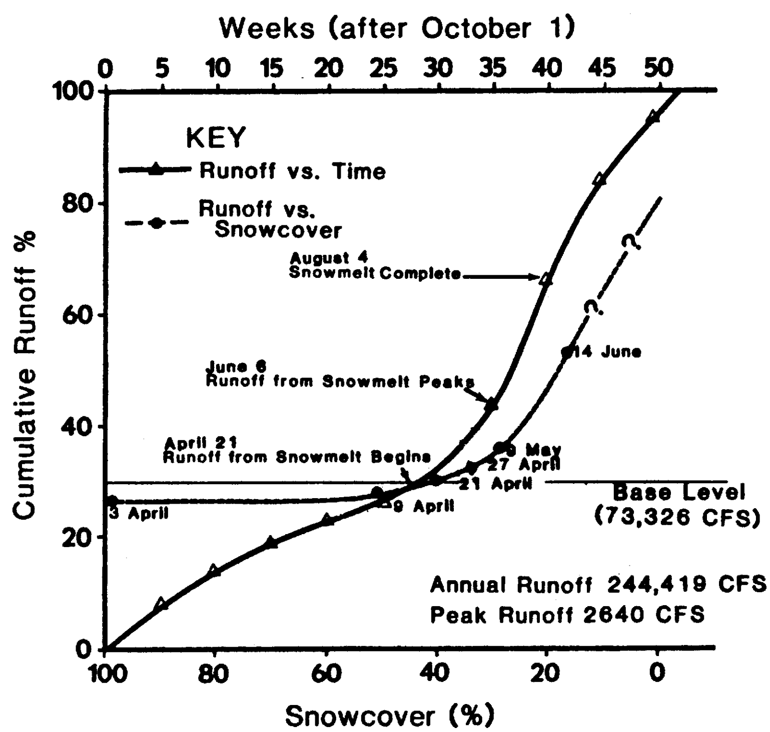
Upper & Middle Wind River
RUNOFF VS. TIME AND SNOWCOVER (%),1977-78



Upper & Middle Wind River
RUNOFF VS. TIME AND SNOWCOVER (%), 1972-73



Upper & Middle Wind River
RUNOFF VS. TIME AND SNOWCOVER (%), 1976-77



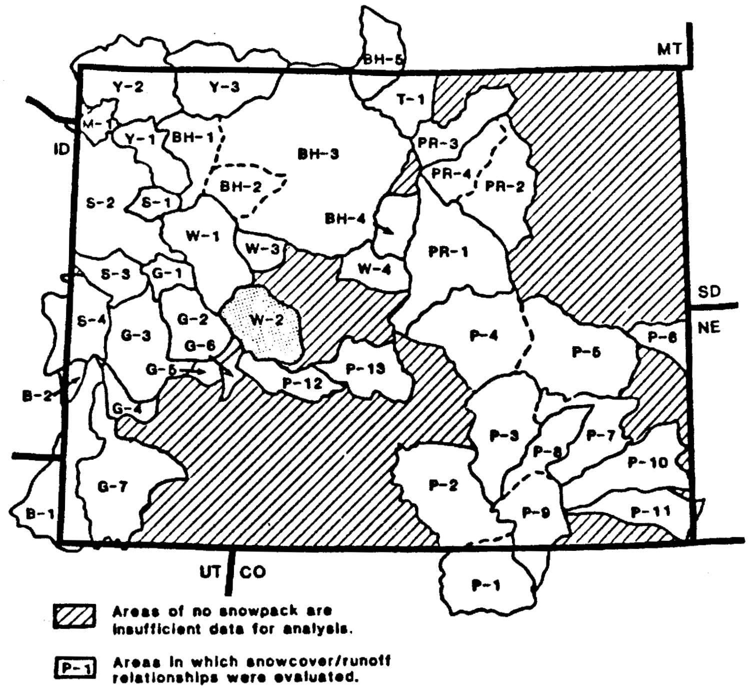
SNOWMELT AND RUNOFF PATTERNS: POPO AGIE AND LITTLE WIND RIVER

Landsat imagery for only one snowmelt season was available for the relatively brief period of recorded runoff on the Popo Agie and Little Wind rivers. Only one snowcover/runoff curve could be constructed (1981). However, seven dates of coverage are available for the 1981 snowmelt season; so, the curve is considered very reliable, but it provides only a single record for a year in which the annual discharge was somewhat below normal (141,646 cfs as compared to the 1980 thru 1982 average discharge of 186,224 cfs). Thus, 1981 is considered a dry year (runoff 76% of normal). Four snowcourses in the area also show that 1981 was a dry year with snowfall well below normal. It is interesting to note that the snowcourse data for the Popo Agie and Little Wind river areas for 1973 and 1978 indicate that this area sometimes has snow accumulations that contrast sharply with those recorded in other parts of the Wind River Range. However, in 1977 and 1981 the snowcourse data show similar snow accumulation patterns for the entire region.

During a normal snowmelt season, the base level for runoff would probably be slightly lower in terms of percent runoff, but higher or about the same as recorded in 1981 in terms of volume of runoff (cfs). Also the peak flow period and the end of snowmelt should occor at a slightly later time than in 1981. The snowmelt season might be expected to extend into mid-August for a year of normal snow accumulation. Percent runoff from snowmelt should also increase to 70 or 75 percent for a typical year. Both peak flow rate and average discharge for the season would probably be 20 to 25% higher for a normal year.

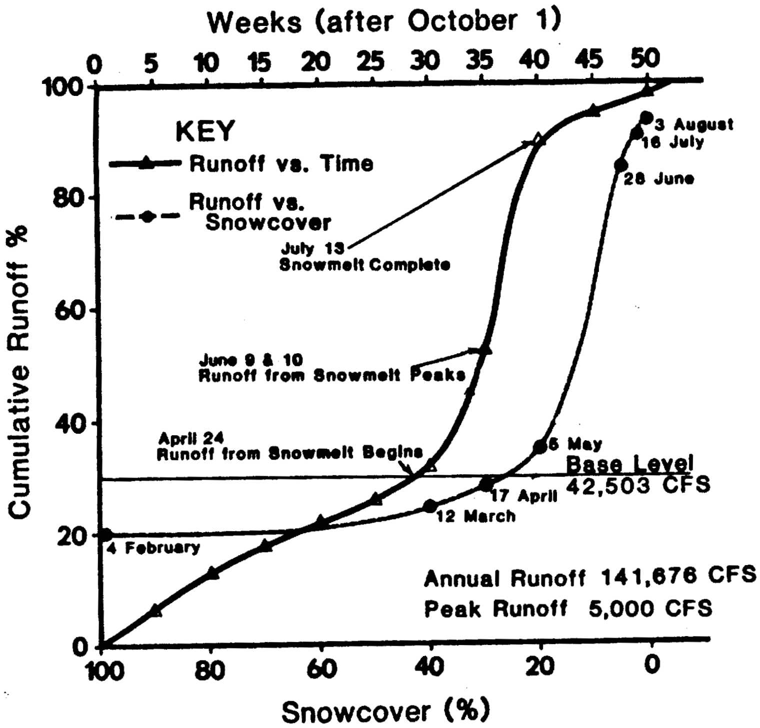
CRITICAL VALUES (for 1981, a dry year)

Beginning of runoff from snowmelt: April 24
Peak of runoff augmented by snowmelt: June 9 or 10
Snowmelt complete (no visible snow): August 3 (runoff decreases markedly about July 13, prior to completion of snowmelt)
Percent runoff provided by snowpack: 58%
Peak runoff volume: 5000 cfs/day
Guage stations used in estimating runoff: #06239 on the Popo Agie River above Arapahoe and #062310 on the Little Wind River above Arapahoe. Measured flows from these guage stations were summed to obtain values for runoff.



Little Wind and Popo Agie Rivers

RUNOFF VS. TIME AND SNOWCOVER (%), 1981



SNOWMELT AND RUNOFF PATTERNS: MUDDY AND FIVEMILE CREEKS

The discharge data is limited to two water years (1972 and 1973). Even though only four Landsat images were available for the 1973 water year, the 1973 snowmelt curve is considered fairly reliable because the data are well distributed through the melt season.

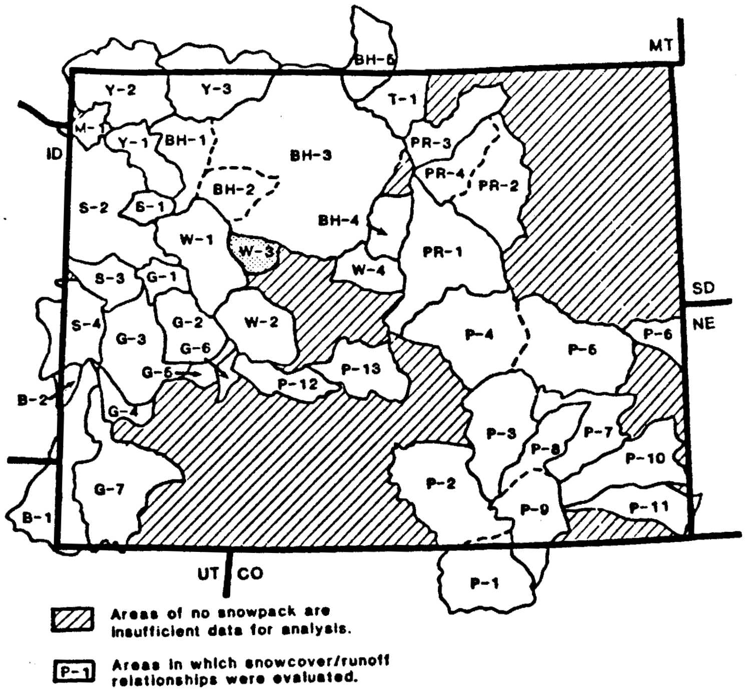
Analysis of water content of snow from snow courses in the Upper Wind River Basin shows that 1973 was a relatively dry year. This is consistent with the flattened S-shape discharge curve for 1973. Discharge curves for normal years have a more pronounced S-shape; while dry or drought years tend towards a straight line. The snowmelt-runoff curve for this area is similar to that of Badwater Creek.

The snowmelt-runoff relationship generated by the analyses of this very limited data set probably gives a reasonable representation of pattern that would be observed on a normal year. Both the peak runoff and annual runoff might be slightly higher most years and the snowpack might last until mid-June in the upper reaches of the basin. Date of peak runoff (May 15) and proportion of runoff resulting from snowmelt (50%) should not vary significantly.

CRITICAL VALUES (values approximate--based largely on 1973 data):

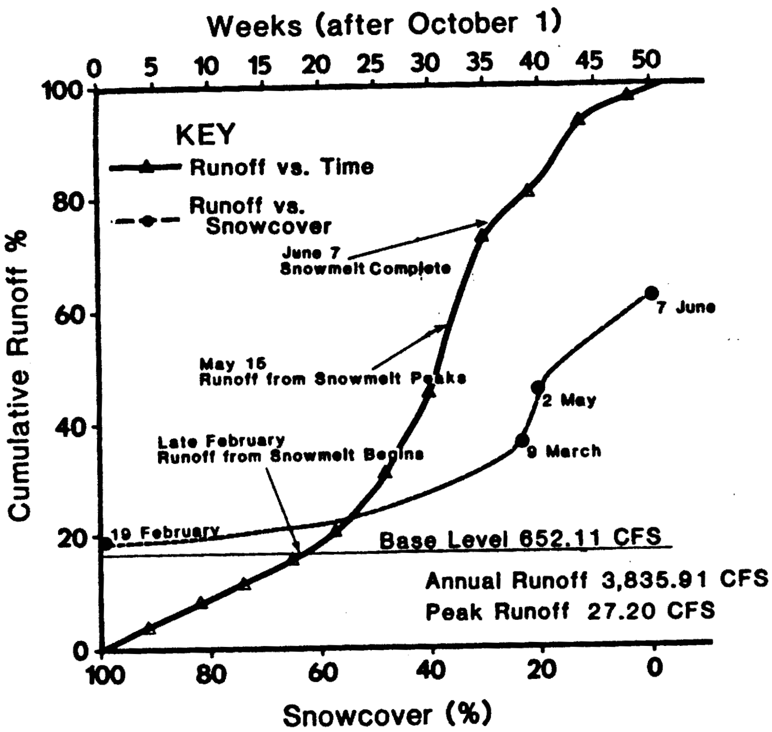
Beginning of runoff from snowmelt: Late February
Peak of runoff augmented by snowmelt: May 15
Snowmelt complete (no measureable snow): June 7
Percent runoff provided by snowpack: 50%
Peak runoff volume: 27 cfs/day
Gauge stations used in estimating runoff: #062575 Muddy Creek near Pavillion, #062445 Fivemile Creek above Wyoming Canal

Runoff from the area estimated as the sum of values recorded at these stations.



Muddy and Fivemile Creeks

RUNOFF VS. TIME AND SNOWCOVER (%), 1973



AREA W-4

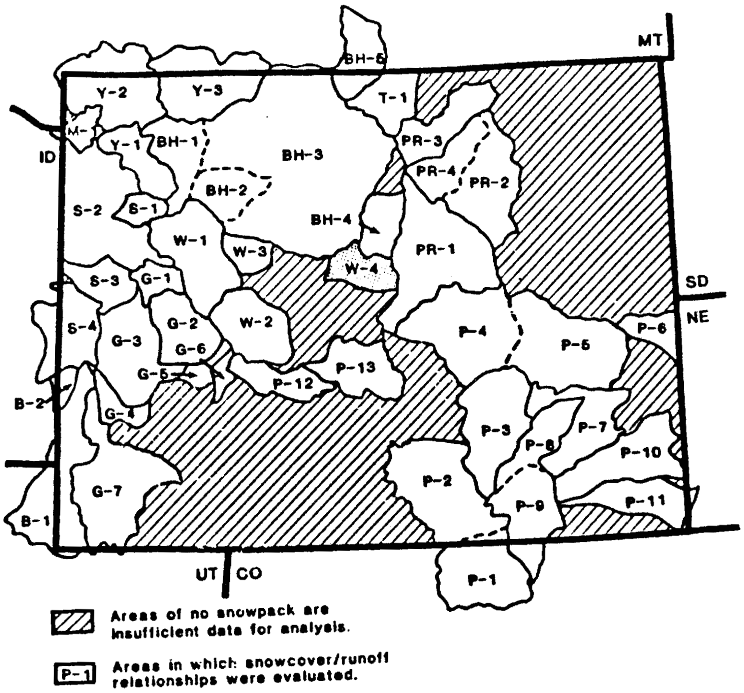
SNOWMELT AND RUNOFF PATTERNS: BADWATER DRAINAGE

Runoff measurements were available only for the 1972-1973 snowmelt season in the Badwater drainage. Fortunately, Landsat data were also available for this same period. The 1973 snowmelt season was only slightly below average in adjacent drainage areas, so the 1973 data for the Badwater drainage are considered reasonably representative of an average year.

Snowmelt begins in the Badwater drainage in late February or early March and continues through April and May. The snowpack is usually depleted by early June. In 1973, peak runoff occurred on May 21 with 800 cfs/day of discharge measured at the Bonneville gauge station. Badwater Creek is somewhat unusual because it is dry for much of the year and runoff is recorded only during spring snowmelt and for brief periods of heavy rain. The snowmelt produces about 80% of the runoff in the Badwater drainage, so water supply from Badwater Creek is greatly dependent upon the snowpack. Snowmelt is rather abrupt and the sparse data (1972-73) indicate that beginning dates and dates of peak discharge fluctuate widely depending upon daily temperature during the spring snowmelt. Prediction of peak flow volumes and their timing is extremely difficult in the Badwater drainage, and the data is considered inadequate for such predictions; but the total expected discharge may be forecast from snowcover estimates if the 1973 data can be considered representative of a near-average year. The snowcover-runoff relationship in the Badwater drainage is similar to that of the Muddy and Fivemile Creek drainages.

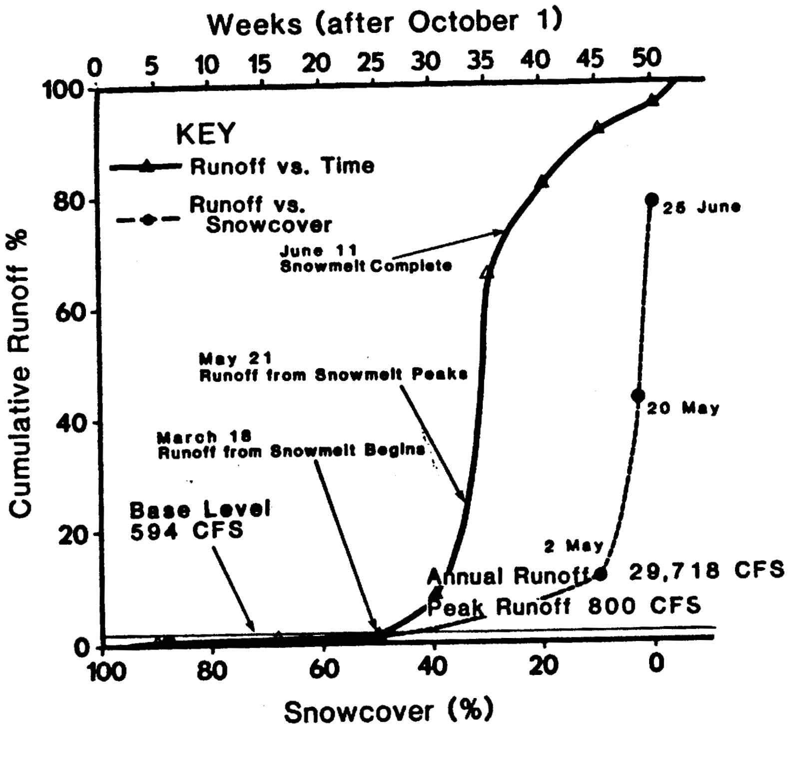
CRITICAL VALUES:

Beginning of runoff from snowmelt: Late February or early March
Peak of runoff augmented by snowmelt: (data insufficient for estimate)
Snowmelt complete (no visible snow remaining): Early June
Percent runoff provided by snowpack: 80-85%
Peak runoff volume: 1600 cfs/day (two-year high)
Gauge station used in estimating runoff: #62570, Badwater Creek near Bonneville, Wyoming

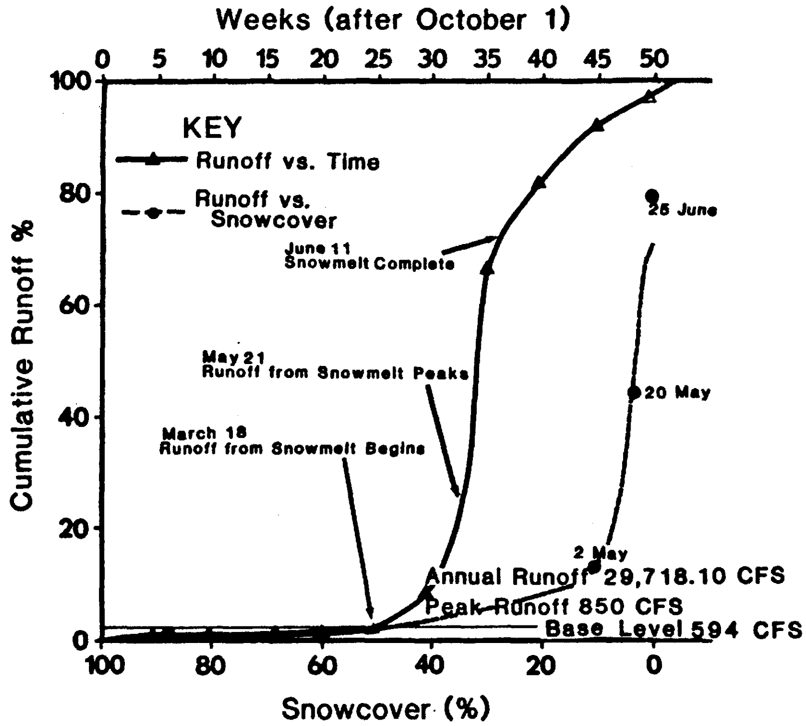


Badwater Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (average)



Badwater Creek
RUNOFF VS. TIME AND SNOWCOVER (%), 1973



SNOWMELT AND RUNOFF PATTERNS: SHOSHONE RIVER (NORTH AND SOUTH FORKS)

Stream gauge data for the North Fork of the Shoshone are limited to 1979-1982, so only the 1981 snowmelt season could be evaluated separately. Although 1981 may have been a reasonably average year, we elected to combine the data from the North and South Forks of the Shoshone River in this analysis. We believe that the two drainage areas have similar snowmelt-runoff patterns.

Snowmelt and runoff data for three years (1977, 1979, and 1981) were used to derive a relationship between snowmelt and runoff for the drainage of the Shoshone River. The 1981 data are most nearly representative of an "average" year for this drainage, with about 121,000 cfs of total runoff for the year. Consequently, the snowmelt pattern interpreted from the 1981 imagery is considered a reasonably close approximation to the expected pattern for a normal year. The average relationship defined for this area is taken from the 1981 data adjusted to reflect the slightly faster snowmelt and larger runoff values expected in a year when the discharge is 147,000 cfs (approximately).

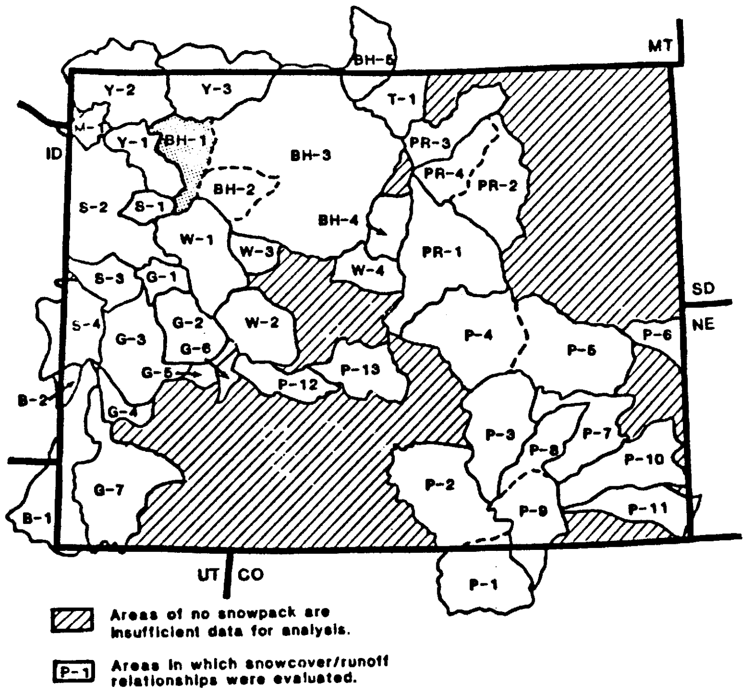
Spring runoff from snowmelt represents 60-65% of the discharge of the Shoshone River. Discharge at the gauging station above Buffalo Bill Reservoir (#62810) increases from about 100 cfs to 3,800 average peak cfs for a typical runoff season. Water management appears to exert relatively little influence on the runoff pattern and the interpreted relationship is a fairly typical one for a mountain drainage in which snowpack is the major component of water supply. The runoff pattern is consistent from year to year, and water supply forecasts can be made from the snowcover-runoff relationships with considerable confidence.

Peak runoff typically occurs on June 15 or 16, but tends to be slightly later on years of heavy snowpack (1982, runoff peak-June 30, total discharge-196,525 cfs) and earlier on years of light snowpack (1977, runoff peak-June 5, total discharge-66,525 cfs). Snowmelt is essentially complete in the Shoshone watershed by July 20.

Snowpack, as estimated from snow course measurements, was well below average for 1981, but runoff was slightly greater than normal, indicating that much of the 1981 runoff was the result of late snows and spring rains. In this area, the snow courses at higher and lower elevation sometimes give conflicting indications of moisture content. We anticipate that estimates of expected runoff from satellite snowcover surveys will prove especially helpful in areas such as this.

CRITICAL VALUES:

Beginning of runoff from snowmelt: April 6
Peak of runoff augmented by snowmelt: June 15 or 16
Snowmelt complete (no visible snow remaining): July 20
Annual average discharge: 146,924 cfs (South Fork)
343,073 cfs (North Fork)
Percent runoff provided by snowpack: 60-65%
Peak runoff volumes (average year): 3,812 cfs (South Fork)
8,250 cfs (North Fork)
Gauge stations used in estimating runoff: #62810, South Fork of the Shoshone River above Buffalo Bill Reservoir, near Cody, Wyoming; #62800, North Fork of the Shoshone River near Wapati, Wyoming



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BH-4
W-1
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PR-1
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G-2
W-2
P-4
P-5
P-6
G-6
G-5
P-12
P-13
B-2
G-4
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P-10
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P-2
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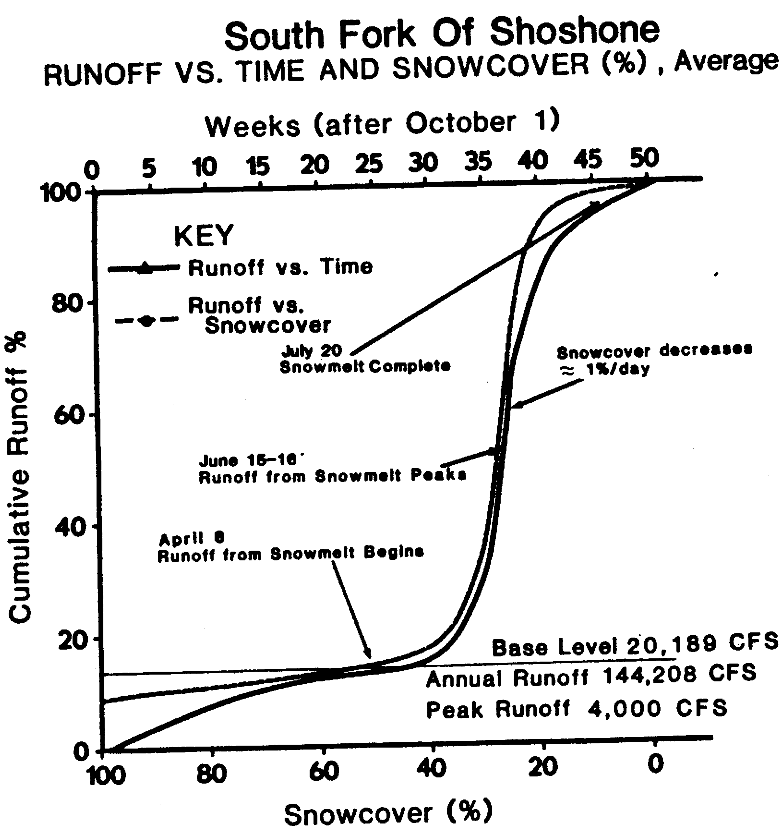
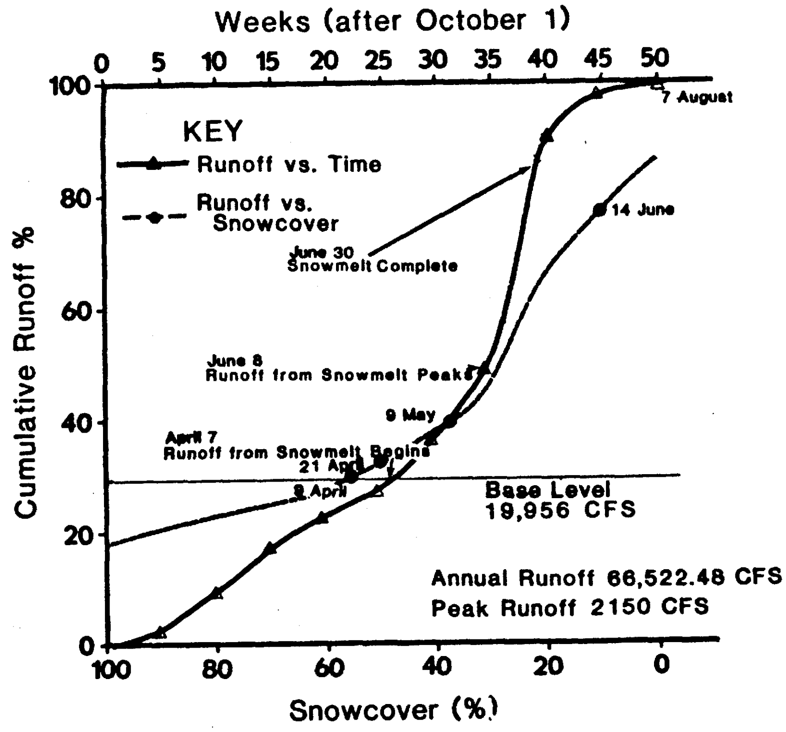
P-9
P-11
P-1
Areas of no snowpack are insufficient data for analysis.
Areas in which snowcover/runoff relationships were evaluated.

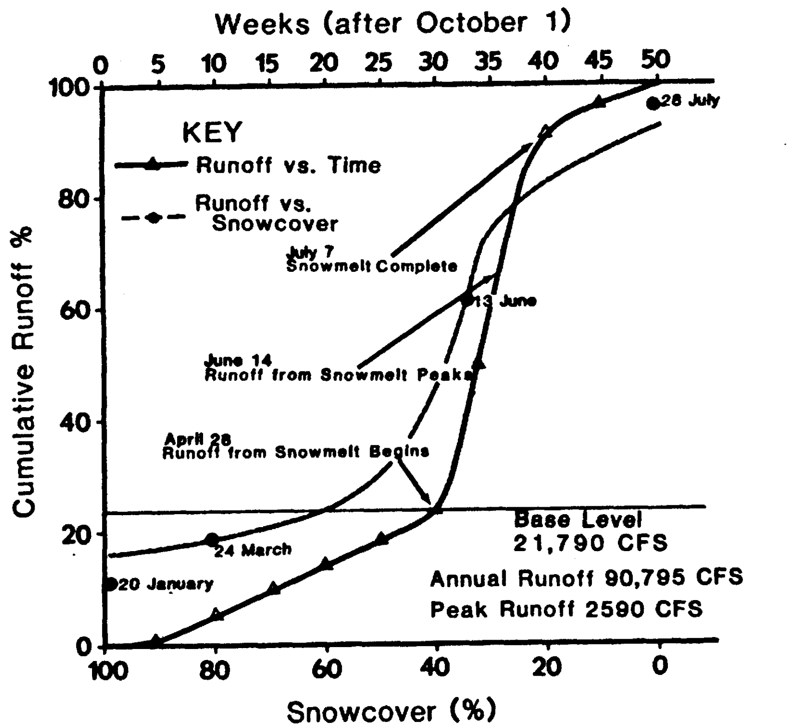


South Fork Of Shoshone
RUNOFF VS. TIME AND SNOWCOVER (%), Average
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
July 20 Snowmelt Complete
Snowcover decreases ≈ 1%/day
June 15-16 Runoff from Snowmelt Peaks
April 8 Runoff from Snowmelt Begins
Base Level 20,189 CFS
Annual Runoff 144,208 CFS
Peak Runoff 4,000 CFS
Cumulative Runoff %
0
20
40
60
80
100
100 80 60 40 20 0
Snowcover (%)

South Fork Of Shoshone
RUNOFF VS. TIME AND SNOWCOVER (%), 1977

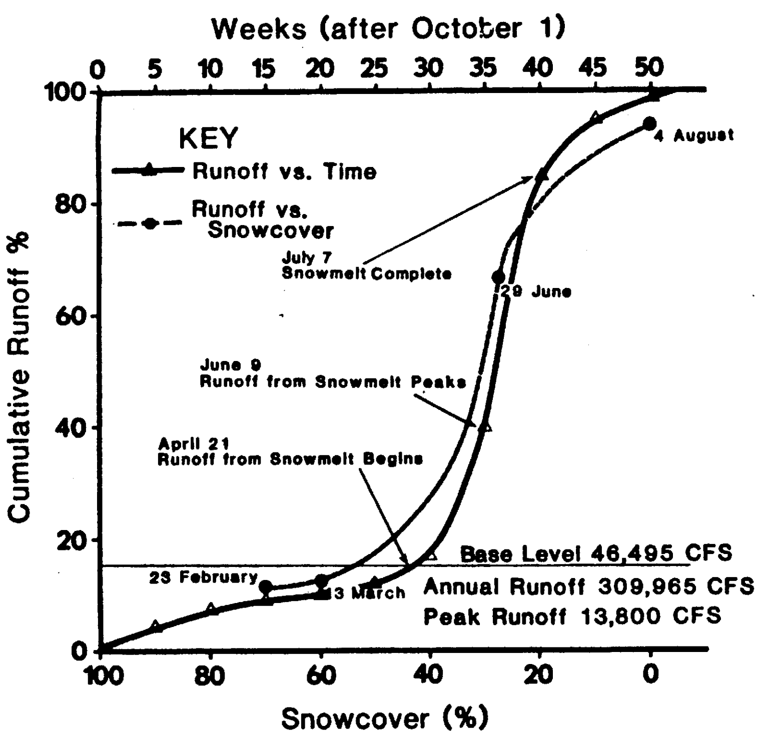


South Fork Of Shoshone
RUNOFF VS. TIME AND SNOWCOVER (%), 1979



North Fork Shoshone River

RUNOFF VS. TIME AND SNOWCOVER (%), 1981



AREA BH-2

SNOWMELT AND RUNOFF PATTERNS: GREYBULL RIVER

In order to determine snowmelt-runoff curves for the Greybull drainage above Meeteetse, estimates of the total annual flow were projected because of incomplete streamflow data for the first six months of the year. Complete streamflow records for other western drainages in this study show a slight increase in moisture during the fall and a decrease in available moisture during intense cold spells during the winter months. Thus, instead of assuming a constant daily flow for the six months of missing data, we assumed a changing flow through time.

This method of estimation does not take into account the variation due to climate fluctuations over the 11 water years (1972-82). Therefore, we expect the slope of the time/runoff curve during the first six months of the year to be steeper for dry years than for average or wet years. The estimated slope of the plotted runoff curve for the first six months is representative of average or wet years.

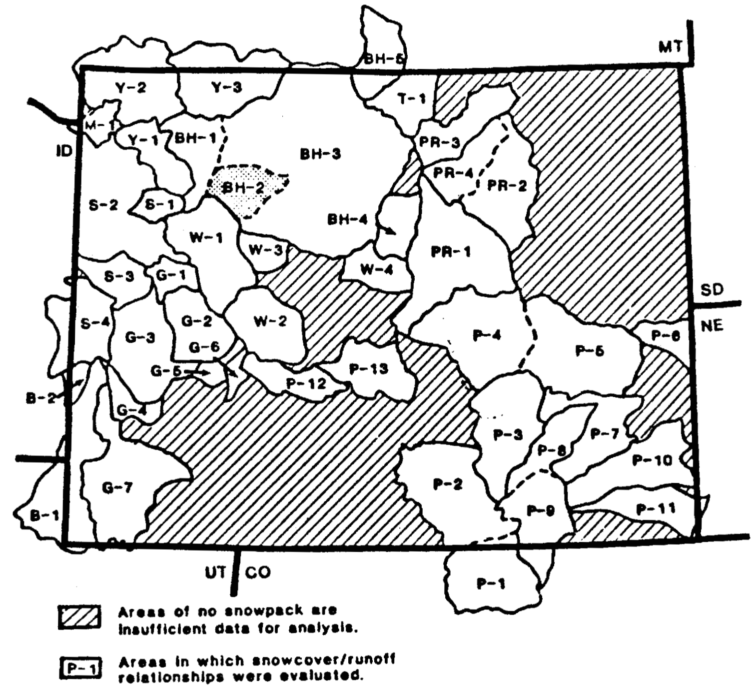
Gauge station #62765 provides information on runoff for the western Bighorn Basin. These curves compare favorably with the data from drainages of the eastern Bighorn Basin, the total Bighorn Basin, and the Clark's Fork River of the western Bighorn Basin.

According to snow course data, the snowpack accumulated for 1981 is below average (dry to very dry) for all drainages on the western side of the Bighorn Basin. Yet, for all the western drainages the 1981 discharge is the highest of the water years examined. The upper Greybull drainage is no exception to this observation. This is attributed to spring snows and abnormally high spring rainfall.

The correlation of discharge values and snow-course data is poor in the western Bighorn Basin drainage. For example, the water year 1979 is above average (wet) according to snow-course data and below average (dry) according to average discharge values. In other drainages in this region snow courses at high and low elevations showed a difference in apparent climate. The Upper Greybull drainage has only one snow course at which available water content of snow was estimated. Thus, we could not determine whether the accumulated snowpack for the entire area was above or below average in 1979.

CRITICAL VALUES:

Beginning of runoff from snowmelt: Late April-early May
Peak of runoff augmented by snowmelt: late May-early June
Snowmelt complete (no visible snow): July
Percent runoff provided by snowmelt: 70%
Peak runoff volume (normal year): 2,171 cfs
Gauge station used in estimating runoff: #062765, Greybull River at Meeteetse



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P-3
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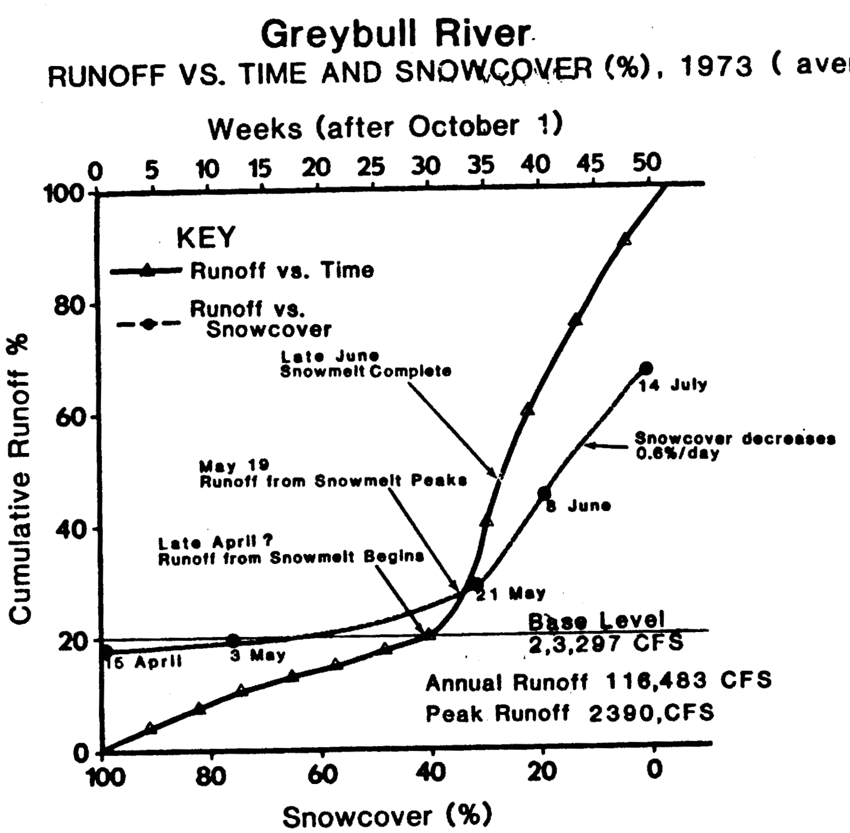
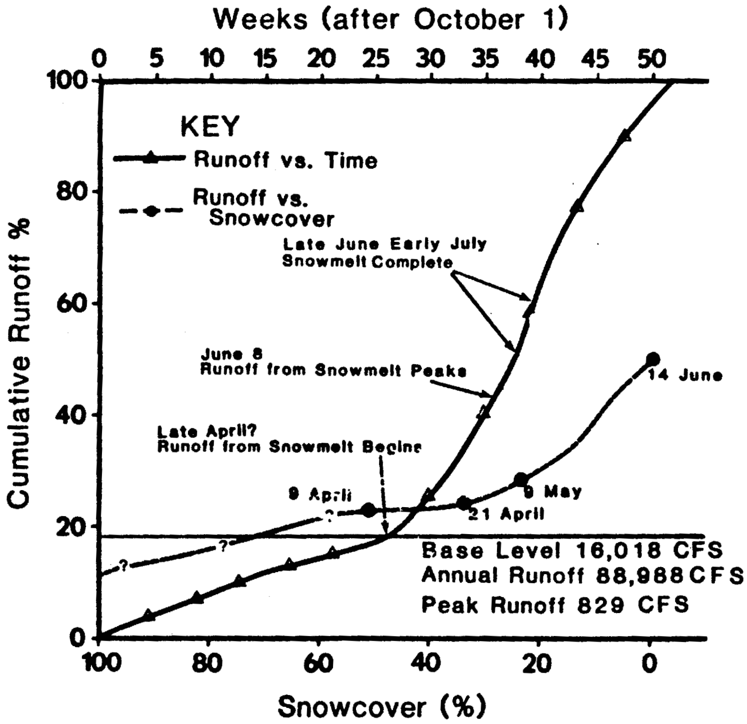
P-7
P-10
G-7
P-2
P-9
P-11
B-1
P-1
Areas of no snowpack are insufficient data for analysis.
P-1 Areas in which snowcover/runoff relationships were evaluated.

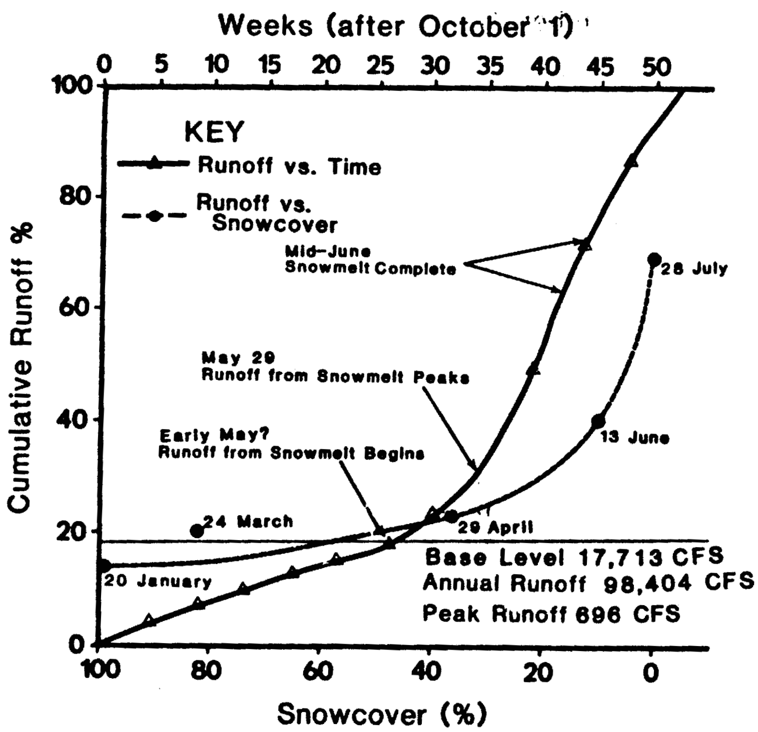


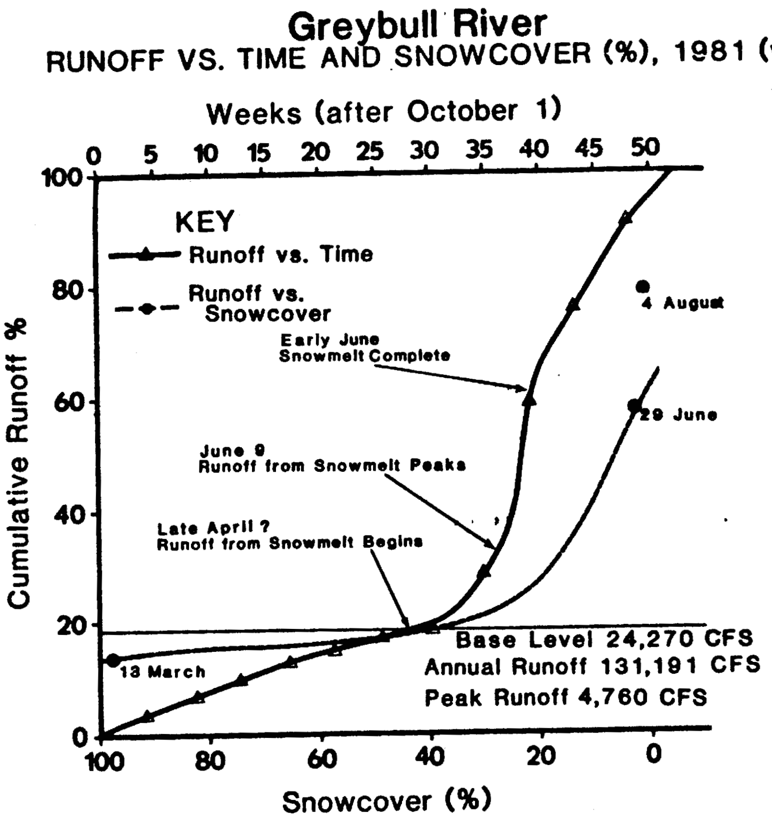
Greybull River
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (average)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
Cumulative Runoff %
100
80
60
40
20
0
Late June Snowmelt Complete
14 July
Snowcover decreases 0.6%/day
May 19 Runoff from Snowmelt Peaks
8 June
Late April ? Runoff from Snowmelt Begins
21 May
Base Level 2,3,297 CFS
15 April
3 May
Annual Runoff 116,483 CFS
Peak Runoff 2390,CFS
100 80 60 40 20 0
Snowcover (%)

Greybull River
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (dry)



Greybull River
RUNOFF VS. TIME AND SNOWCOVER (%), 1979 (dry)




Greybull River
RUNOFF VS. TIME AND SNOWCOVER (%), 1981 (wet)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
Early June Snowmelt Complete
June 9 Runoff from Snowmelt Peaks
Late April ? Runoff from Snowmelt Begins
4 August
29 June
13 March
Base Level 24,270 CFS
Annual Runoff 131,191 CFS
Peak Runoff 4,760 CFS
100 80 60 40 20 0
Snowcover (%)

SNOWMELT AND RUNOFF PATTERNS: BIGHORN RIVER DRAINAGE AREA

The snowmelt-runoff curves for the Bighorn River drainage were constructed differently from other curves because stream data is available only at 2 locations for the Bighorn River, thus making it necessary to use 3 Landsat scenes to cover the total drainage.

Percentages of the drainage covered by the Bighorn Mountains, Northern Absaroka and Wind River Basin images were estimated along with snowcover for each portion. Snowcover estimates from each image were multiplied by the appropriate estimate for 100% of the drainage.

All of the dates on the 1973 runoff curve, except February 19, are dates for which snowcover was estimated for 100% of the basin. The February 19 data was taken from a Bighorn Mountain image and accounts for 66% of the drainage area. It is assumed that the proportion of snowcover measured in the 66% portion of the drainage is representative of the whole.

Unlike other drainage areas, the start and end of snowmelt is gradual and difficult to determine. Runoff data on the Bighorn River near Kane (station no. 062795.00) is considered the best available estimate of basin runoff patterns because it is not influenced by management activity as greatly as the station immediately below Boysen Reservoir.

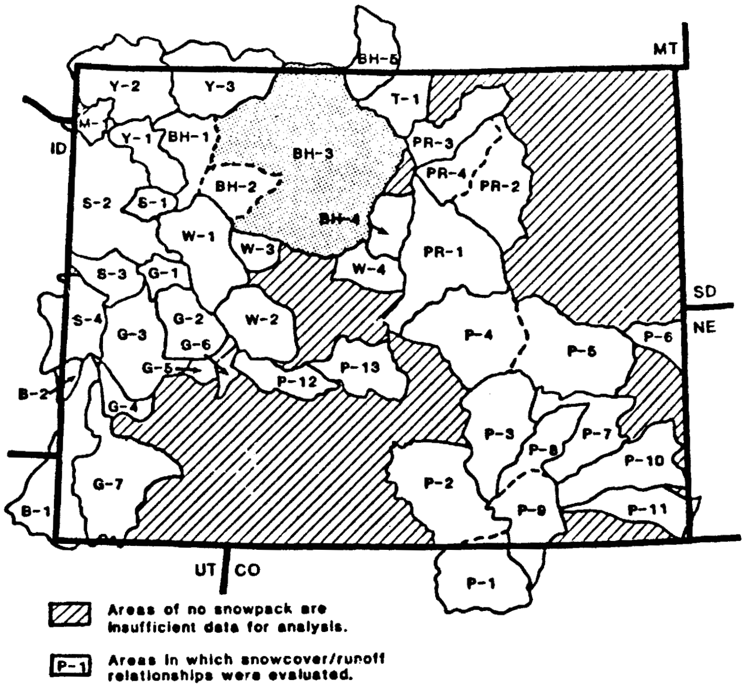
Snowmelt in the Bighorn drainage begins in late February, but runoff increase is not evident at the Kane gauge station until early April. From the end of March to mid-April, temperatures usually remain cool. Late spring snows augment the melting snowpack. Snowmelt usually peaks about May 21 and ends during the first week of July.

The 11-year average flow at Kane is 836,472 cfs. Outflow from Boysen Reservoir, measured at station no. 62590, averages 539,537 cfs. By subtracting Boysen's average outflow from the flow at Kane, the average annual flow for the Bighorn Basin is 295,243 cfs. May and June are the peak months of runoff. The 11-year average peak discharge at Boysen is 2731 cfs. The 11-year average peak discharge at Kane is 7010 cfs.

One unusual feature of the Bighorn River runoff data is that cumulative flow between two gauging stations can exceed 100%, if water use in the area exceeds the inflow of water from tributaries in that region such that some water is used from the inflow from a higher portion of the drainage. In this case, the drought year of 1977 required that the runoff from the Bighorn River be augmented by water from the Wind River Basin flowing through Boysen Reservoir. The runoff pattern recorded for the Bighorn River for the summer months of 1977 is much distorted by water management.

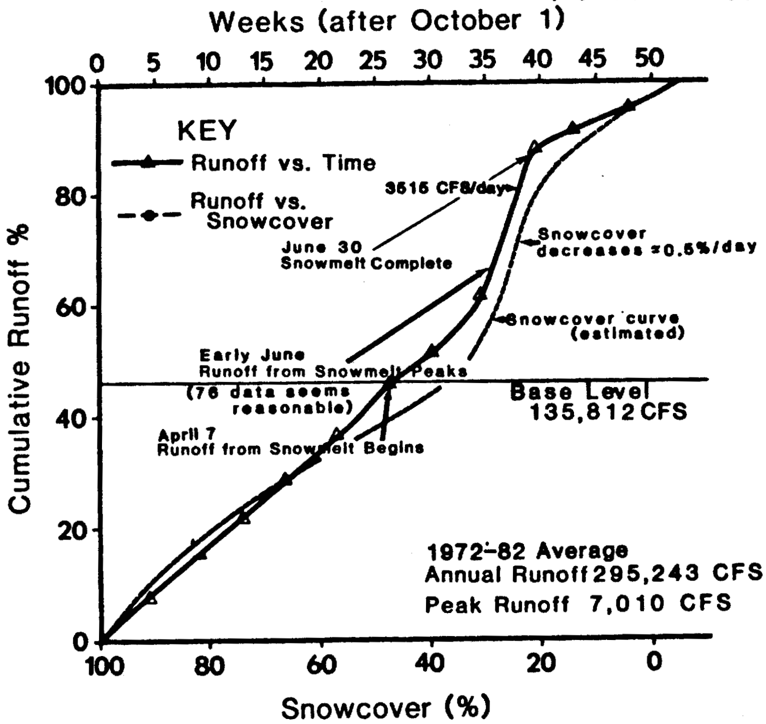
CRITICAL VALUES (for a normal year):

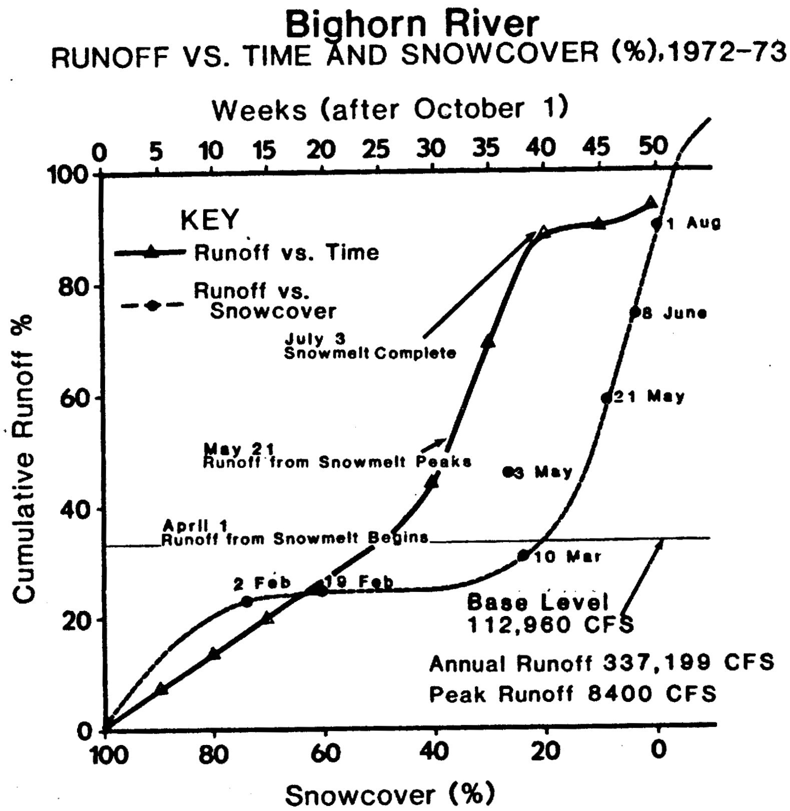
Beginning of runoff from snowmelt: early April
Peak of runoff augmented by snowmelt: early June
Snowmelt complete (no visible snow): June 30
Percent runoff provided by snowpack: 39%
Peak runoff volume: 4,279 cfs (Kane less Boysen values)
Gauge stations used in estimating runoff:
#062795 Bighorn River at Kane less flow values recorded at station
#062590 Wind River below Boysen Reservoir

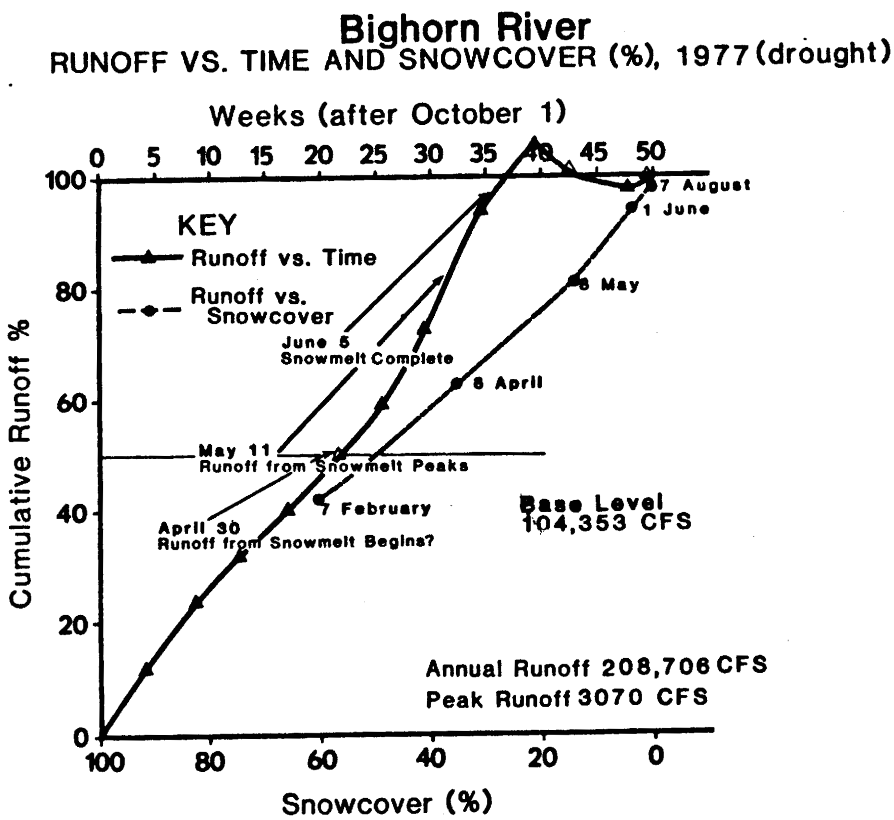


Bighorn River

RUNOFF VS. TIME AND SNOWCOVER (%), Average Curve
(based on 1976 data)




Bighorn River
RUNOFF VS. TIME AND SNOWCOVER (%),1972-73
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
July 3 Snowmelt Complete
May 21 Runoff from Snowmelt Peaks
April 1 Runoff from Snowmelt Begins
2 Feb
19 Feb
10 Mar
3 May
21 May
8 June
1 Aug
Base Level 112,960 CFS
Annual Runoff 337,199 CFS
Peak Runoff 8400 CFS
Cumulative Runoff %
Snowcover (%)


Bighorn River
RUNOFF VS. TIME AND SNOWCOVER (%), 1977(drought)
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
June 5 Snowmelt Complete
May 11 Runoff from Snowmelt Peaks
April 30 Runoff from Snowmelt Begins?
7 February
8 April
8 May
1 June
7 August
Base Level 104,353 CFS
Annual Runoff 208,706 CFS
Peak Runoff 3070 CFS
Cumulative Runoff %
Snowcover (%)

AREA BH-4

SNOWMELT AND RUNOFF PATTERNS: NOWOOD CREEK DRAINAGE

Three years' data were available for assessment of the snowmelt pattern of the Nowood Creek drainage (1973, 1976, and 1979), but none of the three years were near average with regard to annual discharge. 1973 was an unusually wet year, and 1976 and 1979 were dry years. However, the data are considered adequate to derive a composite snowcover-runoff curve which is considered representative of an average year. Average annual discharge for the Nowood drainage is 46,431 cfs with snowpack providing 25-40% of the annual discharge during the spring snowmelt. Runoff typically increases from about 50 cfs/day in late winter to 425 cfs/day during the eight-week snowmelt period in April, May and June. Snowmelt usually peaks about May 14 at 1100 cfs/day. With unusually heavy snowpack (1973, 1975, 1978) peak flow occurs about one week later (May 20) and can peak at volumes as high as 3130 cfs/day (1978).

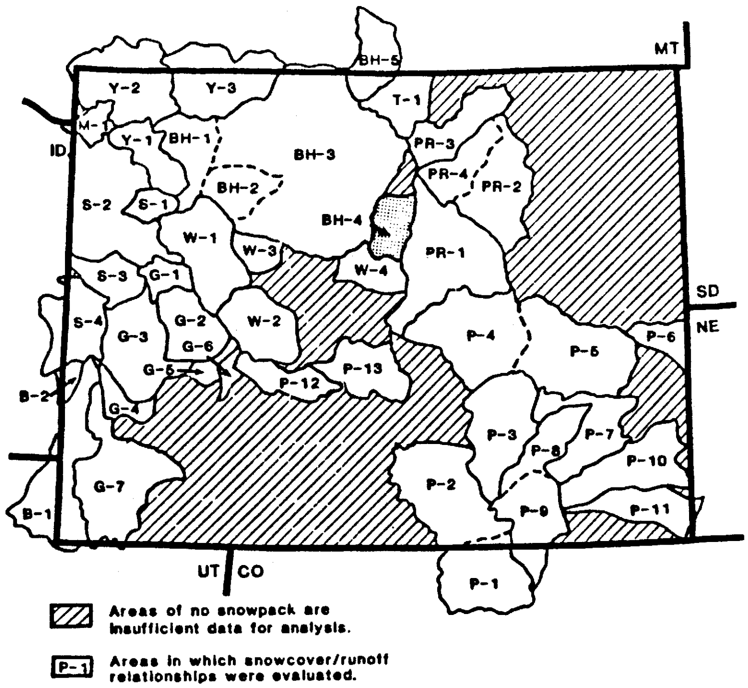
The correlation of discharge and snowcourse data is fair to good for this area. Two out of three estimates show an excellent correlation. The correlation is labelled "fair" because only one snow course with appropriate water content data was located in the Nowood drainage.

According to average discharge values and snow course data, 1973 is a wetter than normal year. Likewise, 1979 is a dry year according to both average discharge values and water content of snow. The water year 1976 shows less than the average discharge (a dry year) yet, the water content of the snow at the Middle Powder site is near average. Thus, as noted in several northwestern drainages, the correlation between average discharge values and estimates of water content of snow is fair to good, but not excellent.

The years for which satellite-derived snowcover data were obtained were not among the wettest or driest years of the past 11 years, so fluctuations in runoff from snowmelt can be expected to span an even broader range than indicated by the plotted curves. In the Nowood Creek area, early estimates of snowcover (early April) may be critical to forecasting available water from snowpack. The snowpack-supplied water can range from 10% to more than 50% of the annual discharge. Larger percentages of discharge are expected in wet years when snowpack is heavy.

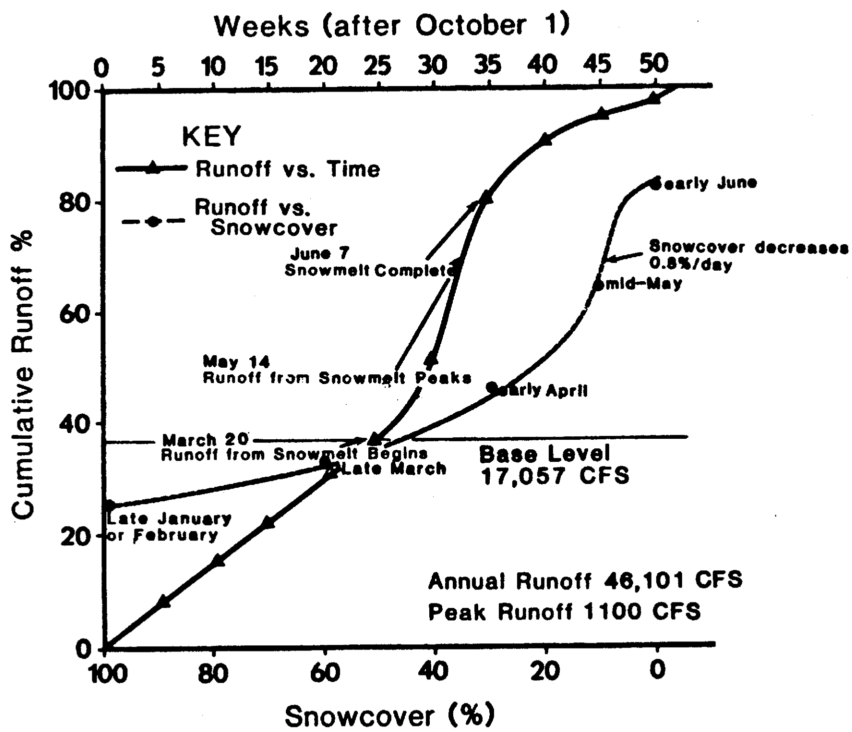
CRITICAL VALUES:

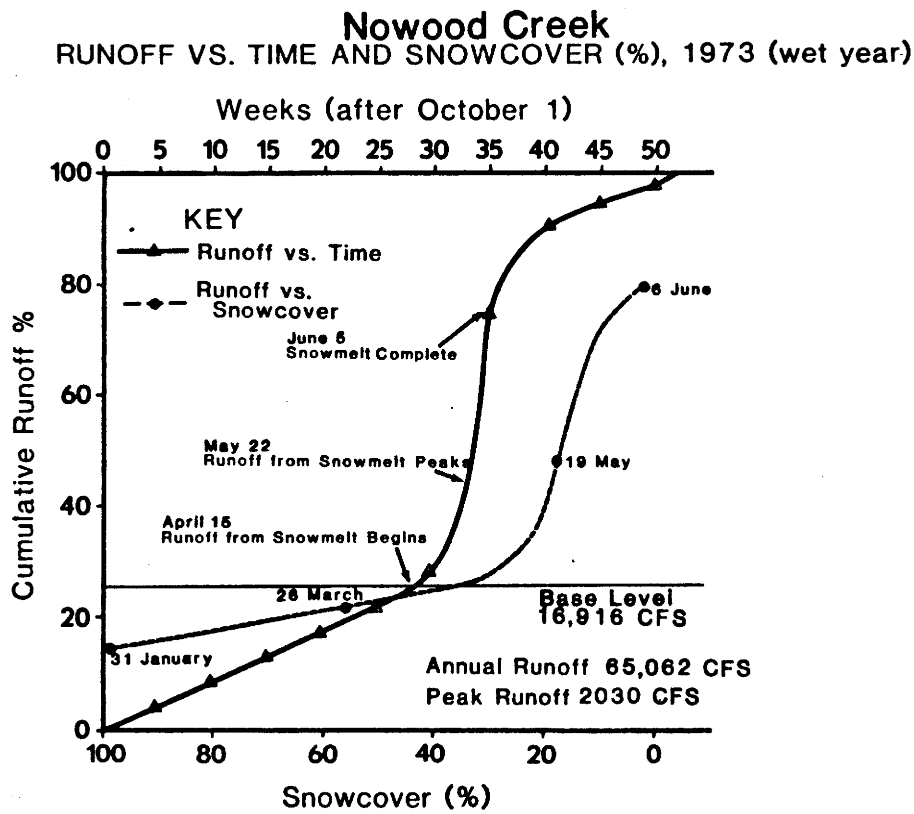
Beginning runoff from snowmelt: March 20
Peak runoff augmented by snowmelt: May 14
Snowmelt complete (no visible snow remaining): June 7
Percent of runoff expected from snowpack: 28%
Peak runoff volume (normal year): 1123 cfs/day
Gauge station used in estimating runoff: #62700, Nowood Creek near Tensleep, Wyoming

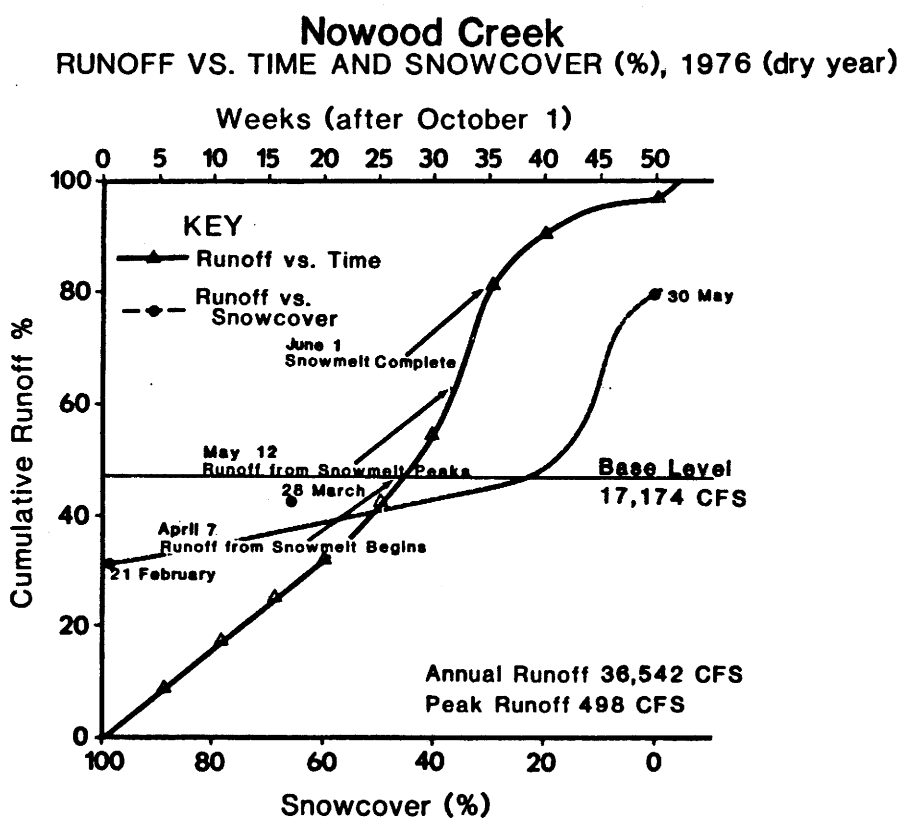


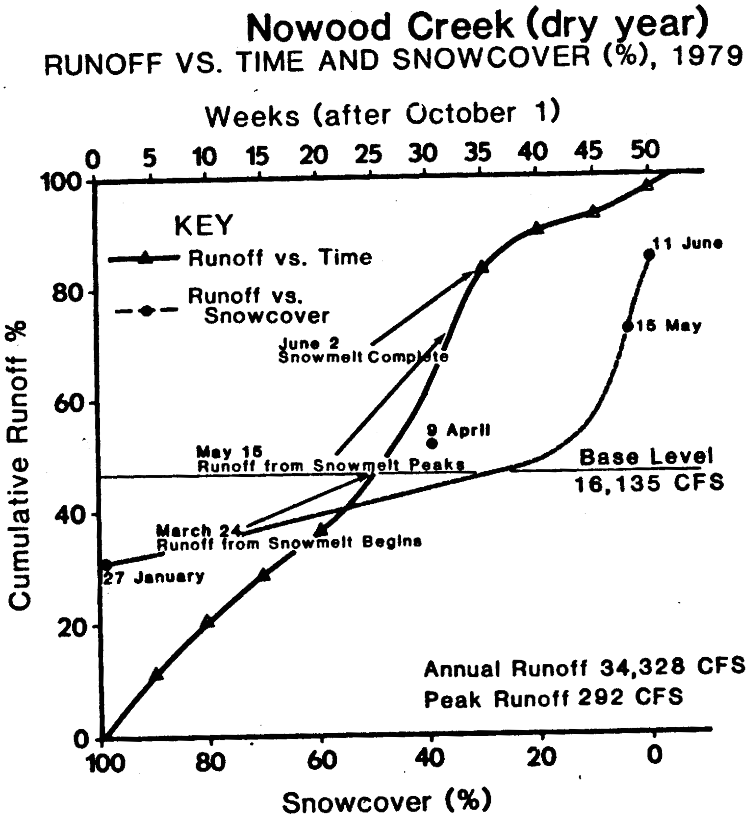
Nowood Creek

RUNOFF VS. TIME AND SNOWCOVER (%), (Average)




Nowood Creek
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet year)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
June 6 Snowmelt Complete
6 June
May 22 Runoff from Snowmelt Peaks
19 May
April 15 Runoff from Snowmelt Begins
28 March
Base Level 16,916 CFS
31 January
Annual Runoff 65,062 CFS
Peak Runoff 2030 CFS
Cumulative Runoff %
100 80 60 40 20 0
Snowcover (%)


Nowood Creek
RUNOFF VS. TIME AND SNOWCOVER (%), 1976 (dry year)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
KEY
Runoff vs. Time
Runoff vs. Snowcover
30 May
June 1 Snowmelt Complete
May 12 Runoff from Snowmelt Peaks
Base Level 17,174 CFS
28 March
April 7 Runoff from Snowmelt Begins
21 February
Annual Runoff 36,542 CFS
Peak Runoff 498 CFS
Cumulative Runoff %
100 80 60 40 20 0
Snowcover (%)


Nowood Creek (dry year)
RUNOFF VS. TIME AND SNOWCOVER (%), 1979
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
Cumulative Runoff %
100 80 60 40 20 0
11 June
15 May
June 2
Snowmelt Complete
9 April
May 15
Runoff from Snowmelt Peaks
Base Level
16,135 CFS
March 24
Runoff from Snowmelt Begins
27 January
Annual Runoff 34,328 CFS
Peak Runoff 292 CFS
100 80 60 40 20 0
Snowcover (%)

AREA BH-5

SNOWMELT AND RUNOFF PATTERNS: LITTLE BIGHORN RIVER

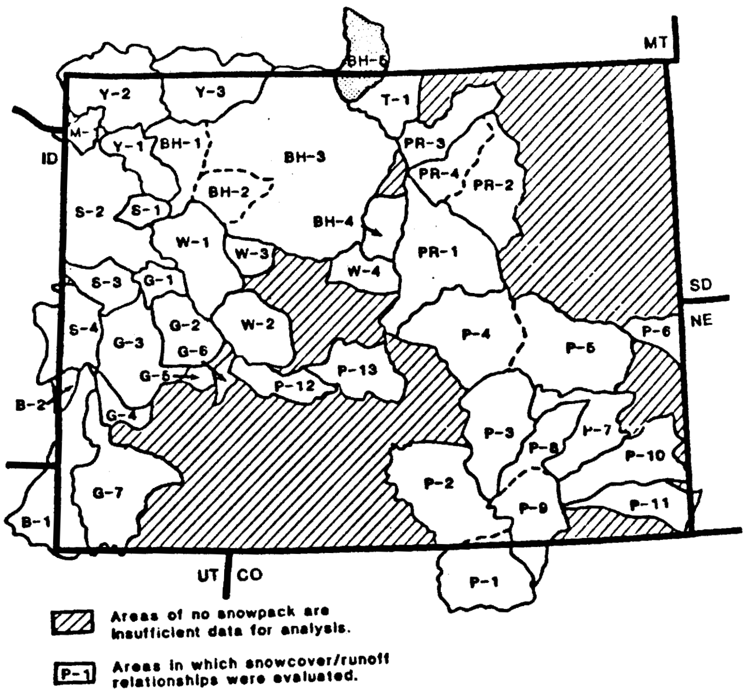
Landsat imagery for the 1973 water year was used to construct the average snowmelt-runoff curve in the Upper Little Bighorn River. Six dates of coverage were available for the 1973 water year. The average snowmelt curve is heavily dependent upon the May 20 and March 9 data values. The large snowcover estimate from the May 2 image probably results from a spring storm. Spring snow storms generally blanket the basin with a thin cover of snow, but do not significantly add to the permanent snowpack in the mountains. The snowcover estimate from the imagery for the 20th of May might also be affected by late spring snows. The abnormally low snowcover estimate for the 9th of March may be due to an error of estimation caused by cloud shadows. The snowcover-runoff curve is projected between these two values.

An average annual discharge of 156,339.80 cfs was computed from five years of available stream flow data. Because the 1973 discharge is only 4% below this average, the 1973 snowmelt-runoff pattern closely approximates an average water year. The change in shape of curves due to variation in discharge (dry or wet years) may be estimated by examining curves from the adjacent Tongue River drainage.

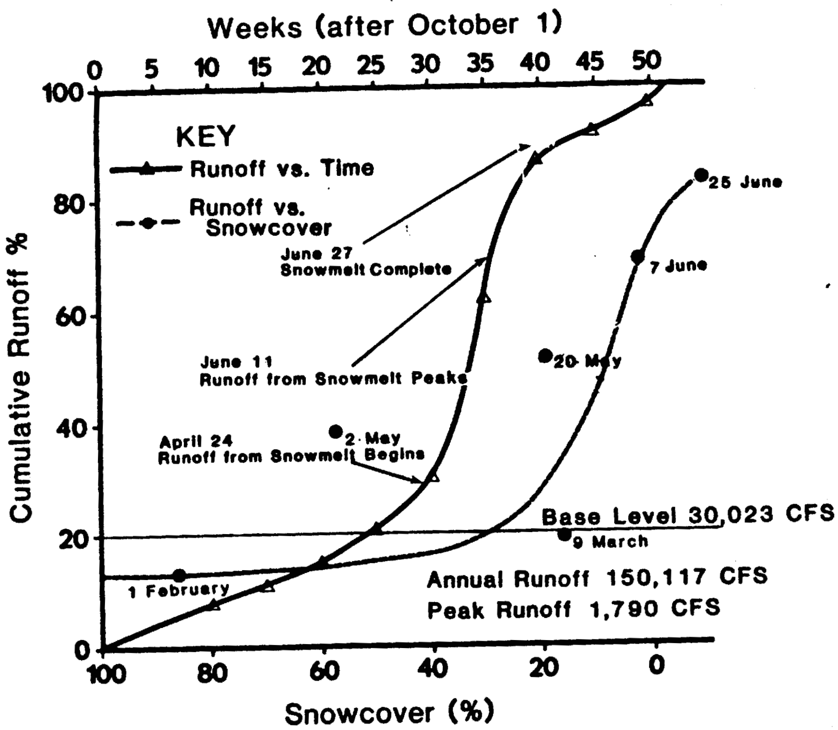
The estimate of a slightly dry water year for 1973 correlates well with water equivalent data from the Bald Mountain snow course. The peak flow of 1790 cfs for the 1973 water year is close to the 5-year average peak flow of 1,752 cfs. Peak runoff occurs in early June.

CRITICAL VALUES (for a normal year):

Beginning of runoff from snowmelt: April 24
Peak of runoff augmented by snowmelt: June 11
Snowmelt complete (no visible snow): June 25
Percent of runoff provided by snowpack: 58%
Peak runoff volume: 1,752 cfs
Gauge station used in estimating runoff: #062940 Little Bighorn River near Hardin, Montana



Little Bighorn River
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (Average)



SNOWMELT AND RUNOFF PATTERNS: TONGUE RIVER DRAINAGE AREA

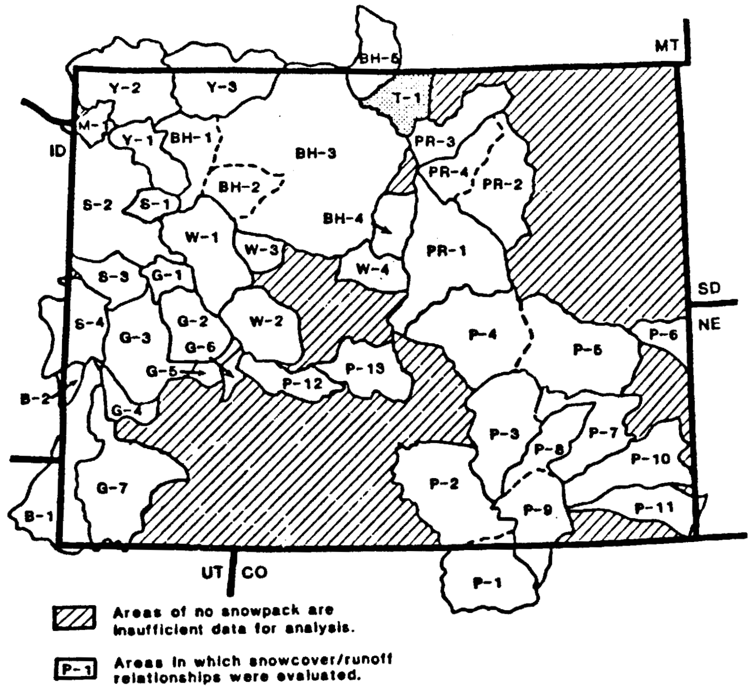
Landsat imagery for 1973, 1977 and 1979 were used to determine the snowmelt-runoff relationship for the Tongue River area. The coverage included six satellite passes for 1973 and seven passes for the spring season, 1977; both data sets well distributed through the melt season. Only four dates of useful coverage were available for 1979; but these four coverage dates are distributed well enough to allow construction of a good snowmelt curve for 1979.

Of the three water years examined, 1979 was the driest year (relative to the average discharge for the eleven-year period 1972-1983 of 182,154cfs). Snow course data for 1979 show that the snowpack was, indeed, below average. The 1977 season was only slightly below average with regard to runoff (159,359cfs). This is also confirmed by snow course measurements in the region. Discharge for 1973 was somewhat above average (202,750cfs).

Snowmelt begins in the Tongue River drainage in early April, peaks in May, and ends in June. The average peak flow for the eleven-year period is 4,010cfs. The highest flow rate recorded during the reference period (1972-1983) was 15,400cfs in 1973 when discharge was 173% of normal for the season. The representative snowmelt/runoff curve for the area was produced by averaging the snowcover values for 1977 (dry year) with those for 1973 (wet year). We believe that the data for the area are reliable and that the computed snowcover/runoff relationship provides a reasonable approximation to the pattern that would be observed in a "normal" year.

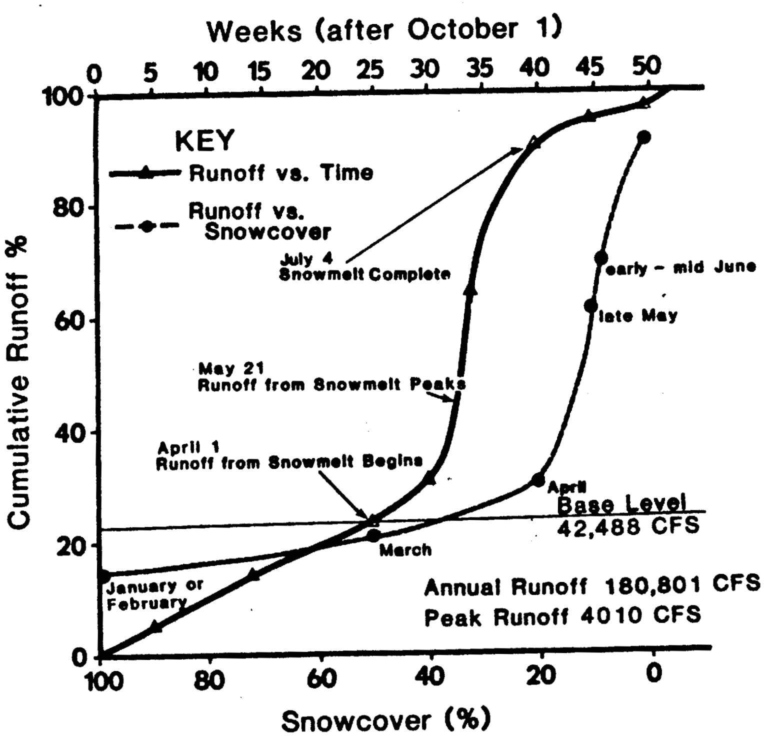
CRITICAL VALUES (approximate for a normal year):

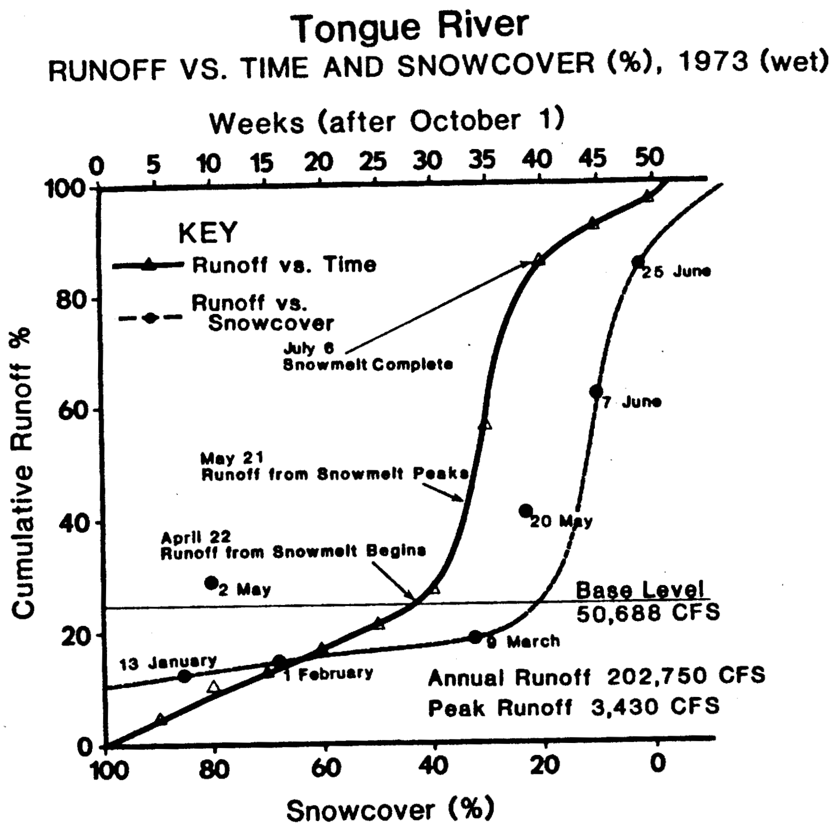
Beginning of runoff from snowmelt: April 1
Peak of runoff augmented by snowmelt: May 21
Snowmelt complete (no visible snow): July 4
Percent runoff provide by snowpack: 60%
Peak runoff volume (normal year): 4,010cfs
Guage station used in estimating runoff: #063063 Tongue River at the Wyoming-Montana state line near Decker, Montana

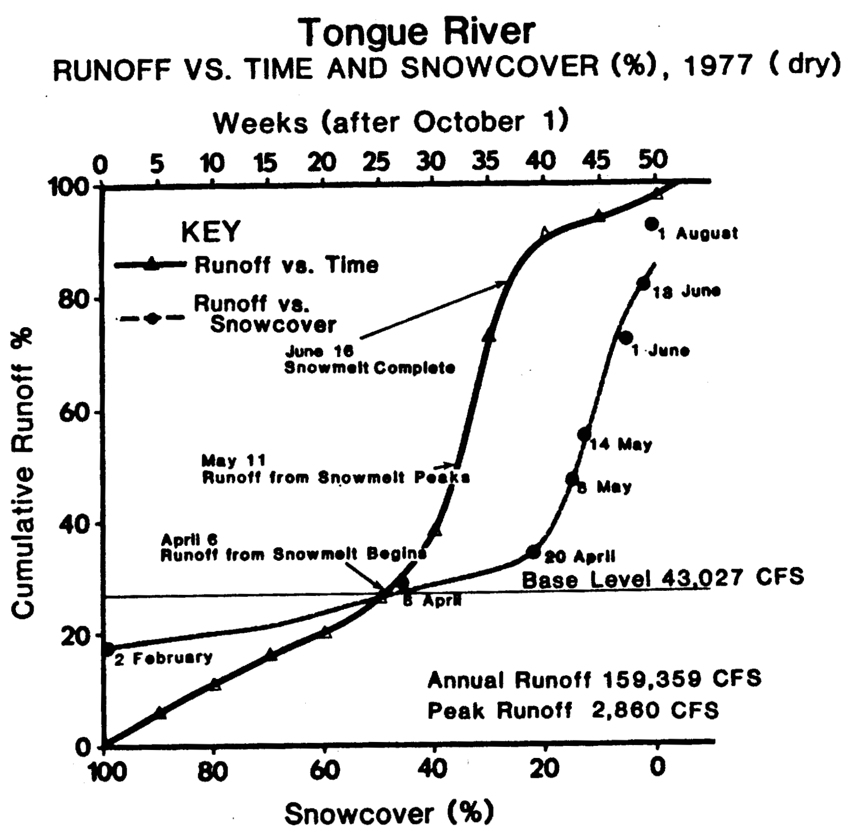


Tongue River

RUNOFF VS. TIME AND SNOWCOVER (%), Average

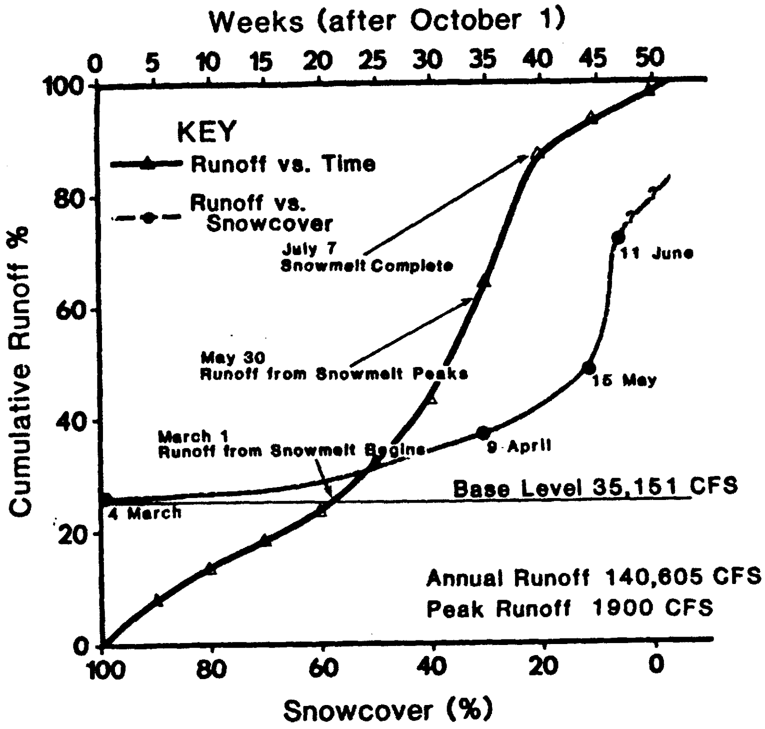



Tongue River
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
July 6
Snowmelt Complete
May 21
Runoff from Snowmelt Peaks
April 22
Runoff from Snowmelt Begins
2 May
13 January
1 February
9 March
20 May
7 June
25 June
Base Level
50,688 CFS
Annual Runoff 202,750 CFS
Peak Runoff 3,430 CFS
Cumulative Runoff %
Snowcover (%)


Tongue River
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (dry)
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
June 16
Snowmelt Complete
May 11
Runoff from Snowmelt Peaks
April 6
Runoff from Snowmelt Begins
2 February
8 April
20 April
8 May
14 May
1 June
13 June
1 August
Base Level 43,027 CFS
Annual Runoff 159,359 CFS
Peak Runoff 2,860 CFS
Cumulative Runoff %
Snowcover (%)

Tongue River

RUNOFF VS. TIME AND SNOWCOVER (%), 1979 (dry)



SNOWMELT AND RUNOFF PATTERNS: UPPER POWDER RIVER DRAINAGE AREA (ABOVE SUSSEX)

Landsat images for 1979 only were used to determine the snowmelt-runoff relationship for the upper Powder River drainage. The Casper Landsat images were used. Part of the drainage area extends onto the area covered by the North Powder River Landsat images; so they were also used when available. Six dates of coverage were available for 1979, the only snowmelt season for which good data were available. The 1979 Landsat data set lacks coverage in February; but a late January and an early March data were available. Stream flow data from station no. 63135.00 on the Powder River at Sussex, Wyoming, were used to determine cumulative runoff values. The flow at this station shows little influence of water management because no major reservoirs are upstream from this gauge station. No sign of water management is apparent from the runoff curve. Flow data were available each day for the years evaluated.

During the 1979 water year, the spring runoff increased 5-fold as snowmelt intensifies during the months of mid-February to early June (from approximately 110 to 540 cfs). A major problem with the data is that only 5 years of gauge data are available, and 1979 runoff is near the 5-year average. Runoff from snowmelt normally begins in mid-February, after the snowpack area has diminished to about 60% of the drainage basin area. Peak runoffs usually occur in late May. The 1979 water year is close to the 5-year average runoff value in which the peak flow occurred on March 14 at 1570 cfs. Peak flows as high as 11,900 cfs (May 19, 1978) were recorded at this station during the 5-year period of record. A typical peak flow rate at this station would be around 2,110 cfs and should occur on May 21.

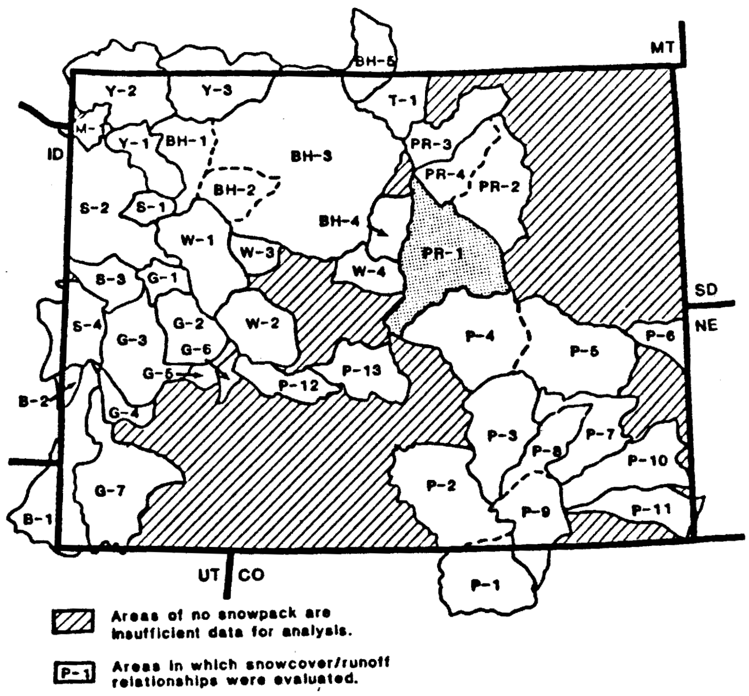
Discharge from the Powder River drainage in 1979 was 1% above the 5-year normal (82,973 cfs in 1979 compared to 82,426 cfs). Consequently, it would appear that the 1979 snowmelt curve is fairly representative of the normal snowmelt pattern for the upper Powder River (and the only one for which data were available). The average snowmelt curve, modeled after the 1979 data, is our best estimate of the configuration of the snowmelt versus runoff curve for an "average" year.

Water supplied from the melting of the snowpack usually represents about 50% of the total discharge from the Powder River drainage. Peak flow rates increase by a factor of 20 during the period of rapid snowmelt that occurs between mid-February and late June. The average base level for this drainage is 29%.

This data set is limited to only 5 years of gauge data and only one year of Landsat imagery was available of the five years. This drainage is not strongly influenced by water use above Sussex and when snowpack builds up and melts, the runoff volume reflects the melt pattern very well.

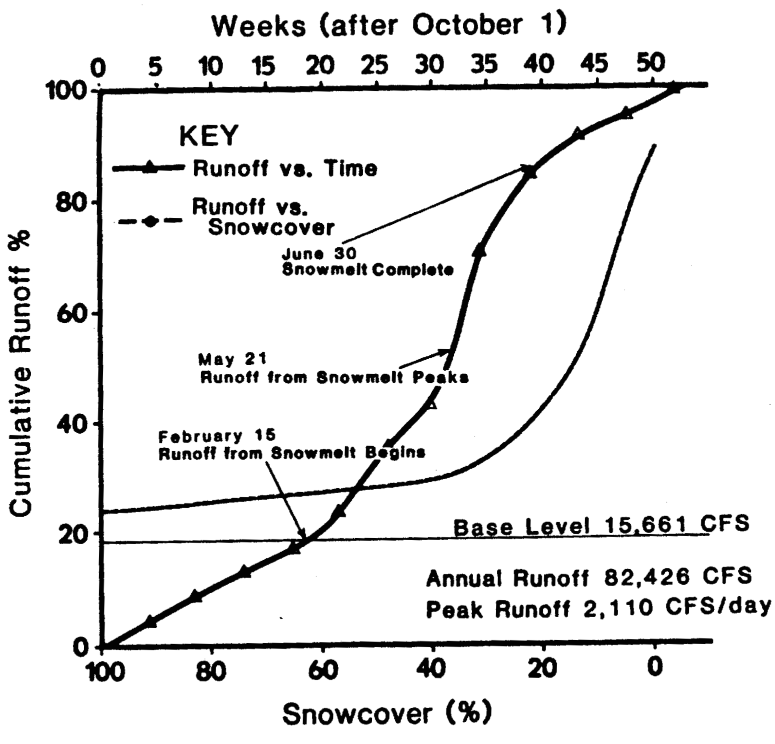
CRITICAL VALUES (approximate for a normal year):

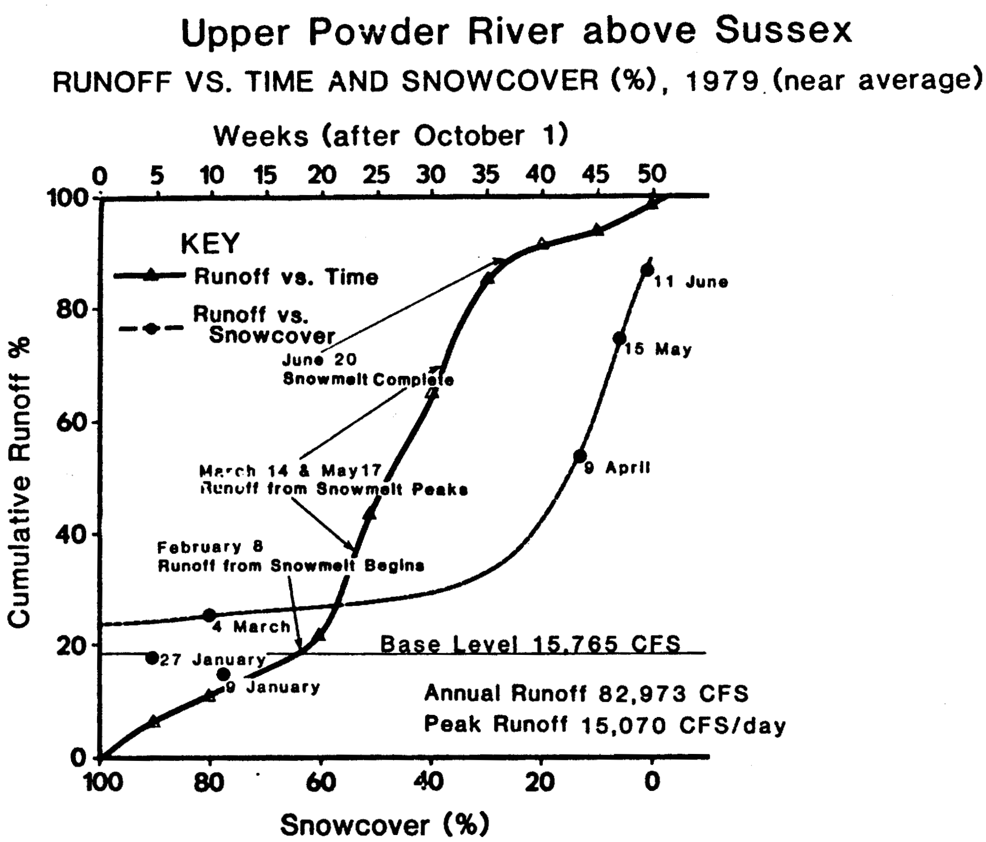
Beginning of runoff from snowmelt: February 8
Peak of runoff augmented by snowmelt: May 21
Peak runoff volume (normal year): 2,110 cfs
Snowmelt complete (no visible snow): June 20
Percent runoff provided by snowpack: 50%
Gauge station used in estimating runoff: #63135.00 at Sussex, Wyoming



Upper Powder River above Sussex

RUNOFF VS. TIME AND SNOWCOVER (%), (average, 5 years)




Upper Powder River above Sussex
RUNOFF VS. TIME AND SNOWCOVER (%), 1979 (near average)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
100
80
60
40
20
0
Cumulative Runoff %
KEY
Runoff vs. Time
Runoff vs. Snowcover
June 20
Snowmelt Complete
March 14 & May17
Runoff from Snowmelt Peaks
February 8
Runoff from Snowmelt Begins
11 June
15 May
9 April
4 March
27 January
9 January
Base Level 15,765 CFS
Annual Runoff 82,973 CFS
Peak Runoff 15,070 CFS/day
100 80 60 40 20 0
Snowcover (%)

SNOWMELT AND RUNOFF PATTERNS: MIDDLE POWDER RIVER DRAINAGE AREA (BETWEEN SUSSEX AND ARVADA)

Landsat imagery for 1979 were the only data available to determine the snowmelt-runoff relationship for the middle Powder River drainage between Sussex and Arvada. The Casper and North Powder River Landsat images were used to obtain weighted percentages of snowcover for each date. Six dates were used for the 1979 coverage (which lacked coverage in February). Runoff data were available for only 5 years (1978-1982). Stream flow data from stations 63170.00 and 63135.00 on the Powder River near Arvada and Sussex were used to determine cumulative runoff values. The difference in flow between these stations shows considerable influence of water management. Flow data were available each day for the years evaluated.

During the year, the flow rates usually increase about 3-fold (accumulated averages of the five years). Runoff from snowmelt usually begins in mid-January, after the snow covered area has diminished to approximately 50% (or less) of the drainage area. Peak runoffs usually occur in late June. The 1979 water year was much below average in runoff and snow accumulation. Peak flow occurred on June 17 at 1809 cfs. Peak flows as high as 10,700 cfs (May 20, 1978) were recorded in this drainage area during the 5-year period used in this evaluation. A typical peak flow rate during snowmelt would be around 2,917 cfs/day and should occur on June 3 or 4.

Discharge from the middle portion of the Powder River drainage was only half of normal for the 1979 water year (23,920 cfs in 1979 compared to the 5-year average of 46,892 cfs); but it is only a little below the 11-year average of the flow-volume of the Powder River at Arvada. The 1979 water year and snowmelt curve is the only year for which both runoff and snowcover data could be obtained for the middle Powder River.

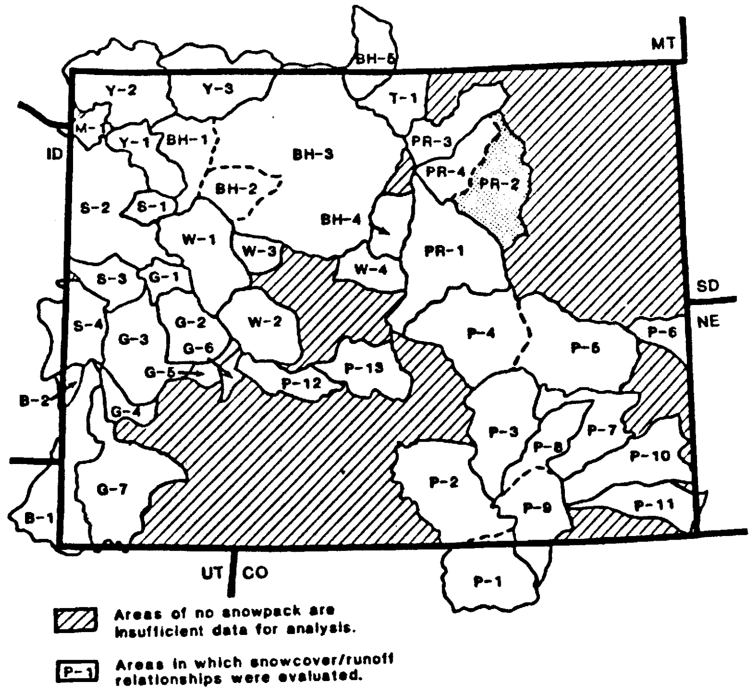
The middle portion of the Powder River drainage (between Sussex and Arvada) covers a small area along the east flank of the Bighorn Mountains and a much larger area of the adjacent Powder River basin. The annual snowpack is essentially restricted to the higher elevations; so the bulk of the area is only snow covered immediately after winter storms. In 1979, the snowpack covered only 10% of the drainage area at the onset of the spring melt season, but 1979 was a very dry year, and the snowpack was undoubtedly below normal. For a normal year, we might expect the snowcover to build up over as much as 20 or 25% of the drainage area.

The runoff pattern of the middle portion of the Powder River drainage is severely complicated by water use (either irrigation or storage). The average over the five-year period of available runoff data shows that the months of April and August-September are periods of heavy water use in this region--so much so that the flow in the Powder River increases only slightly (if at all) during these times because the use is nearly equal to the inflow of the tributaries supplying the river along this stretch. Both periods of heavy use show as "flat spots" in the runoff curve. In 1979, the water shortage was such that use of water during the period of February through April and August through September actually exceeded the water supply so that the flow of the Powder River decreased in volume between the Sussex and Arvada stations and the cumulative flow values decreased accordingly during these periods.

The combined problems of very limited snowmelt-runoff data and the substantial seasonal water use evident in the runoff records precludes the development of a reliable runoff-snowmelt relationship. Many of the key values relating runoff to snowcover can not be estimated from the 1979 data because 1979 was a drought year. The available water was much below normal, and consumption was probably well above normal. However, the use patterns evident in 1979 are also apparent in the average runoff curve.

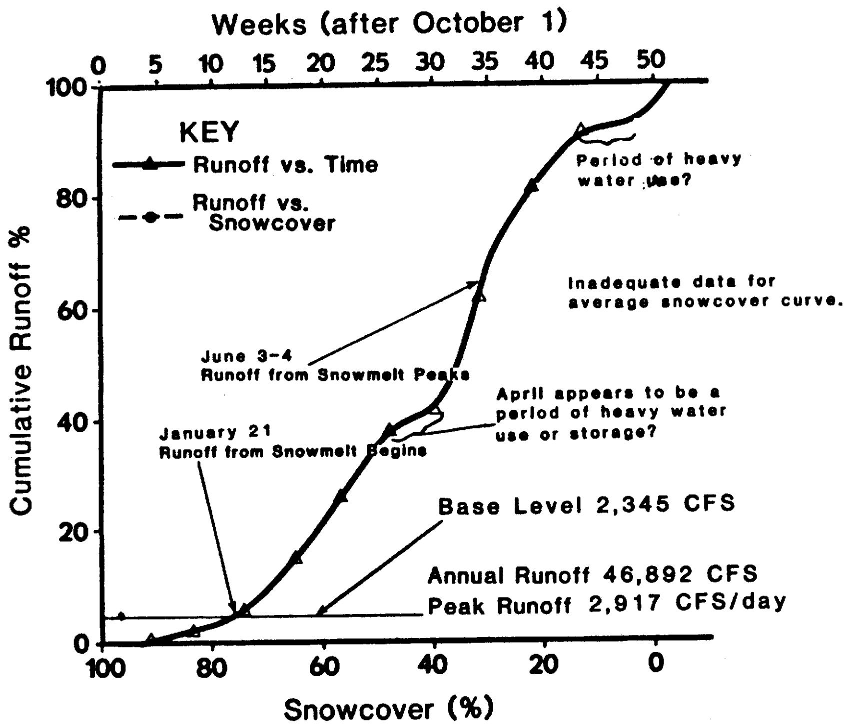
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: mid-January
Peak of runoff augmented by snowmelt: June 3 or 4
Snowmelt complete (no visible snow): mid-June?
Percent runoff provided by snowpack: ?
Peak runoff volume (normal year): 2,917 cfs
Gauge stations used in estimating runoff: #63170.00 at Arvada less flow values recorded at station #63135.00 at Sussex, Wyoming



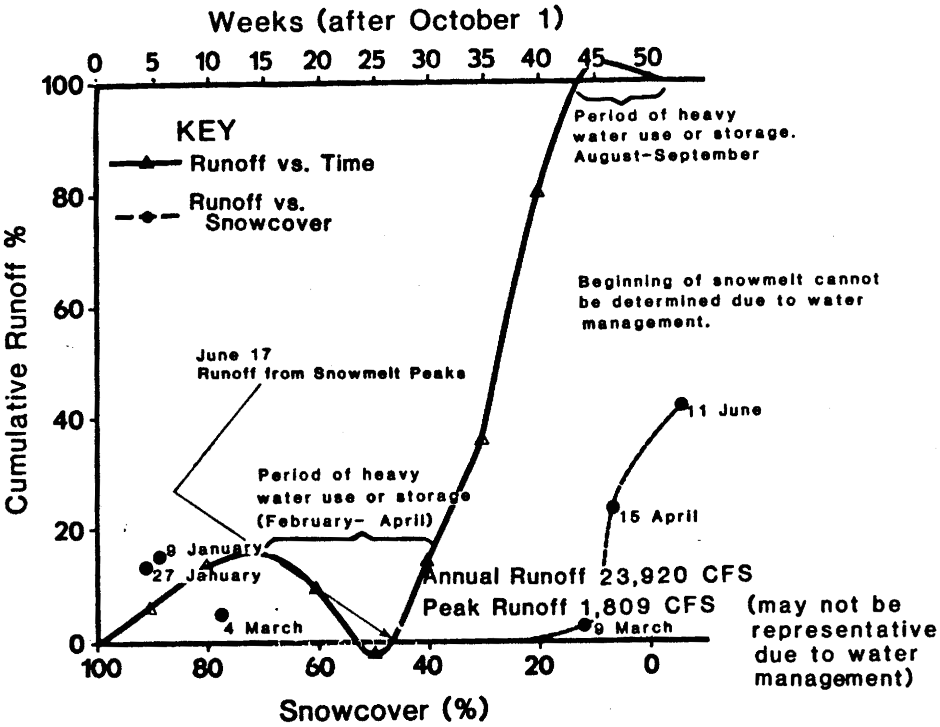
Middle Powder River Between Arvada and Sussex

RUNOFF VS. TIME AND SNOWCOVER (%), (average)



Middle Powder River Between Arvada and Sussex

RUNOFF VS. TIME AND SNOWCOVER (%), 1979 (dry)



SNOWMELT AND RUNOFF PATTERNS: CLEAR CREEK DRAINAGE

Landsat imagery for 1973 and 1979 were used to determine the snowmelt-runoff relationship for the Clear Creek drainage which flows into the Powder River. The North Powder River Landsat images were used. Four dates were used for the 1973 coverage, while six dates were used for 1979. Both years lacked coverage in February. The 1973 imagery had a gap between May 19 and July 30, while the 1979 data covers the snowmelt season only to June 11 (12% snowcover remains). The 1979 imagery is probably more reliable. Stream flow data from station no. 63240.00 on Clear Creek near Arvada were used to determine cumulative runoff values. The exact location of this gauge station is questionable and it was assumed to be near where Clear Creek runs into the Powder River. The flow at this station should show essentially no influence of water management because no major reservoirs are upstream from this gauge station. Flow data were available each day for the years evaluated.

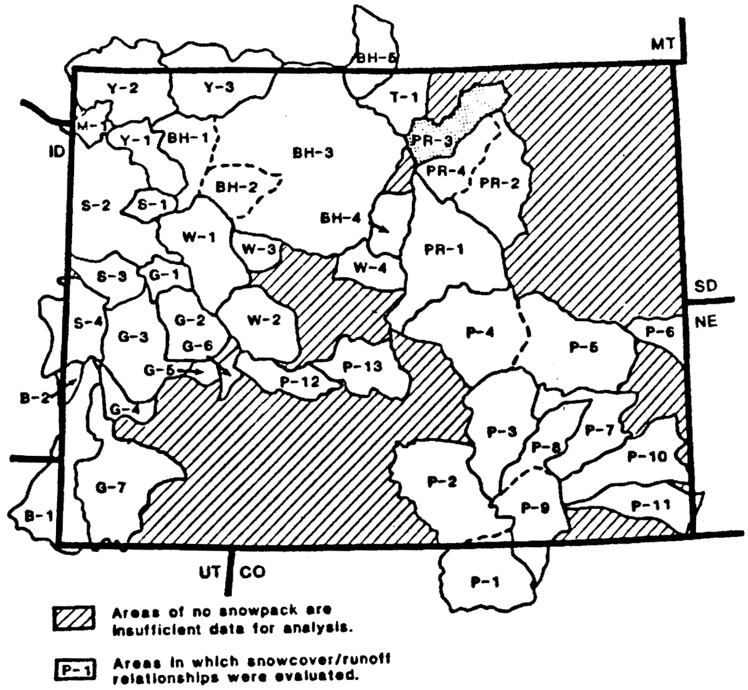
Runoff from snowmelt usually begins early in April after the snowpack area has diminished to about 45% of the basin area. Peak runoffs usually occur in late May (May 27). The 1979 water year shows extreme drought conditions in which the peak flow occurred on May 30 at only 496 cfs. 1973 was a more typical year, but a slightly above average peak flow occurred on June 11 at 1790 cfs. Peak flows as high as 4440 cfs (May 19, 1978) were recorded at this station during the 11-year period used in this evaluation. A typical peak flow rate at this station would be around 1500 cfs and should occur on May 27.

Discharge from the Clear Creek drainage was above normal for 1973 (78,660 cfs in 1973 compared to the 11-year average of 64,791 cfs, 21.4% above normal). The 1979 season was much below average (28,928 cfs or 55.4% below average). Consequently, it would appear that the 1973 snowmelt curve is closer to representing the normal snowmelt pattern for Clear Creek. The 1974 season is closest to the average total runoff at 63,544 cfs. The average snowmelt curve given is our best estimate of the configuration of the snowmelt versus runoff curve for an "average" year.

The data suggest the water supplied from the melting of the snowpack usually represents about 50% of the total discharge from the Clear Creek drainage. Peak flow rates can be increased by a factor of 3.5 to 7 during the relatively brief period of rapid snowmelt that occurs between late April and early July. The average base level for this drainage is 32%

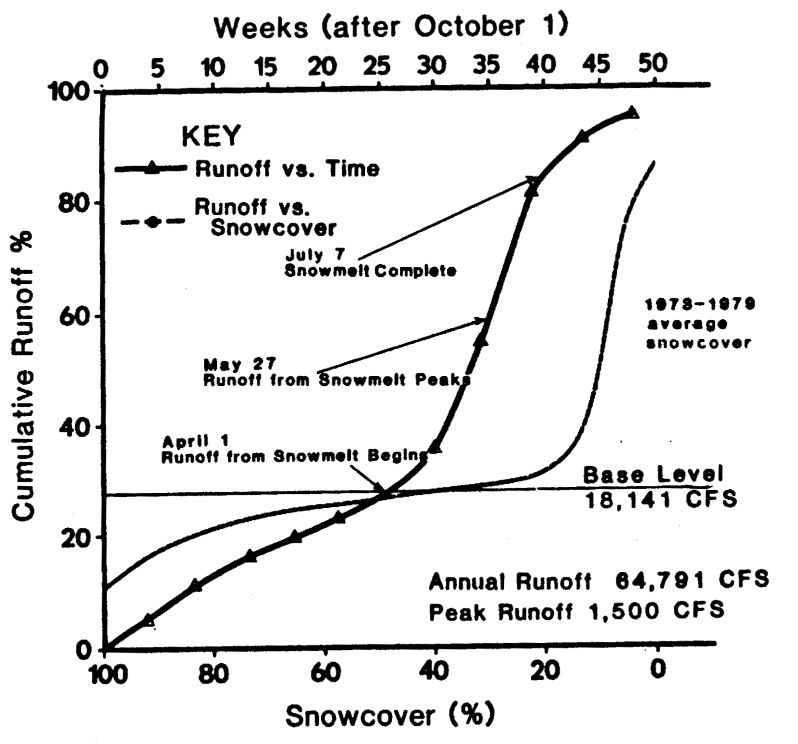
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: April 1
Peak of runoff augmented by snowmelt: May 27
Snowmelt complete (no visible snow): July 7
Percent runoff provided by snowpack: 50%
Peak runoff volume (normal year): 1500 cfs
Gauge station used in estimating runoff: #63240.00 at Arvada, Wyoming



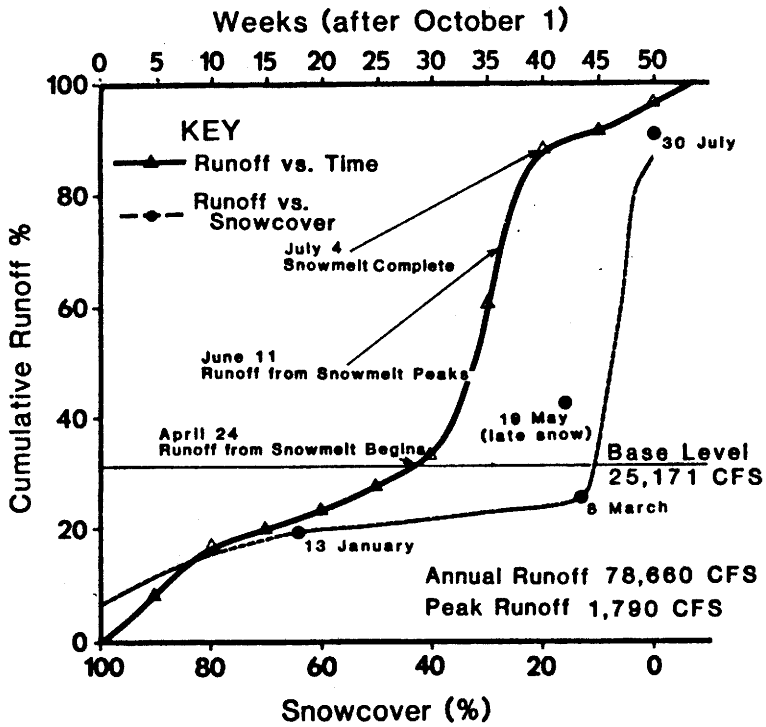
Clear Creek

RUNOFF VS. TIME AND SNOWCOVER (%), (average 12 years)



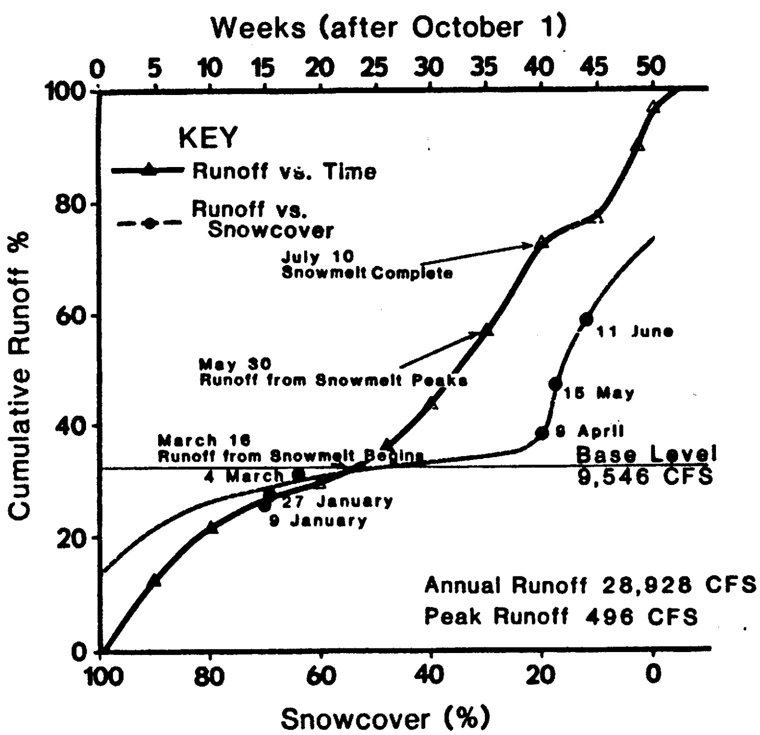
Clear Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



Clear Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1979 (very dry)



SNOWMELT AND RUNOFF PATTERNS: CRAZY WOMAN CREEK DRAINAGE

Landsat imagery for 1979 only were used to determine the snowmelt-runoff relationship for the Crazy Woman Creek drainage because only 4-years runoff data were available (1978-1981). The North Powder River Landsat images were used. Six dates were available for the 1979 coverage. The major shortcoming in the data set is that only four years of gauge data were available for estimating runoff. Stream flow data from station no. 63164.00 on the Crazy Woman Creek, near Arvada, Wyoming, were used to determine cumulative runoff values. The exact location of this gauge station is uncertain, and it was assumed to be near the junction of Crazy Woman Creek with the Powder River. The flow at this gauge station should show essentially no influence of water management. Flow data were available each day for the 1979 year evaluated.

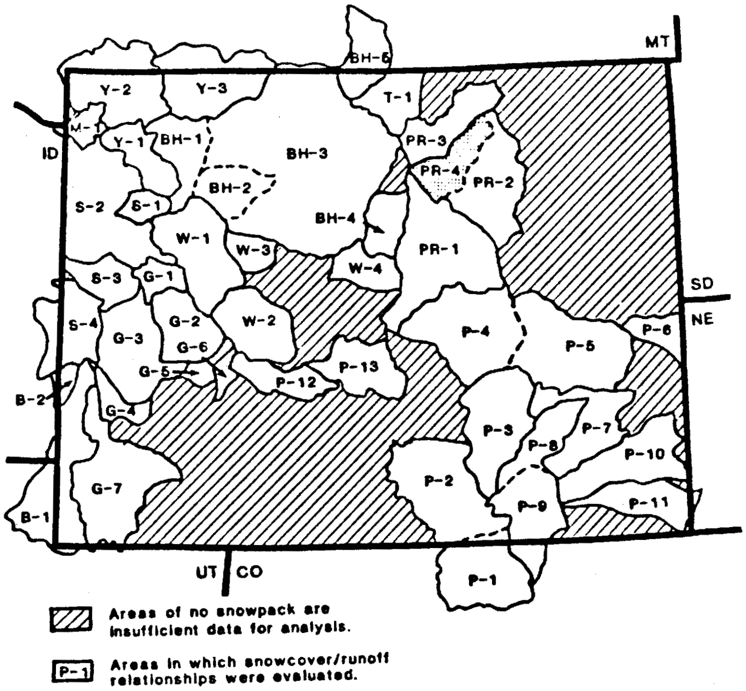
During the 1979 water year, the spring runoff increases 5 fold as snowmelt intensifies during the months of March to early June (from 20 to 100 cfs). Runoff from snowmelt usually begins in mid-March, after the snowcovered area has diminished to 35-65% of the drainage area. Peak runoffs usually occur early in June. The peak flow in 1979 occurred on June 20 at 307 cfs. Peak flows as high as 1380 cfs (May 19, 1978) were recorded during the 4-year period used in this evaluation. A typical peak flow rate at this station would be around 547 cfs and should occur on May 18.

Discharge from the Crazy Woman Creek drainage was slightly below the four-year average for 1979 (19,610 cfs in 1979 compared to the 4-year average of 21,854 cfs, 10% below normal). When compared with the 11-year average of Clear Creek, 1979 was much below average (55.4% below average). The 1979 season shows a more gentle runoff slope when comparing it with the average time versus percent curve. The average snowmelt curve given is our best estimate of the configuration of the snowmelt versus runoff curve for an "average" year.

The data suggest the water supplied from the melting of the snowpack usually represents about 40% of the total discharge from the Crazy Woman Creek drainage. Discharge from Crazy Woman Creek flows into the Powder River and is also included in the evaluation of the Powder River drainage above Sussex.

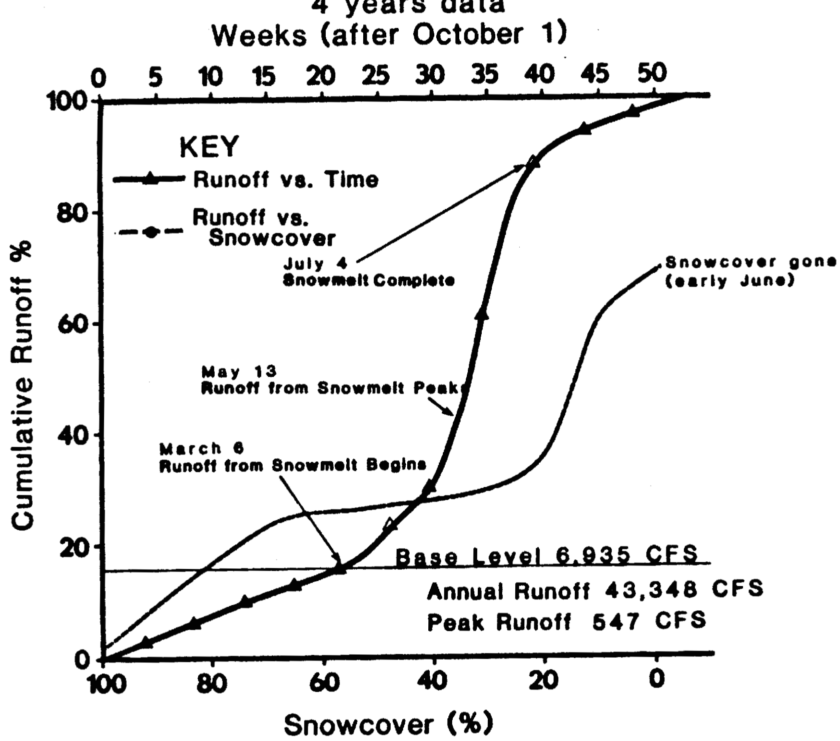
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: March 11
Peak of runoff augmented by snowmelt: June 1
Snowmelt complete (no visible snow): June 15
Percent runoff provided by snowpack: 40%
Peak runoff volume (normal year): 547 cfs
Gauge station used in estimating runoff: #63164.00 at Upper Station, near Arvada, Wyoming



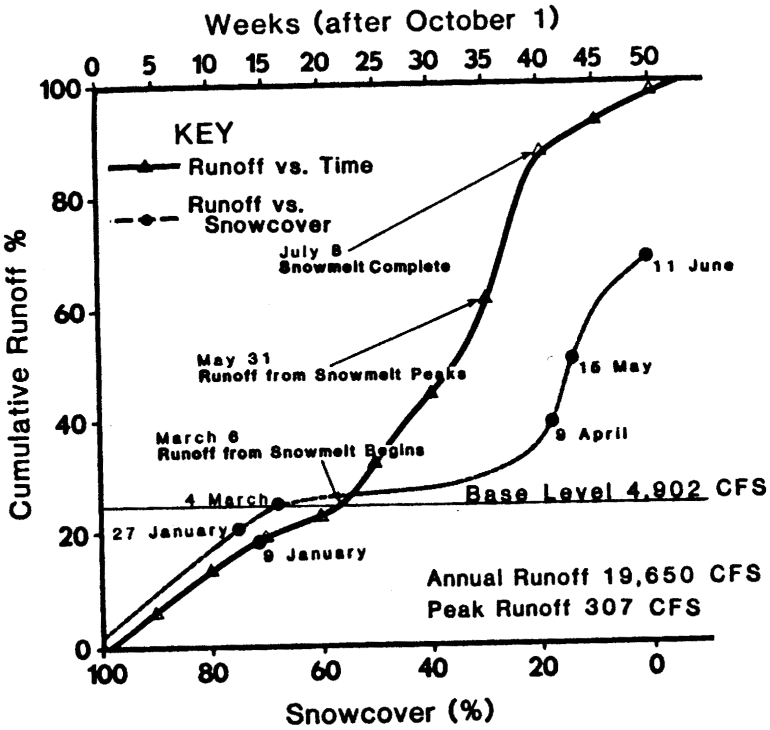
Crazy Woman Creek

RUNOFF VS. TIME AND SNOWCOVER (%), (average)
4 years data



Crazy Woman Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1979



AREA P-1

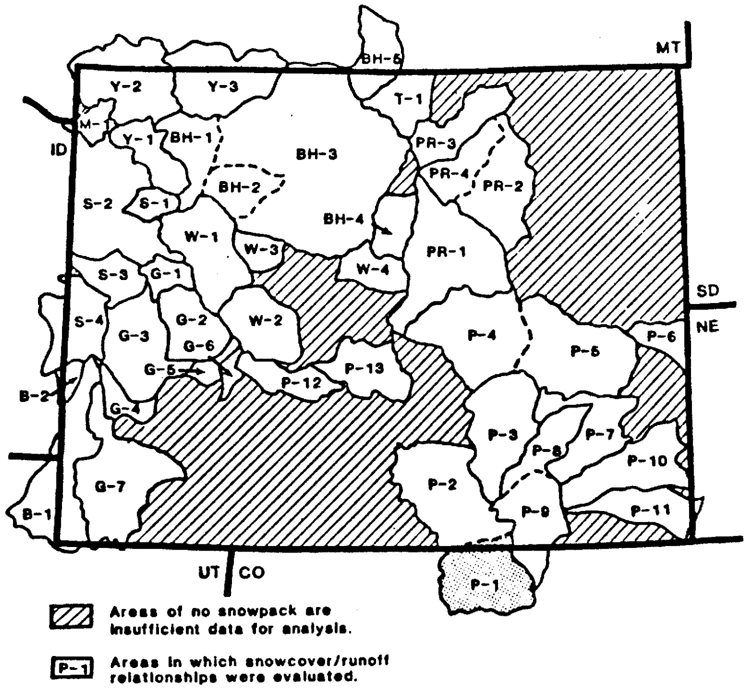
SNOWMELT AND RUNOFF PATTERNS: NORTH PLATTE RIVER DRAINAGE ABOVE NORTHGATE (NORTH PARK, COLORADO)

The Platte River heads in North Park, Colorado, and much of the discharge originates as snowmelt in the high mountains surrounding North Park. This area was evaluated because the contribution of this watershed is a very important part of the Platte River water supply. Landsat images of the North Park area were available for four snowmelt seasons (1973, 1974, 1975 and 1976). Runoff was above average in 1973 (133%) and in 1974 (137%) and below average in 1976 (65%) as compared to the 11-year average (1972-1983). 1975 was a near average year (runoff 100% of normal). As a result, the 1975 snowmelt curve and runoff curves serve as an excellent model for a "typical" year.

The runoff rate usually increases sharply (about 7 times) the last few days of March as snowmelt begins. Runoff peaks in early June and is not complete until late July or early August. The meltwater from snowpack represent 75-80% of the annual runoff in this region, although only 40-50% of the area accumulates a substantial snowpack (largely restricted to the mountain areas). The snowmelt pattern is much the same in this area regardless of whether the accumulation is above or below average. The runoff-snowcover relationships should, therefore, prove very useful for estimating runoff with no adjustment necessary for atypical years.

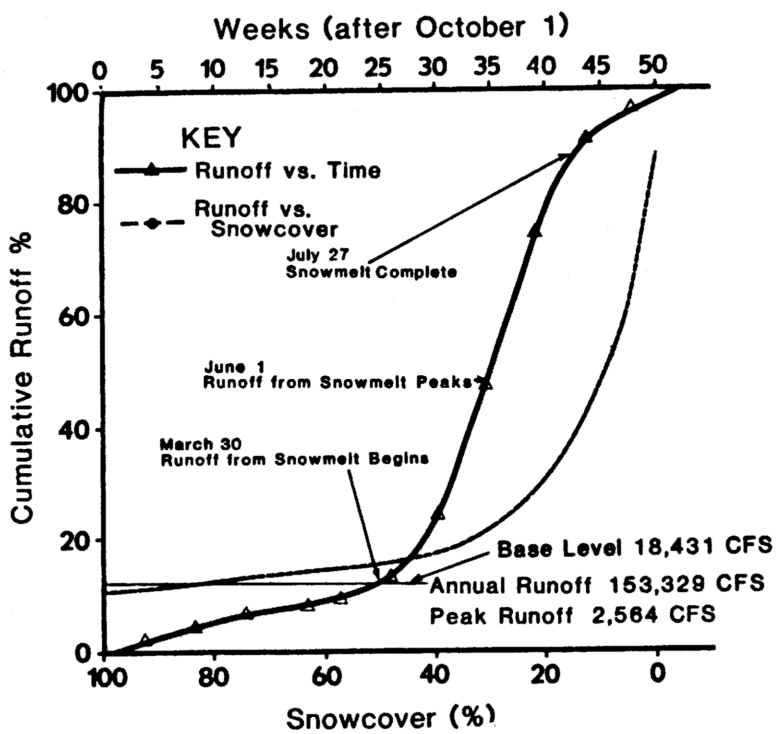
CRITICAL VALUES:

Beginning of runoff from snowmelt: March 30
Peak of runoff augmented by snowmelt: May 25
Snowmelt complete (runoff diminishing): August 1
Percent runoff provided by snowpack: 75-80%
Peak runoff volume (normal year): 2564 cfs/day
Gauge station used in estimating runoff: #66200.00 at Pinkhampton, Colorado



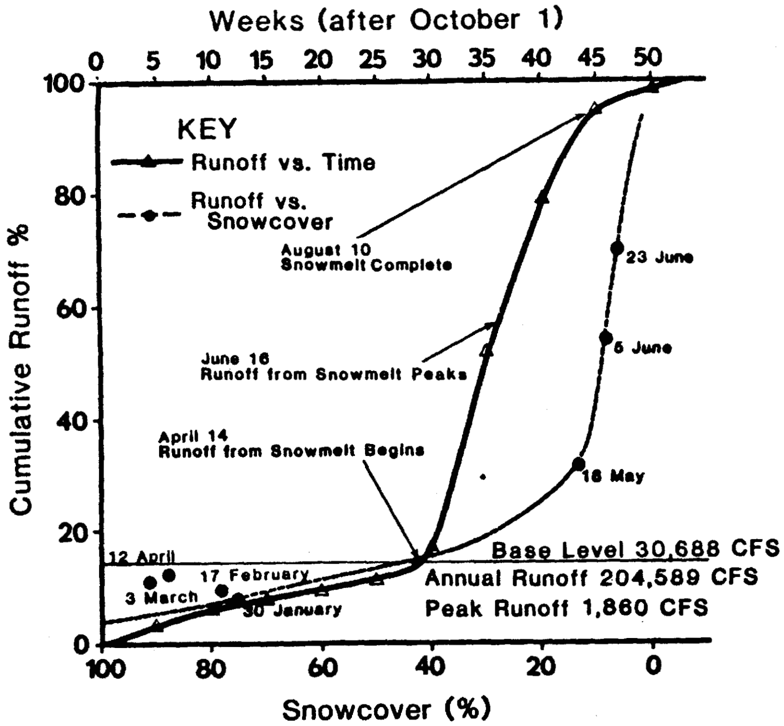
North Platte River near Northgate Colorado

RUNOFF VS. TIME AND SNOWCOVER (%), (Average)



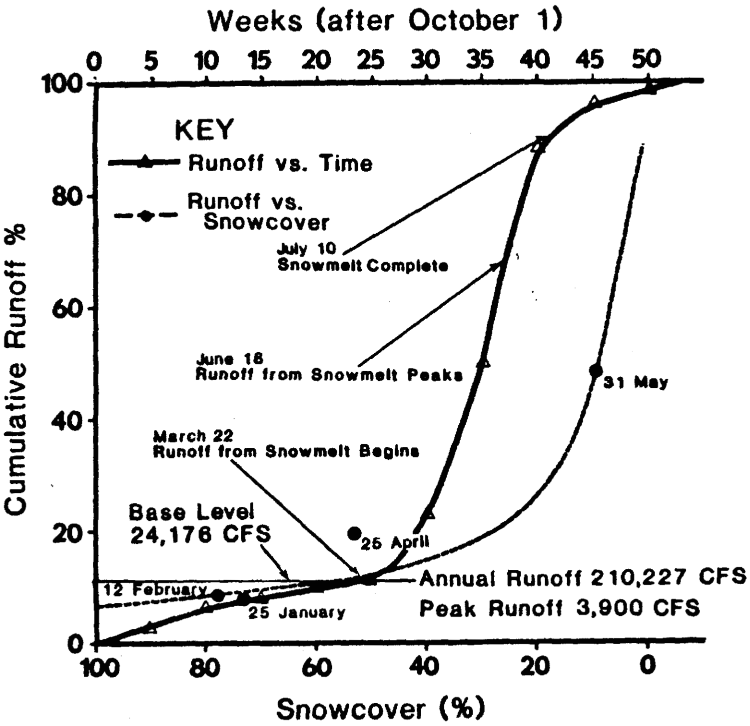
North Platte River near Northgate Colorado

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)

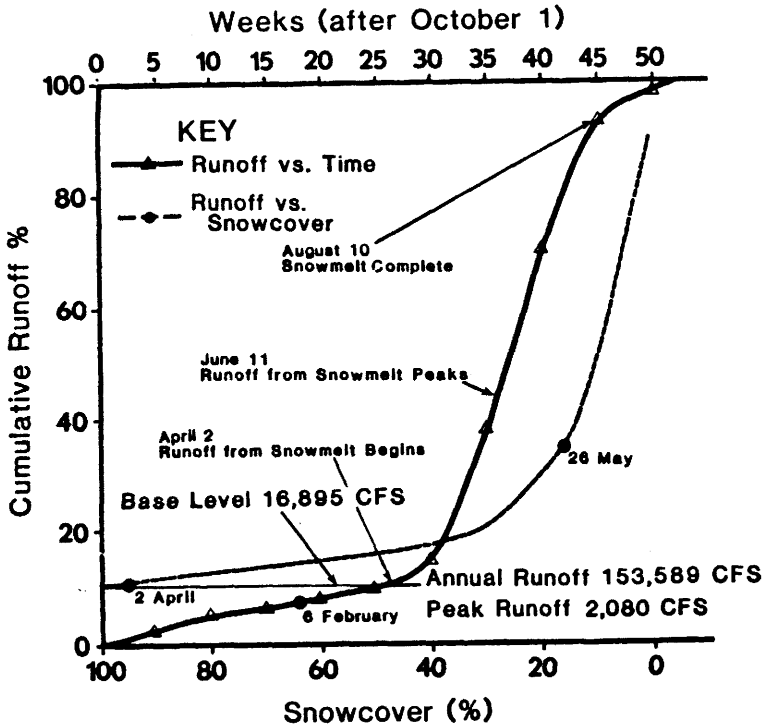


North Platte River near Northgate Colorado

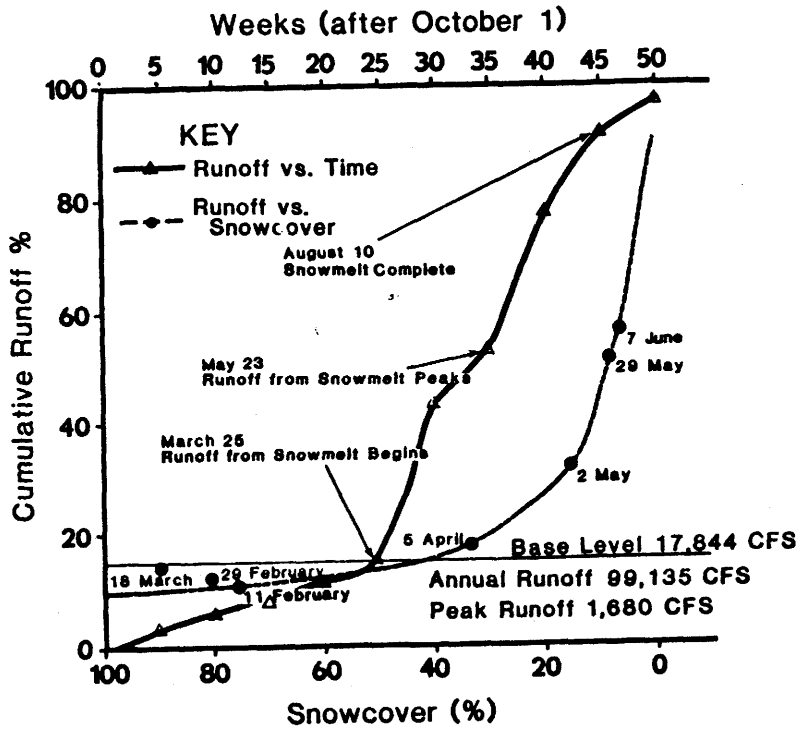
RUNOFF VS. TIME AND SNOWCOVER (%), 1974 (wet)



North Platte River near Northgate Colorado
RUNOFF VS. TIME AND SNOWCOVER (%), 1975 (near average)



North Platte River near Northgate Colorado
RUNOFF VS. TIME AND SNOWCOVER (%), 1976 (dry)



AREA P-2

SNOWMELT AND RUNOFF PATTERNS: NORTH PLATTE RIVER DRAINAGE (NORTH PARK AND SARATOGA VALLEY)

Landsat imagery for 1973, 1974, 1975 and 1976 were used to determine the snowmelt-runoff relationship for the North Platte River drainage. The North Park and Laramie Basin Landsat images were used. Weighted percents were determined using the Laramie Basin as the reference with which to compare the North Park images. Six image dates were used for the 1973 and 1976 snowpack years, while four image dates were used for both the 1974 and 1975 snowpack years. Both 1973 and 1976 were excellent data bases. 1973 lacked coverage in February; 1974 lacked coverage in March; 1975 lacked coverage in January and March and 1976 lacked coverage in January. Stream flow data from station no. 66300.00 on the North Platte River above Seminoe Reservoir, near Sinclair, Wyoming, were used to determine cumulative runoff values. The flow at this station shows essentially no influence of water management because no major reservoirs are upstream from this gauge station. Flow data were available each day for the years evaluated.

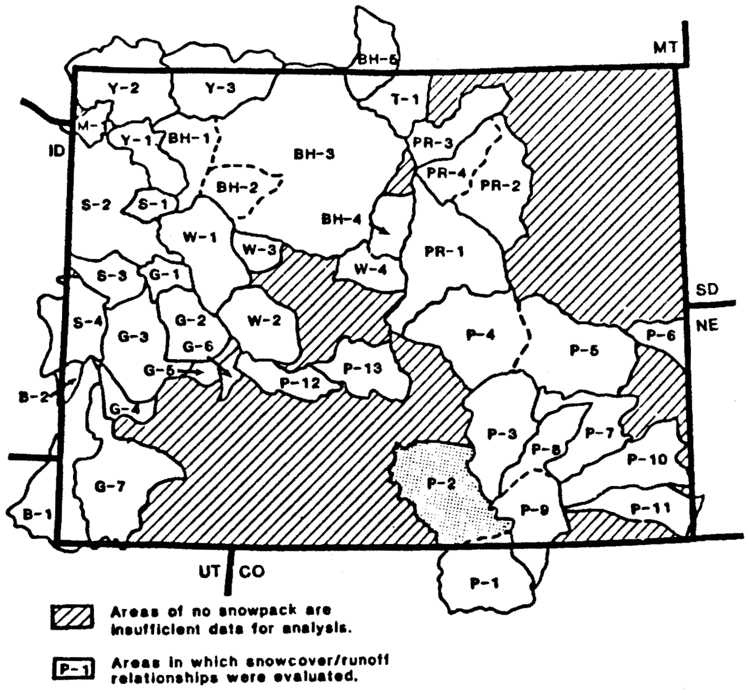
During the 1973 water year, the spring runoff increases 16 fold as snowmelt intensifies during the months of late April to early July (from approximately 354 to 5611 cfs). In 1974 water year, the spring runoff increases 16.4 fold as snowmelt intensifies during the months of late April to early July (from approximately 344 to 5644 cfs). During the 1975 water year, the spring runoff increases 13.3 fold as snowmelt intensifies during the months of late April to early July (from approximately 288 to 3838 cfs). In 1976 water year, the spring runoff increases only 9.7 fold as snowmelt intensifies during the months of early April to early July (from 300 to 2904 cfs). The differences between the average flow rate in January, 1973, of 354 cfs; 1974 of 344 cfs; 1975 of 288 cfs and 1976 of 300 cfs is probably due to the 1975 and 1976 runoff being lower than the 1973 and 1974 runoff. Runoff from snowmelt usually begins in late March, after the snowpack area has diminished to 50% of the drainage basin area. Peak runoffs usually occur mid-May to mid-June. The 1973 water year shows runoff to be much above average in which the peak flow occurred on June 16 at 10,200 cfs. The 1974 water year was also above average in which the peak flow occurred on May 11 at 7,710 cfs. 1975 was a more typical year, in which the peak flow occurred on June 9 at 6,950 cfs. The 1976 water year was below average in which the peak flow occurred on May 24 at only 4,440 cfs. Peak flows as high as 10,200 cfs (June 16, 1973) were recorded at this station during the 11-year period used in this evaluation. A typical peak flow rate at this station would be around 7,128 cfs and should occur on June 4. The snowcover area generally decreases most rapidly approximately 15 weeks before this date. This is partly attributed to the lag time it takes for the snow to melt and then arrive at the gauge station.

Discharge from the North Platte River drainage was above normal for 1973 (574,600 cfs in 1973 compared to the 11-year average of 424,066 cfs, 35% above normal). The 1974 season was also above average (547,294 cfs, 29% above normal). The 1975 season was slightly above average (461,736 cfs, 9% above normal). The 1976 season was below average (337,275 cfs, 20% below normal). Consequently, it would appear that the 1975 snowmelt curve is closest to representing the normal snowmelt pattern for the North Platte River. The 1975 runoff curve is similar to the average runoff curve, except that the runoff occurring before the snowmelt begins is slightly less steep in 1975 than on the average curve. The average snowmelt curve given is our best estimate of the configuration of the snowmelt versus runoff curve for an "average" year.

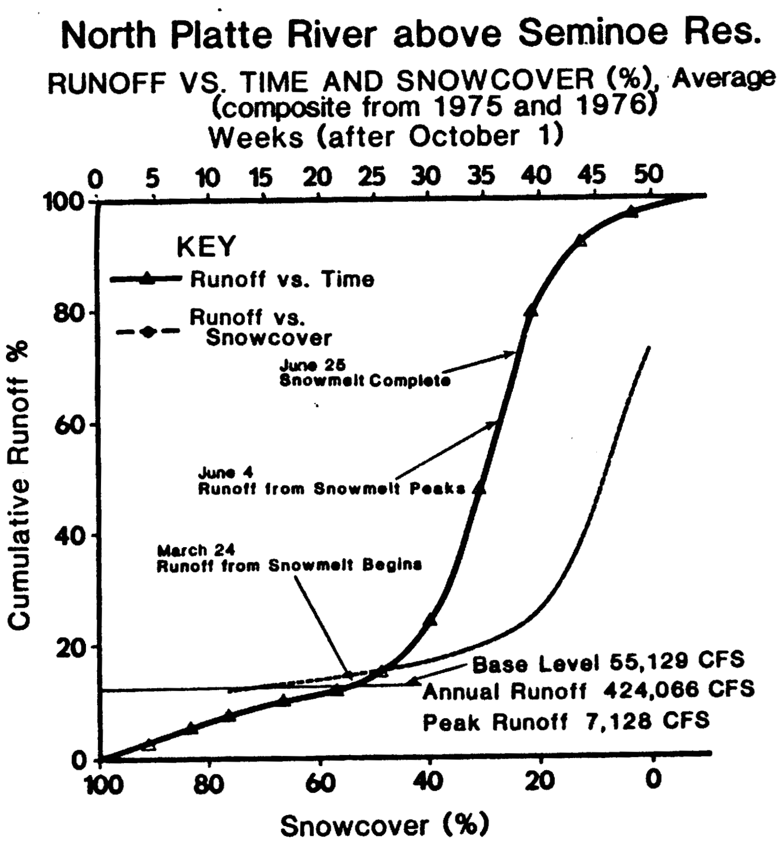
The data suggest the water supplied from the melting of the snowpack usually represents about 70% of the total discharge from the North Platte drainage. Flow rates increase by a factor of 12.4 to 136 during the relatively brief period of rapid snowmelt that occurs between mid-April to early July. The average base level for this drainage is 18%.

CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: April 1
Peak of runoff augmented by snowmelt: June 4
Peak runoff volume (normal year): 7,128 cfs
Snowmelt complete (no visible snow): July 1
Percent runoff provided by snowpack: 70%
Gauge station used in estimating runoff: #66300.00 above Seminoe Reservoir, near Sinclair, Wyoming



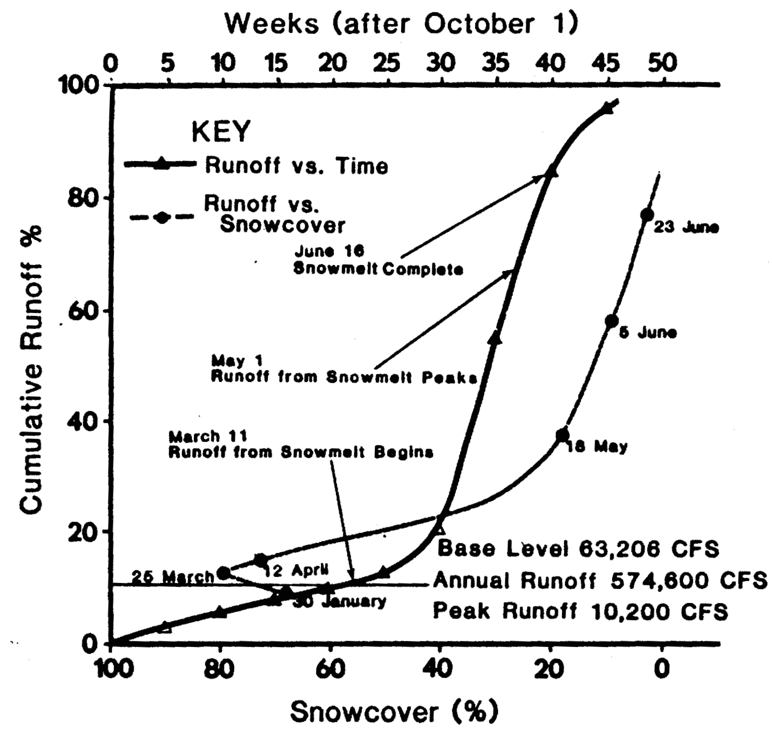
MT
ID
SD
NE
UT
CO
Y-2
Y-3
BH-5
T-1
M-1
Y-1
BH-1
BH-3
PR-3
PR-4
PR-2
BH-2
S-2
S-1
BH-4
W-1
W-3
PR-1
S-3
G-1
W-4
S-4
G-2
W-2
G-3
G-6
P-4
P-5
P-6
G-5
P-13
P-12
B-2
G-4
P-3
P-8
P-7
P-10
G-7
P-2
P-9
P-11
B-1
P-1
Areas of no snowpack are insufficient data for analysis.
Areas in which snowcover/runoff relationships were evaluated.



North Platte River above Seminoe Res.
RUNOFF VS. TIME AND SNOWCOVER (%), Average
(composite from 1975 and 1976)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
June 25
Snowmelt Complete
June 4
Runoff from Snowmelt Peaks
March 24
Runoff from Snowmelt Begins
Base Level 55,129 CFS
Annual Runoff 424,066 CFS
Peak Runoff 7,128 CFS
Cumulative Runoff %
100
80
60
40
20
0
Snowcover (%)

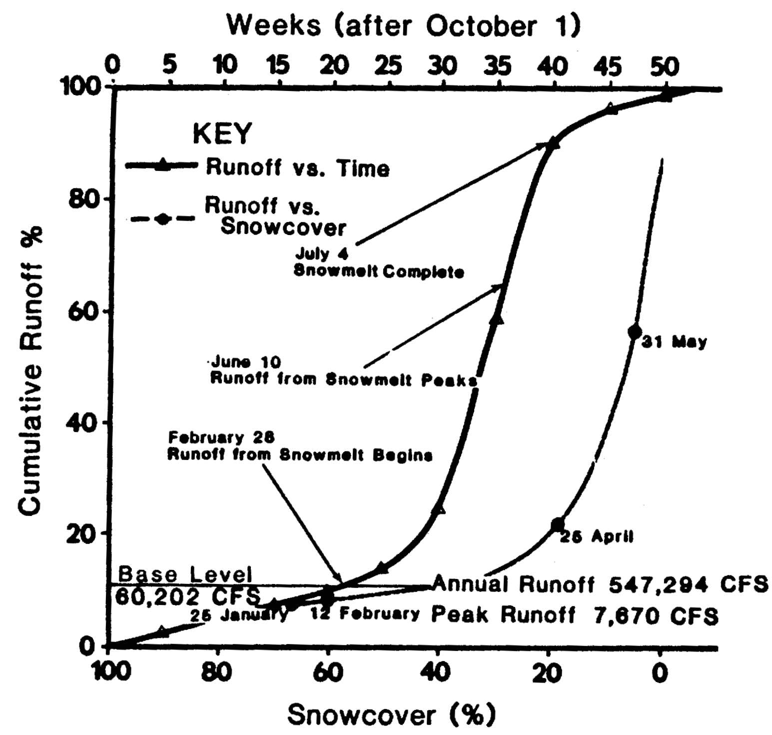
North Platte River above Seminoe Res.

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



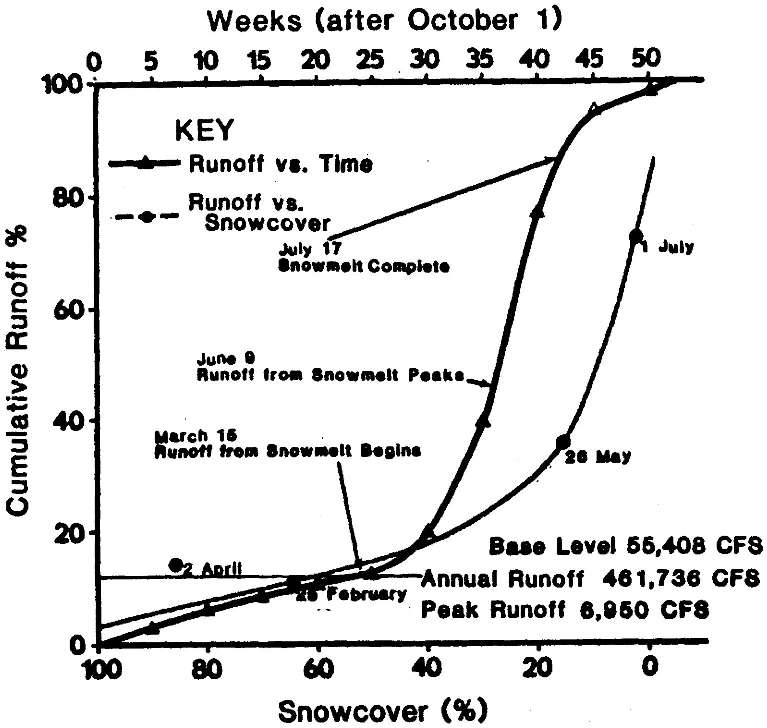
North Platte River above Seminoe Res.

RUNOFF VS. TIME AND SNOWCOVER (%), 1974 (wet)



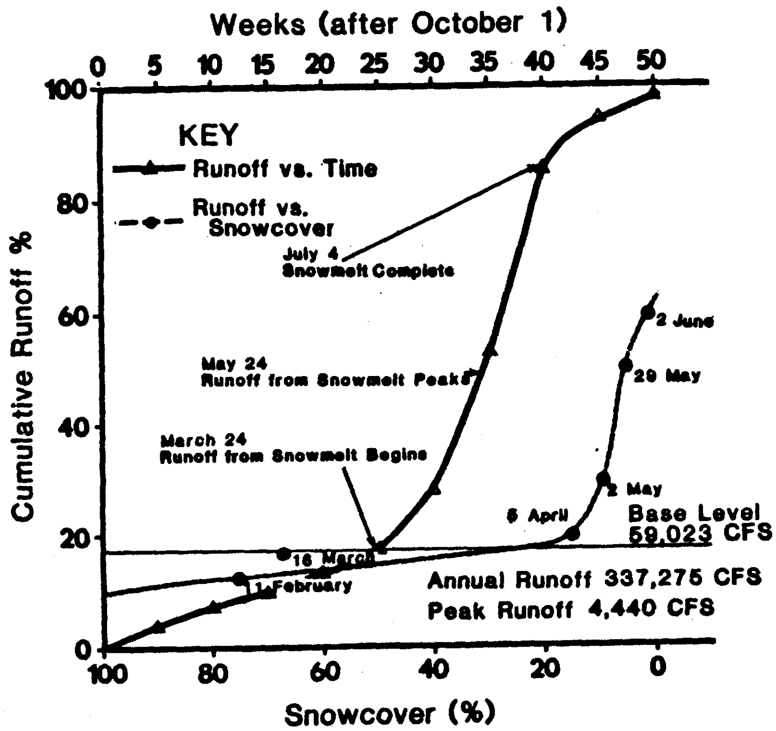
North Platte River above Seminoe Res.

RUNOFF VS. TIME AND SNOWCOVER (%), 1975 (near average)



North Platte River above Seminoe Res.

RUNOFF VS. TIME AND SNOWCOVER (%), 1976 (dry)



AREA P-3

SNOWMELT AND RUNOFF PATTERNS: MEDICINE BOW RIVER DRAINAGE

Landsat imagery for 1973, 1974 and 1976 were used to determine the snowmelt-runoff relationship for the Medicine Bow River drainage which flows into the North Platte River. The Rock River or Laramie Basin Landsat images were used. Six dates of coverage were used for 1973, only four dates were available for 1974, and six coverage dates were available for the 1979 season. The 1973 coverage is missing a February date, but coverage is available through June 23 when only 1% snowcover is remaining. The 1974 coverage is missing a March date and then extends through May 31 when there is only 3% snowcover remaining. The 1976 imagery has no January date and extends until June 7. This data base is extremely good for this drainage. Both the 1973 and 1976 imagery are probably most reliable because only four coverage dates were available for 1974. Stream flow data from near Hanna, Wyoming, station no. 66350 on the Medicine Bow River above Seminoe Reservoir were used to determine cumulative runoff values. No major reservoirs lie above the gauge station and there appears to be no significant influence of water management. Flow data were available each day for the years evaluated.

Runoff from snowmelt usually begins about March 1, after snowpack has diminished to 50-55% of the drainage basin area. Peak runoffs usually occur in May. The 1973 water year shows abnormally high runoff in which the peak flow occurred on May 11 at 5330 cfs. 1974 was a more typical year, but is also slightly above average with peak flow occurring on June 12 at 1670 cfs. The 1976 water year is below average. The peak flow occurred on May 25 at 836 cfs. Peak flows as high as 5330 cfs (May 11, 1973) were recorded at this station during the 11-year period used in this evaluation. A typical peak flow rate at this station would be around 1878 cfs and should occur on May 24 or 25.

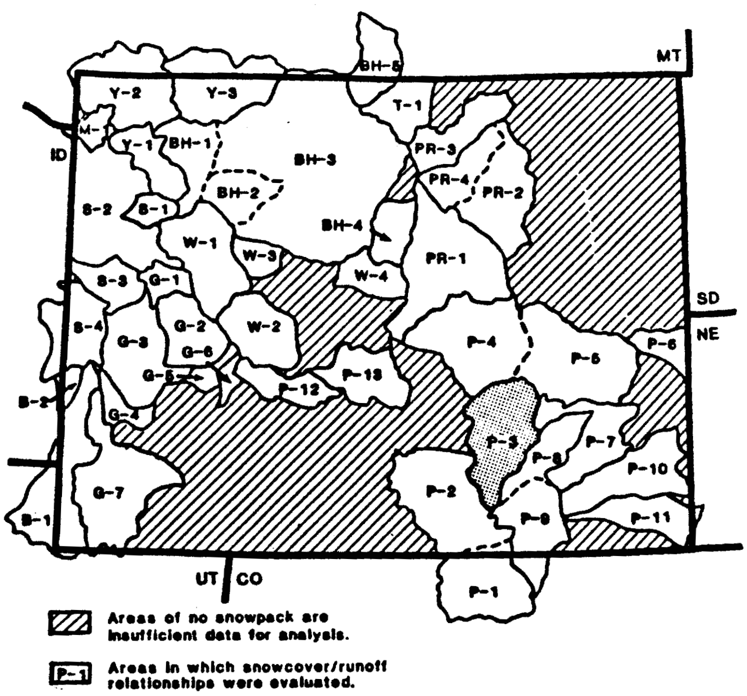
Total discharge from the Medicine Bow River drainage was much above average (144%) for 1973 (193,794 cfs in 1973 compared to the 11-year average of 79,452 cfs). The 1974 season was slightly above average at 98,395 cfs (24% above normal). The 1976 season was below average at 61,060 cfs (23% below average). Consequently, it would appear that when the 1974 and 1976 snowmelt curves are averaged, they might approximate the normal snowmelt pattern for Medicine Bow River. The average curve for time versus cumulative percent should be flatter than the curve derived from the 1974 satellite data, and steeper than the curve derived from the 1976 satellite data. However, both curves are quite close to the average curve. The 1975 and 1982 seasons are the closest to the average total runoff at 73,017 cfs and 83,442 cfs. The average snowmelt curve given is our best estimate of the configuration of the snowmelt versus runoff curve for an "average" year.

The data suggest the water supplied from the melting of the snowpack usually represents about 70% of the total discharge from the Medicine Bow River drainage. Peak flow rates can increase by a factor of 11 to 52 times during the relatively brief period of snowmelt that occurs between late March to early July. The average base level for this drainage is 9%.

This drainage provides an example of what a drainage runoff curve should look like if water management is minimal and snowmelt provides a large portion of the annual runoff. This drainage also has a very good image data set. By averaging the 1974 and 1976 runoff curves, a curve very close to the computed 11-year average was produced.

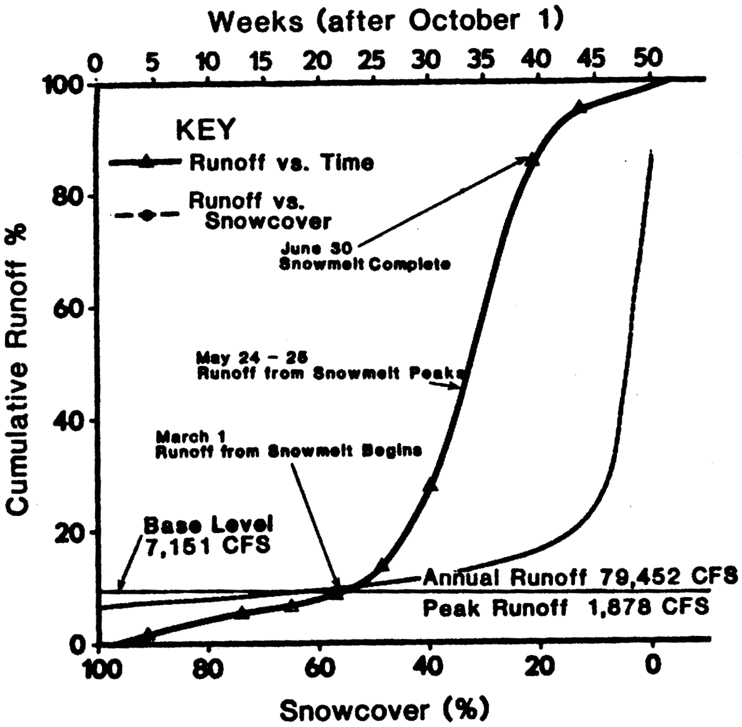
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: March 1
Peak of runoff augmented by snowmelt: May 24 or 25
Snowmelt complete (no visible snow): June 30
Percent runoff provided by snowpack: 70%
Peak runoff volume (normal year): 1878 cfs
Gauge station used in estimating runoff: #66350 above Seminoe Reservoir near Hanna, Wyoming



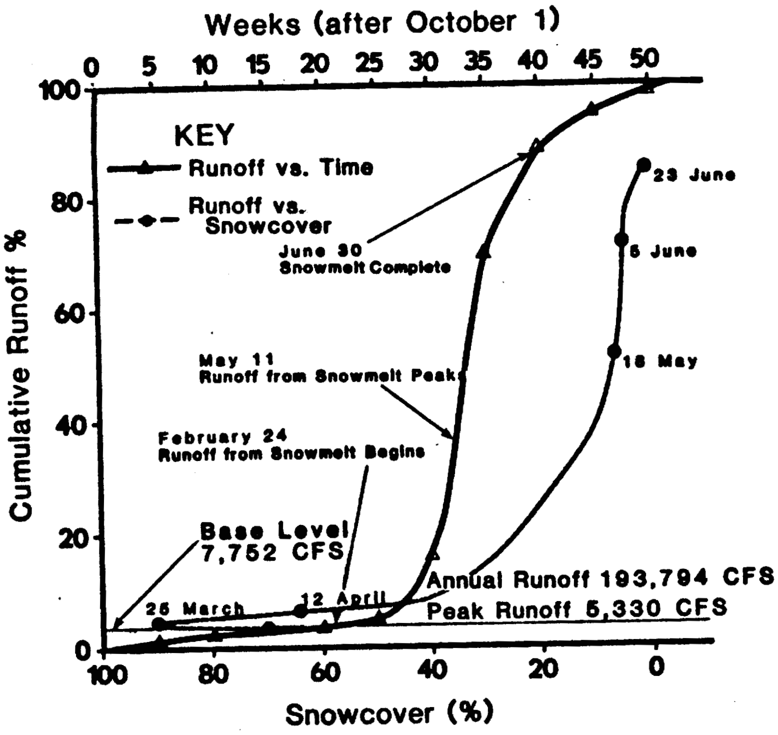
Medicine Bow River above Seminoe Reservoir

RUNOFF VS. TIME AND SNOWCOVER (%) (average)



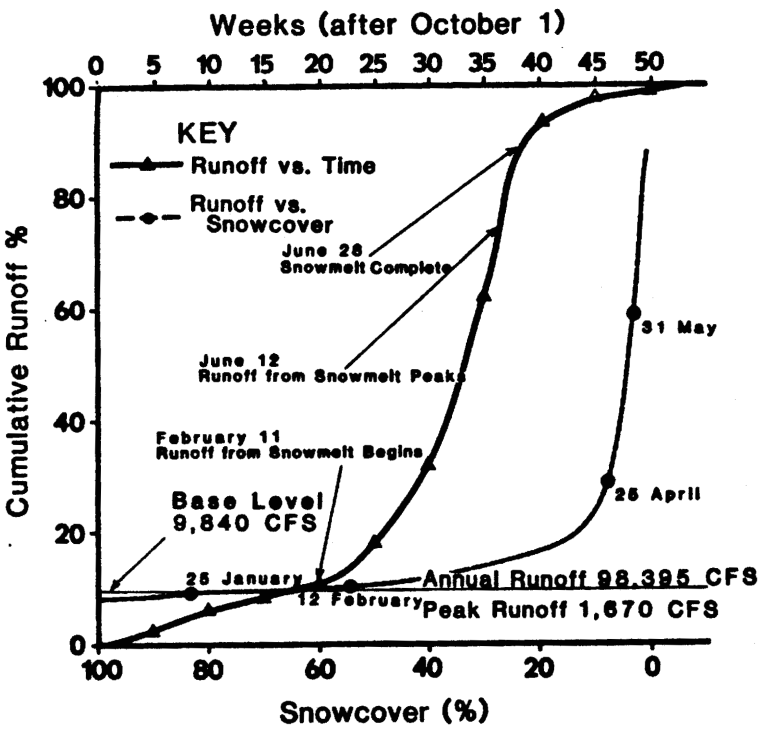
Medicine Bow River above Seminoe Reservoir

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



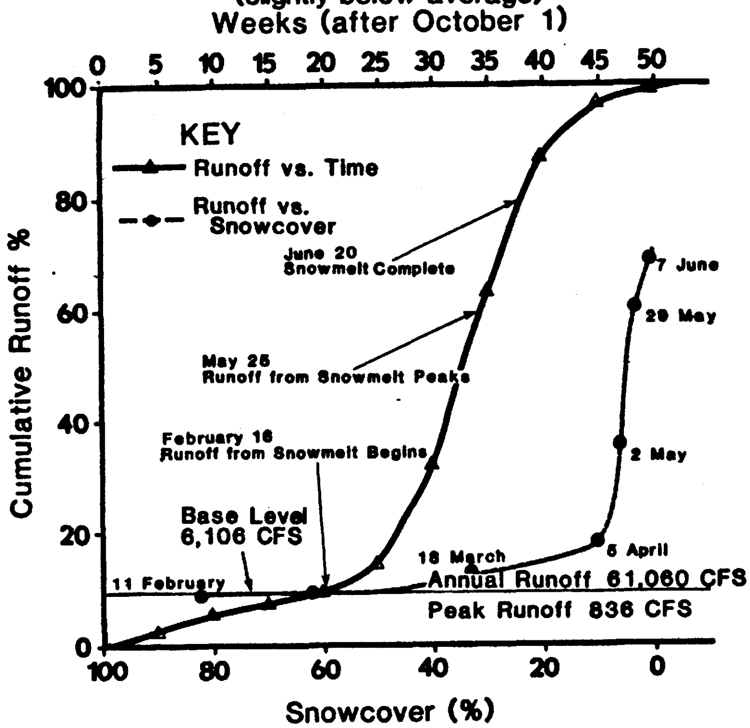
Medicine Bow River above Seminoe Reservoir

RUNOFF VS. TIME AND SNOWCOVER (%), 1974 (near normal)



Medicine Bow River above Seminoe Reservoir

RUNOFF VS. TIME AND SNOWCOVER (%), 1976
(slightly below average)



SNOWMELT AND RUNOFF PATTERNS: NORTH PLATTE RIVER DRAINAGE BELOW ALCOVA

Landsat imagery for 1973 and 1977 were used to determine the snowmelt-runoff relationship for the North Platte River drainage. The North Converse County Landsat images were used; the basin extends into areas covered on the Casper, Laramie Basin and Laramie Range Landsat scenes. These small areas were not included in measurements. Five dates were used for the 1973 coverage, and four dates were available for 1977. The 1973 imagery was missing February coverage and the 1977 imagery had no January coverage. Otherwise, both years' data are fairly reliable. Stream flow data were taken from two stations and subtracted to obtain the snowpack-runoff data of a much smaller area. Orin Junction (station no. 66520.00) was the lower station, so the flows measured at the Alcova gauge station (no. 66420.00) were subtracted to obtain information on runoff from the drainages that flow off the Northern Laramie Range and Casper Creek areas. The runoff pattern for the area is much distorted by water management between the two gauge stations (due to irrigation on that stretch of the North Platte River). The effects of water use are particularly noticeable during seasons of below normal runoff such as in 1977. However, no major reservoirs are present between those two gauge stations. Flow data were available each day for the years evaluated.

Runoff from snowmelt usually begins in mid-to-late March, after the snowpack area had diminished to 30% of the basin area. Peak runoffs usually occur in late April. The 1973 runoff was much above average. Peak flow (difference of station flow readings) occurred on May 21 at 10,120 cfs. 1977 was a more typical runoff year, but slightly below average. A typical peak flow rate for the area would be around 3197 cfs and should occur about May 5. The snowcover generally decreases most rapidly approximately 10 to 15 weeks before this date.

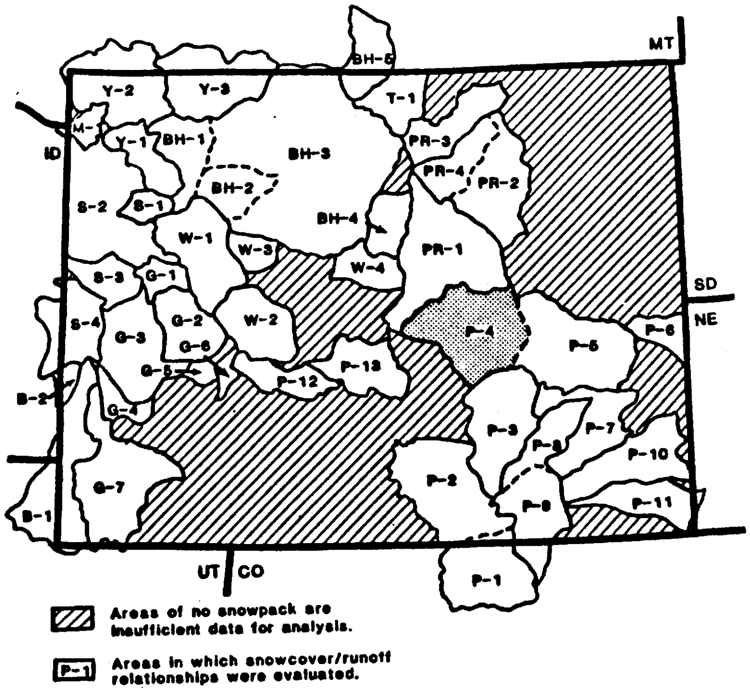
Discharge from the North Platte River drainage was way above normal for 1973 (281,310 cfs in 1973 compared to the 11-year average of 110,642 cfs, 154% above normal). It would appear that neither year is very close to representing a normal runoff year for the North Platte River. The 1976 or 1978 seasons are closest to the average total runoffs at 90,826 and 133,792 cfs respectively. The average snowmelt curve shown is our best estimate of the configuration of the snowmelt versus runoff curve for an "average" year. It represents an average of the 1973 (wet) and 1977 (dry) snowmelt patterns with 1977 weighted more heavily.

The data suggest the water supplied from the melting of the snowpack usually represents about 60% of the total discharge from the North Platte River between Alcova and Orin Junction. Flow rates typically increase by a factor of 10 during the relatively brief period of rapid snowmelt that occurs between late March and early June. The average base level for this drainage is 16%.

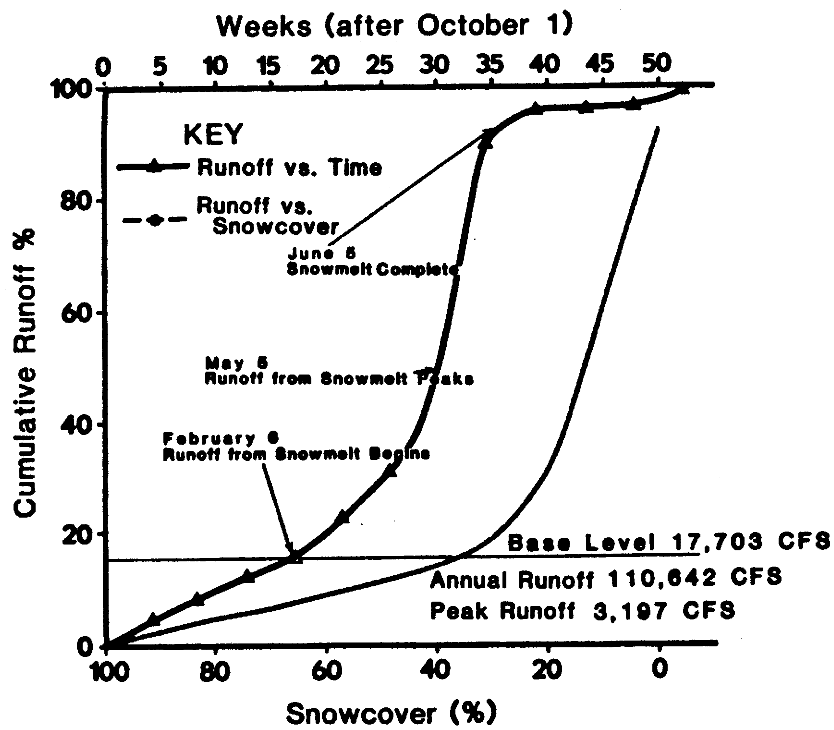
Cumulative runoff appears to rise above 100% during the period of June-July 1977. This is due to the fact that water consumption in the area of analysis actually exceeds the inflow from tributaries of the Platte River during this period. This effect is marked during dry seasons when snowmelt is minimal and consumption is greatest due to agricultural demands.

CRITICAL VALUES (approximate for a normal year):

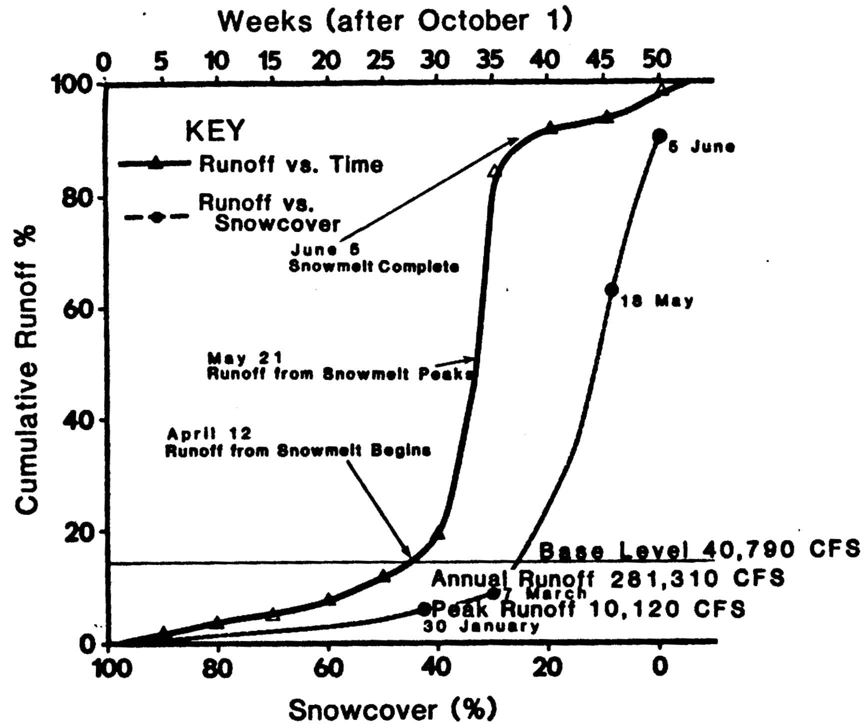
Beginning of runoff from snowmelt: February 6, increasing sharply in late March
Peak of runoff augmented by snowmelt: May 5
Peak runoff volume (normal year): 3197 cfs
Snowmelt complete (no visible snow): June 5
Percent runoff provided by snowpack: 60%
Gauge stations used in estimating runoff: Readings at station #66520.00 near Orin Junction, less flow values recorded at #66420.00 near Alcova, Wyoming



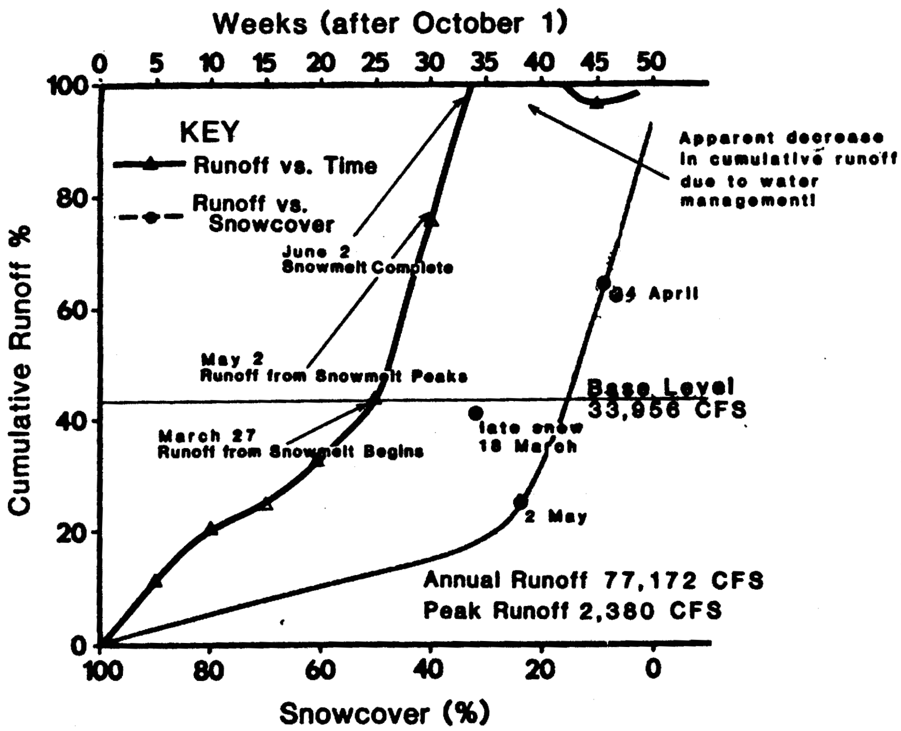
North Platte River
between Alcova and Orin Junction
RUNOFF VS. TIME AND SNOWCOVER (%) (average)



North Platte River
between Alcova and Orin Junction
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



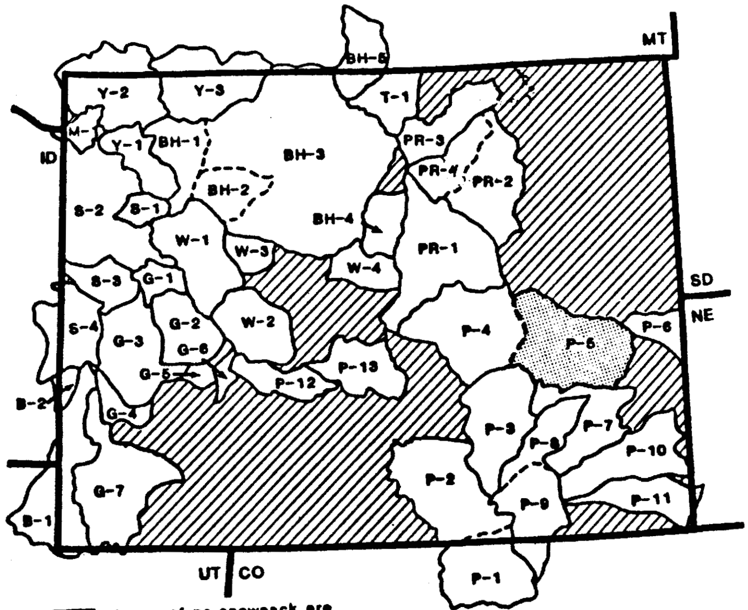
North Platte River
between Alcova and Orin Junction
RUNOFF VS. TIME AND SNOWCOVER (%), 1977 (dry)



AREAS P-5 & P-6

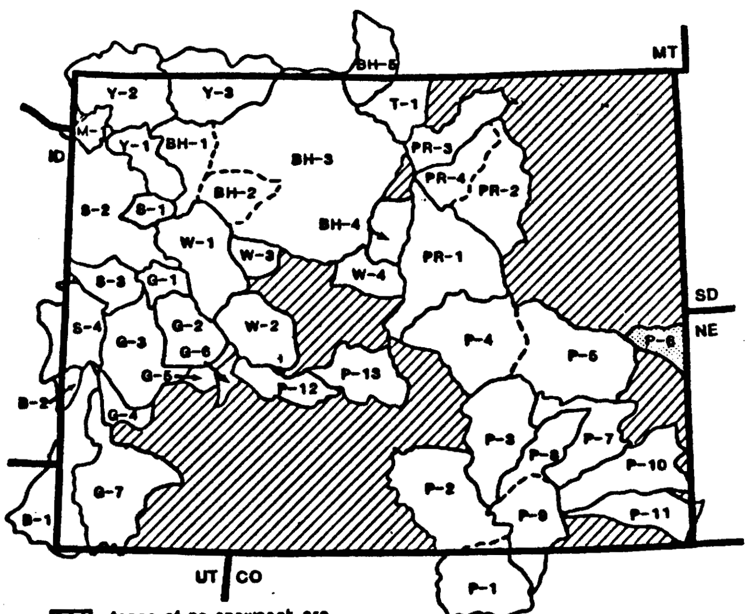
SNOWMELT AND RUNOFF PATTERNS: LOWER NORTH PLATTE RIVER DRAINAGE (BELOW ORIN JUNCTION)

Inflow from tributaries of the Platte River below Orin Junction is minimal except for the Laramie River and Lodgepole Creek. These major tributaries of the lower Platte River have been handled separately. Water management along the lower North Platte River is extensive, with major storage facilities at Glendo and Guernsey Reservoirs and heavy agricultural use. Consequently, the variations in flow attributed to input from minor tributaries is not discernable against the background of larger variations due to water management. We were unable to derive a meaningful snowcover-runoff relationship for the lower North Platte River.



Areas of no snowpack are insufficient data for analysis.

P-1 Areas in which snowcover/runoff relationships were evaluated.



Areas of no snowpack are insufficient data for analysis.

P-1 Areas in which snowcover/runoff relationships were evaluated.

SNOWMELT AND RUNOFF PATTERNS: NORTH LARAMIE, CHUGWATER, AND FISH CREEK DRAINAGE AREA BETWEEN UVA AND FORT LARAMIE

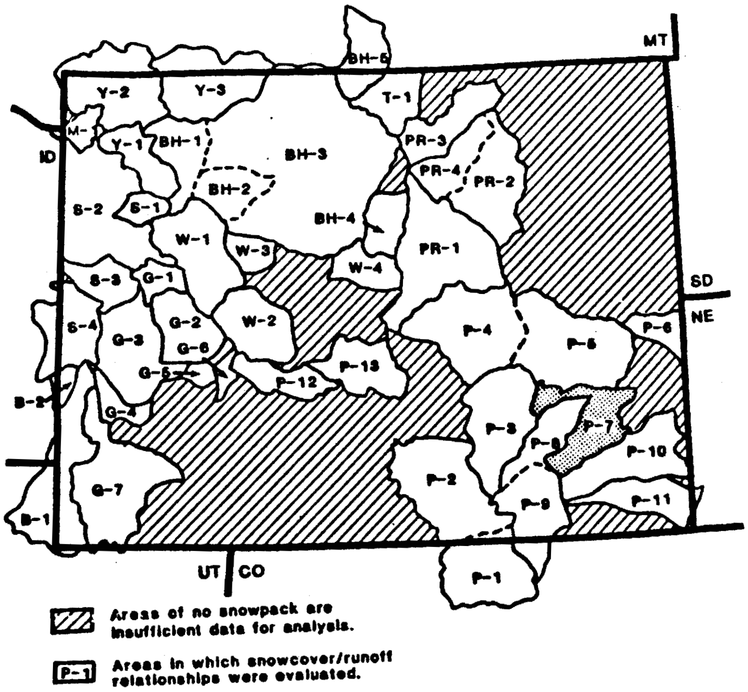
Landsat imagery for 1974, 1975 and 1979 were used to determine the snowmelt-runoff relationship for the Laramie River drainage between Uva and Ft. Laramie. The Laramie Range Landsat images were used to map the snowpack buildup and snowmelt. Four dates were available for the 1974 coverage, three dates were used for the 1975 snowmelt season and five dates are included in the 1979 coverage. 1974 had no gaps in the coverage and extended through late April (0% snowcover). The 1975 image set lacks coverage for the period between February and late June which makes this year of questionable reliability. The 1979 coverage is good, except it could be improved with a May date (3% snowcover remains in April). Both the 1974 and 1979 snowcover estimates from imagery are quite reliable. Stream flow data was acquired for two gauge stations and values were subtracted to determine the cumulative runoff for the North Laramie, Fish Creek and Chugwater River drainages. Station no. 66705.00 at Ft. Laramie was the lower station and station no. 66670.60 at Uva was the upper station. Flows at both stations show strong influence by water management. By subtracting the two, we hoped to eliminate much of the effect of water management; but some influence is still noticeable in the runoff pattern. Flow data were available each day for the years evaluated.

Runoff from snowmelt usually begins very gradually in late January. The beginning of runoff is very difficult to identify. The snowpack area occupies only 20-30% of the drainage basin area. Peak runoffs usually occur in mid-May. Runoff for the 1974 water year was much above average. Runoff for 1975 is below average, and runoff for the 1979 water year is much below average. 1974 probably represents a near-typical runoff year, but the 1975 data are also useful. Peak flows as high as 701 cfs (May 20, 1978) were recorded in this area during the 6-year period used in this evaluation (only 6 years data available at Uva station). A typical peak flow rate would be around 321 cfs and should occur on May 11.

The amount of water supplied from the melting of the snowpack can not be accurately determined due to water management. However, the runoff curves suggest that 10-15% of the annual runoff might be directly attributed to spring snowmelt. The relatively small amount of runoff from snowmelt reflects the fact that most of the drainage area lies at lower elevations, where snow accumulation is minimal.

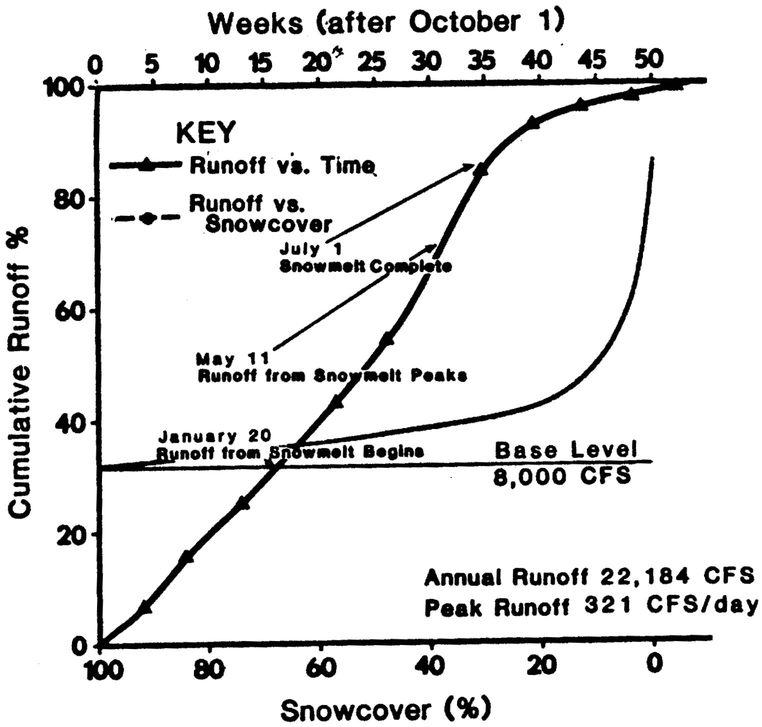
CRITICAL VALUES (approximate for a normal year):

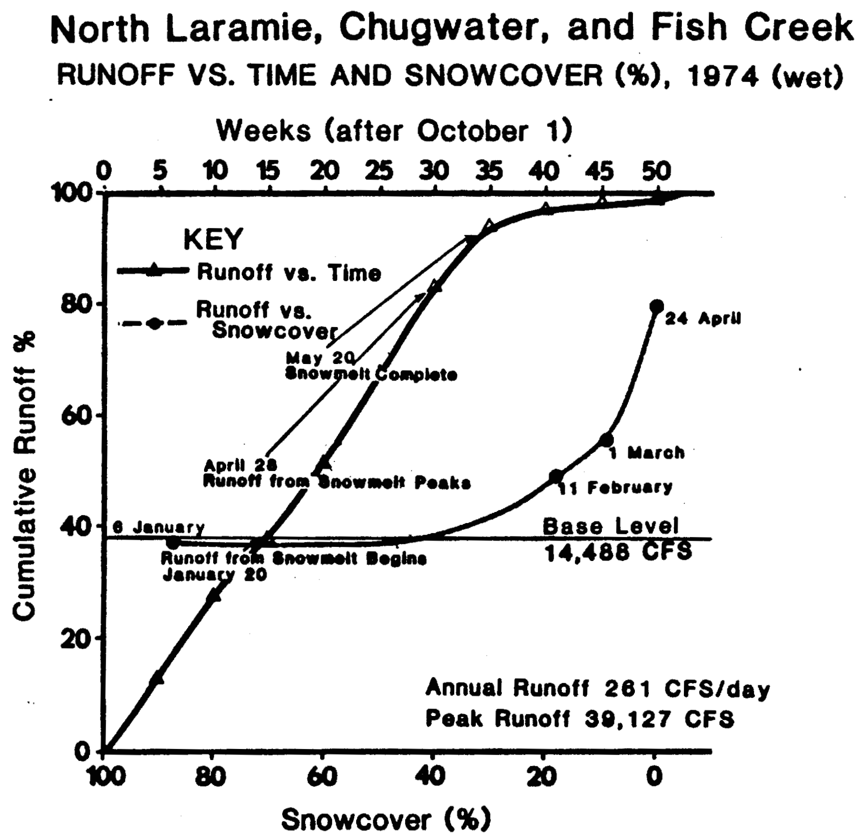
Beginning of runoff from snowmelt: January 20
Peak of runoff augmented by snowmelt: May 11
Peak runoff volume (normal year): 321 cfs
Snowmelt complete (no visible snow): July 1
Percent runoff provided by snowpack: 10%?
Gauge station used in estimating runoff: Flow values at station #66705.00 near Fort Laramie less those recorded at station #66670.60 near Uva, Wyoming

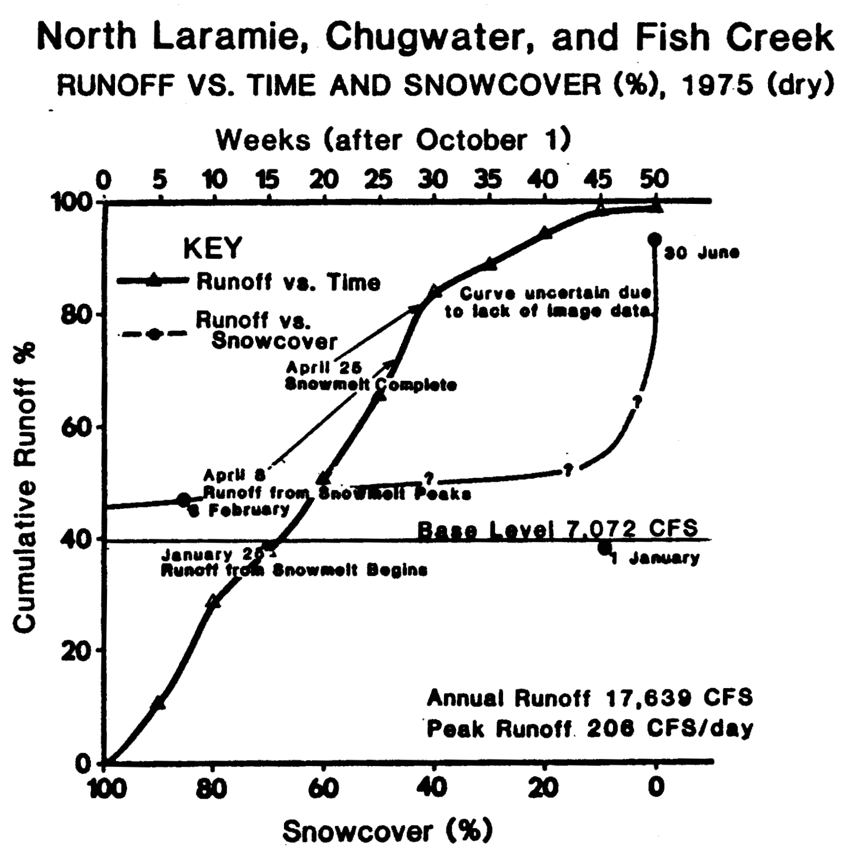


North Laramie, Chugwater, and Fish Creek

RUNOFF VS. TIME AND SNOWCOVER (%), (average, 6 years)

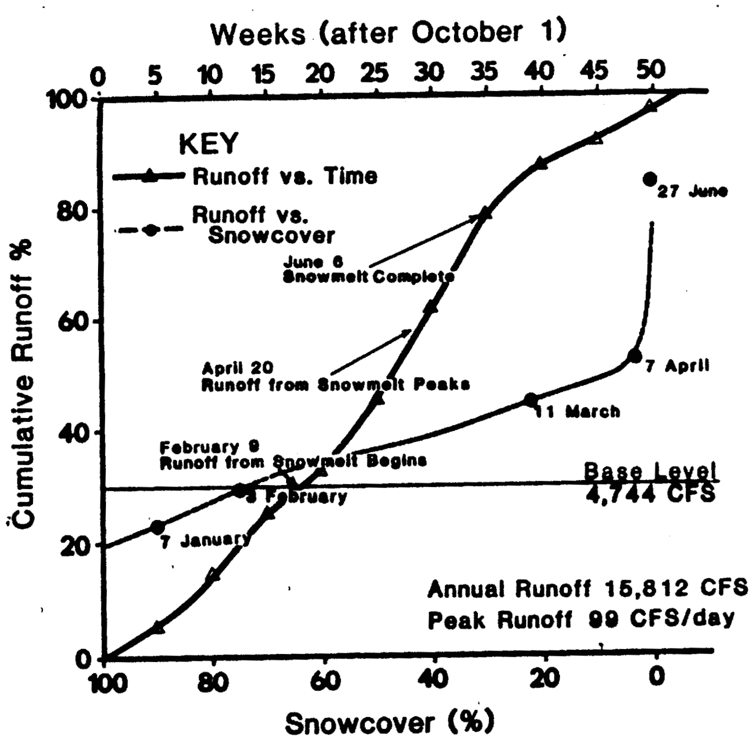



North Laramie, Chugwater, and Fish Creek
RUNOFF VS. TIME AND SNOWCOVER (%), 1974 (wet)
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
May 20 Snowmelt Complete
April 28 Runoff from Snowmelt Peaks
6 January
Runoff from Snowmelt Begins January 20
24 April
1 March
11 February
Base Level 14,488 CFS
Annual Runoff 261 CFS/day
Peak Runoff 39,127 CFS
Cumulative Runoff %
Snowcover (%)


North Laramie, Chugwater, and Fish Creek
RUNOFF VS. TIME AND SNOWCOVER (%), 1975 (dry)
Weeks (after October 1)
KEY
Runoff vs. Time
Runoff vs. Snowcover
30 June
Curve uncertain due to lack of image data
April 25 Snowmelt Complete
April 8 Runoff from Snowmelt Peaks
5 February
Base Level 7,072 CFS
1 January
January 20 Runoff from Snowmelt Begins
Annual Runoff 17,639 CFS
Peak Runoff 206 CFS/day
Cumulative Runoff %
Snowcover (%)

North Laramie, Chugwater, and Fish Creek

RUNOFF VS. TIME AND SNOWCOVER (%),1979 (very dry)



SNOWMELT AND RUNOFF PATTERNS: MIDDLE LARAMIE RIVER DRAINAGE (above Uva)

Landsat imagery for 1974, 1975 and 1976 were used to determine the snowmelt-runoff relationship for the middle Laramie River drainage. Snowcover estimates were made from the Laramie Basin and North Park Landsat images. Four dates were used for the 1974 analysis, only three dates were available for 1975, but six coverage dates were available for 1976. The 1974 coverage lacked a March date. The 1975 year lacked coverage in both January and March and 1976 lacked coverage in January. The 1976 imagery is the most reliable of the three years evaluated. Stream flow data from station no. 66670.60 on the Laramie River above the North Laramie River, near Uva, Wyoming, were used to determine cumulative runoff values. The flow values measured at this station reflect substantial water management at the Wheatland Reservoirs just upstream from the gauge station. Flow data were available each day for the years evaluated.

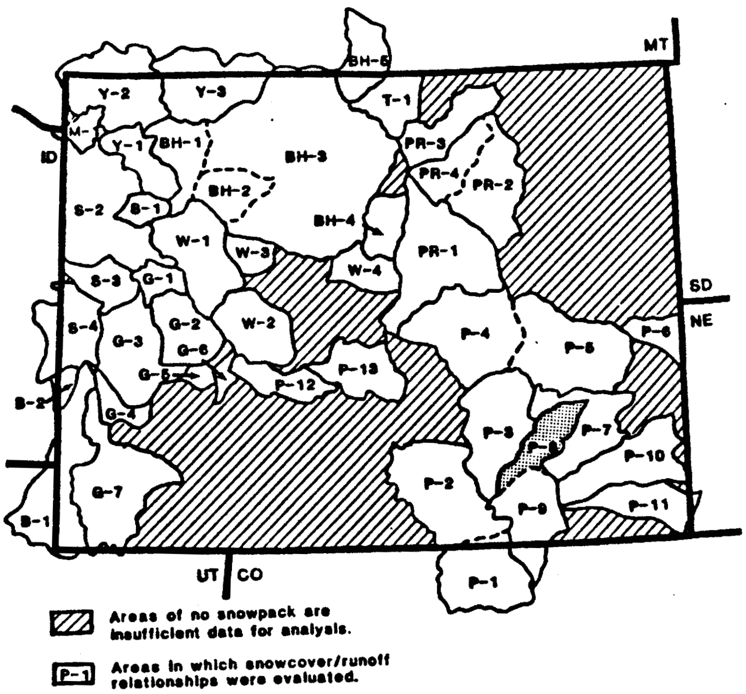
Runoff from snowmelt is often too severely regulated to be visible on the average runoff curve, but its effect can be seen during high snowmelt seasons (1974). Its effect is most pronounced after the snowpack area has diminished to 40-50% of the drainage basin area. Peak runoffs usually occur in late April. The 1974 water year represents above average runoff in which the peak flow occurred on April 3 at 167 cfs. 1975 is below average and the peak flow, due to snowmelt, is not discernable. 1976 water year is a more typical year. Peak flow occurred on May 25 at 112 cfs. Peak flows as high as 192 cfs (May 18, 1978) were recorded at this station during the only 6-year period used in this evaluation. A typical peak flow rate at this station would be around 132 cfs and should occur on April 24. Snowcover generally decreases most rapidly approximately 10 weeks before this date.

Discharge from the Laramie River drainage was much above normal for 1974 (23,331 cfs compared to the 6-year average of 13,379 cfs, 74% above average). The 1975 season was below average (11,358 cfs or 15% below average). Discharge was approximately average for the 1976 season at 13,673 cfs or 2% above normal). Consequently, the 1976 snowmelt curve best represents the normal snowmelt pattern for the Laramie River. The 1976 runoff curve is relatively flat and shows additional late runoff (probably due to water released from the reservoir system) compared to the average time versus runoff calculated for the 6-year average. Of the years that we have gauge data for, 1979 represents the closest to the normal runoff at 13,657 cfs. The average snowmelt curve given is our best estimate of the configuration of the snowmelt versus runoff curve for an "average" year.

The data suggest the water supplied from the melting of snowpack in the area of the middle Laramie River is usually not allowed to pass the reservoirs in significant amounts, so little effect is see at the Uva gauge stations. As a result of the intense water management, the runoff pattern measured at the Uva gauge station is affected only slightly by snowmelt during a normal melt season. When snowmelt is above normal (1974) its effect can be seen in the runoff rates. Although the snowmelt pattern can be monitored from the satellite imagery, it can not be used to predict expected flow values because of the management practices in the area. Most snowmelt occurs between March 15 and June 1, but the actual volume of water produced can not be determined from the available stream flow records.

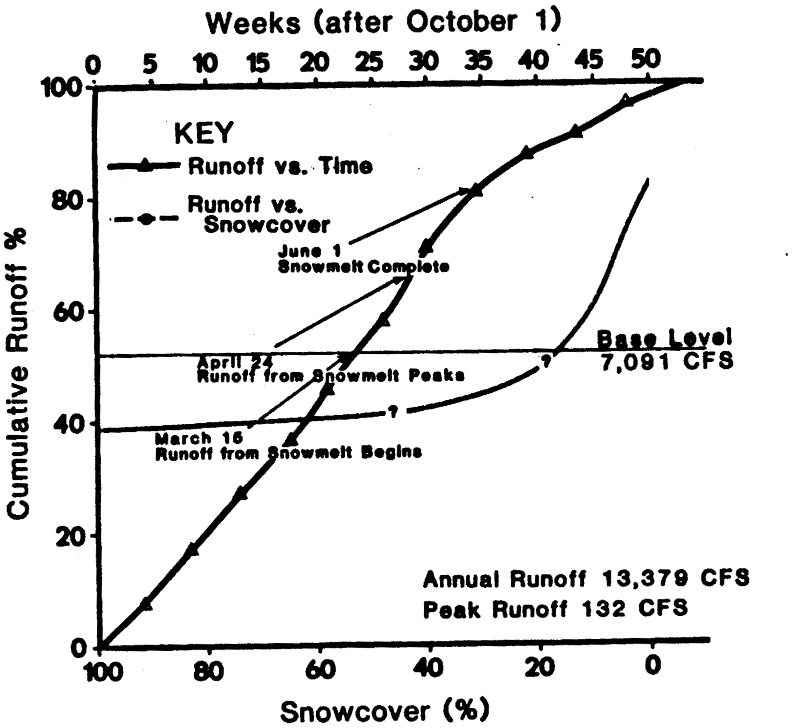
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: mid-February
Peak of runoff augmented by snowmelt: April 24
Peak runoff volume (normal year): 132 cfs
Snowmelt complete (no visible snow): June 1
Percent runoff provided by snowpack: 15%
Gauge station used in estimating runoff: #66670.60 above North Laramie River near Uva, Wyoming



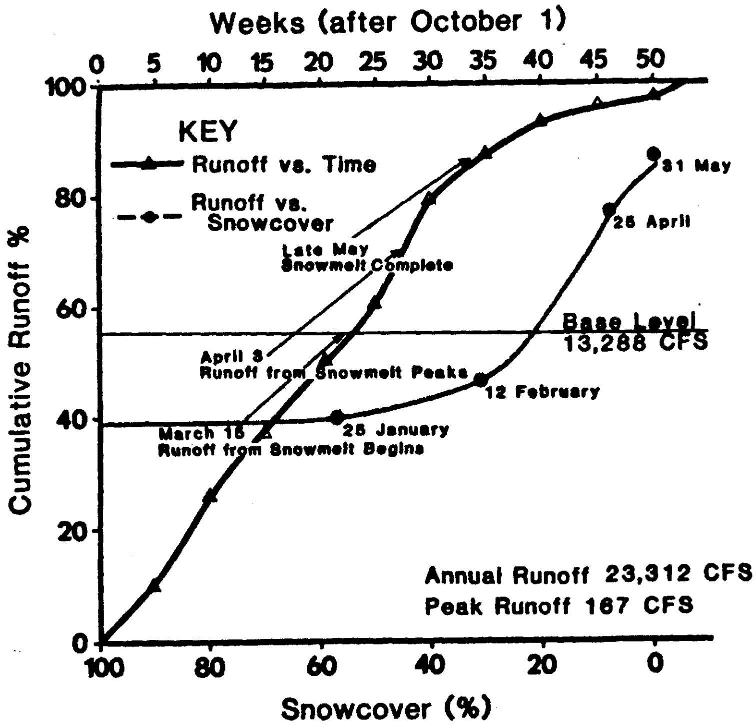
Laramie River above Uva

RUNOFF VS. TIME AND SNOWCOVER (%). (average)



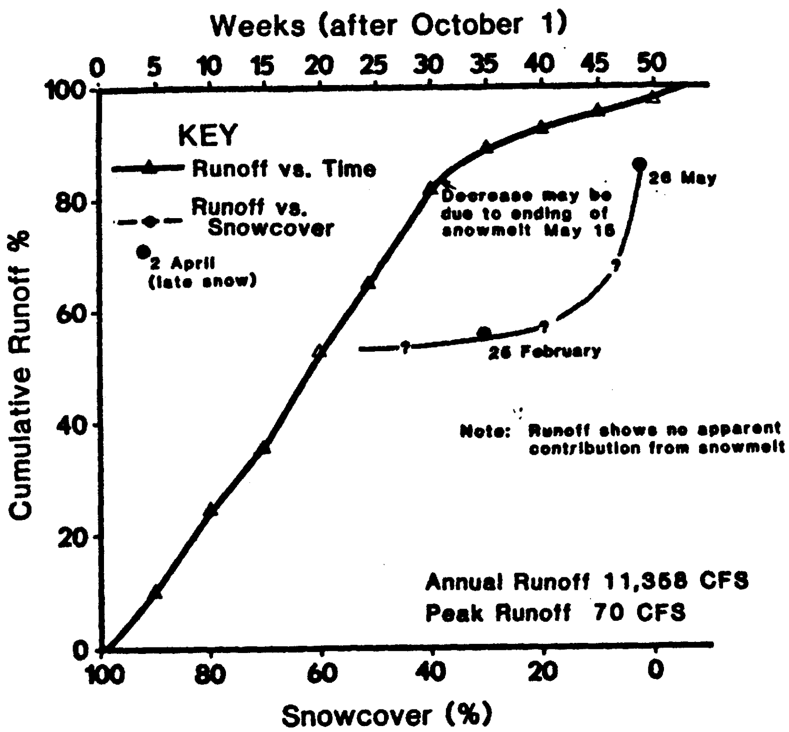
Laramie River above Uva

RUNOFF VS. TIME AND SNOWCOVER (%), 1974 (wet)



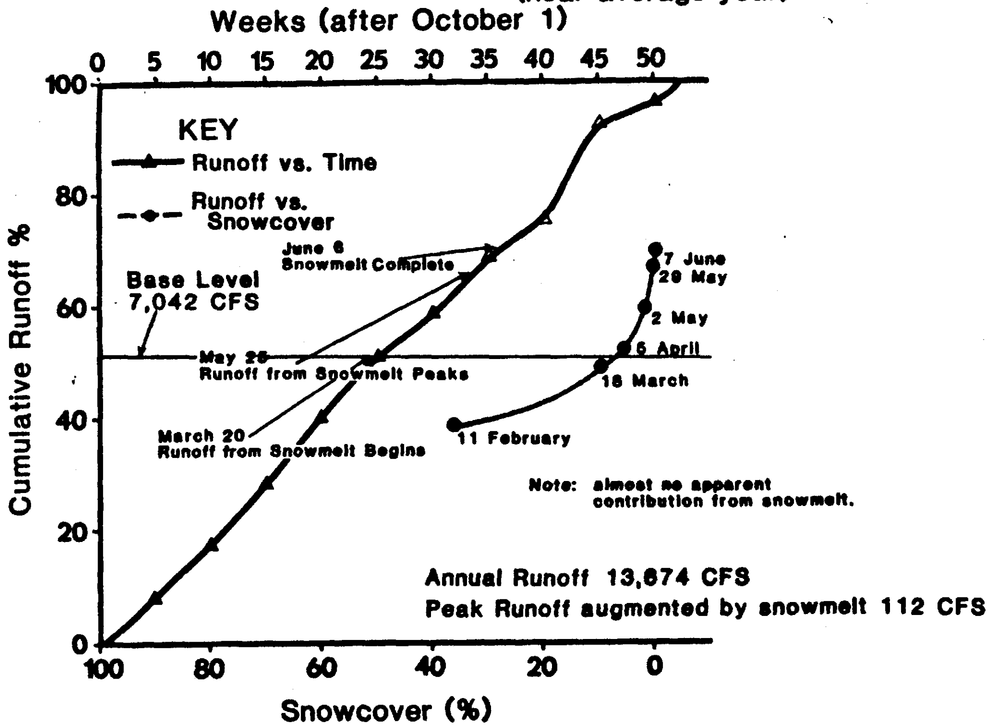
Laramie River above Uva

RUNOFF VS. TIME AND SNOWCOVER (%), 1975 (dry)



Laramie River above Uva

RUNOFF VS. TIME AND SNOWCOVER (%), 1976
(near average year)



SNOWMELT AND RUNOFF PATTERNS: LARAMIE RIVER DRAINAGE AREA (ABOVE BOSLER)

Landsat imagery for 1973, 1974, 1975 and 1976 were used to determine the snowmelt-runoff relationship for the Laramie River drainage above Bosler. Laramie Basin and North Park Landsat images were used. Six dates provided good coverage for 1973, three dates were available for both the 1974 and 1975 seasons, and five dates were used for 1976. 1973 imagery lacked coverage in February, but a late January date was available. The 1974, 1975, and 1976 imagery lacked coverage for January, and the 1974 and 1975 imagery also missed a March date. The 1973 and 1976 coverage is quite adequate. Stream flow data from station no. 66615.85 on the Laramie River near Bosler, Wyoming were used to determine the cumulative runoff values. The flow at this station shows little effect of water management, but some management is necessary for certain lakes and reservoirs (Lake Hattie, Cooper Lake, Chambers Lake and James Lake). Flow data were available each day for the years evaluated.

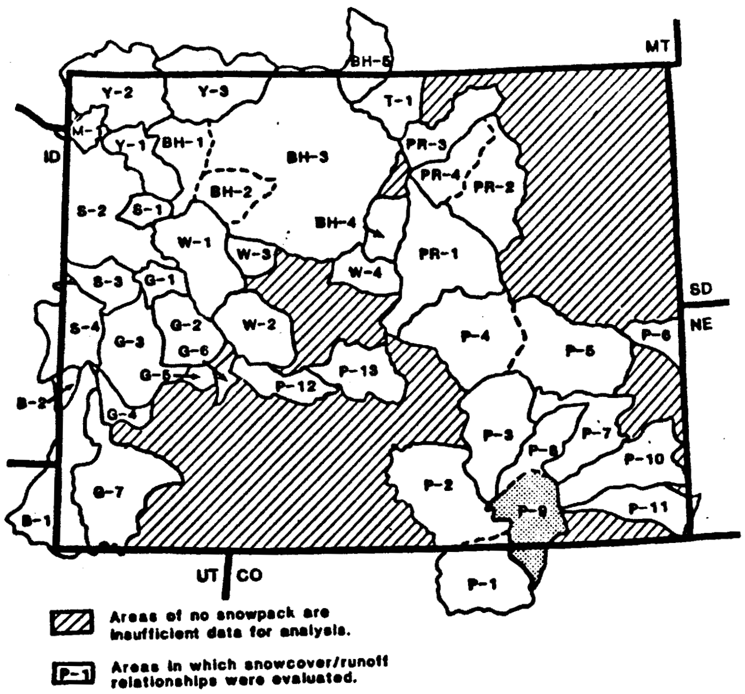
During a normal year, such as 1975, the spring runoff increases 16.5 fold as the snowmelt intensifies during the months of early June to early August (from approximately 32 to 529 cfs). But, in the 1976 water year, the spring runoff increased only 5.6 fold with snowmelt (from approximately 45 to 253 cfs). The spread in the total volume of runoff from snowmelt is quite large through the years. The 1973 water year shows extreme flood conditions in which the peak flow occurred on June 19 at 1620 cfs. 1974 is a more normal runoff year, but is still above average. Peak flow occurred on June 10 and 11 at 1280 cfs. The 1975 water year is the most nearly typical year represented by the available imagery. Peak flow occurred on June 19, 1975 at 1160 cfs. 1976 shows below average runoff conditions, in which the peak flow occurred on June 21 at 560 cfs. Peak flows as high as 1970 cfs (June 29, 1982) were recorded at this station during the 10-year period used in this evaluation. A typical peak flow rate at this station would be around 1183 cfs and should occur on June 14 or 15.

Discharge from the Laramie River drainage was much above normal for 1973 (93,746 cfs in 1973 compared to the 10-year average of 53,840.2 cfs, 74% above normal). The 1974 season was also above average (68,754 cfs or 28% above average). The 1975 runoff was almost normal (53,174 cfs or 1% below normal) while the 1976 runoff year was below average (39,286 cfs or 27% below average). Consequently, the 1975 snowmelt curve most nearly represents the normal snowmelt pattern for the Laramie River. The average runoff curve shows a lower rate of runoff in the fall than the curve derived from the 1975 stream flow data. Both curves show runoff beginning at approximately the same time, but the runoff ends slightly later in 1975.

Water supplied from the melting of the snowpack usually represents about 70% of the total discharge from the Laramie River drainage. Flow rates normally increase by a factor of ten during the relatively brief period of rapid snowmelt that occurs between late April and early July.

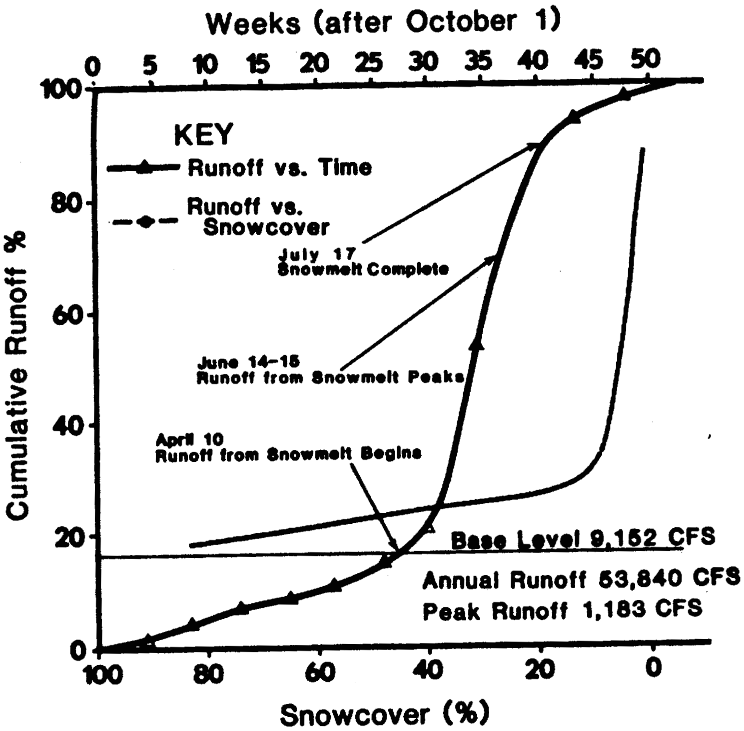
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: April 15
Peak of runoff augmented by snowmelt: June 14-15
Peak runoff volume (normal year): 1183 cfs
Snowmelt complete (no visible snow): July 17
Percent runoff provided by snowpack: 70%
Average total runoff: 53,840 cfs
Gauge number used in estimating runoff: #66615.85 near Bosler, Wyoming



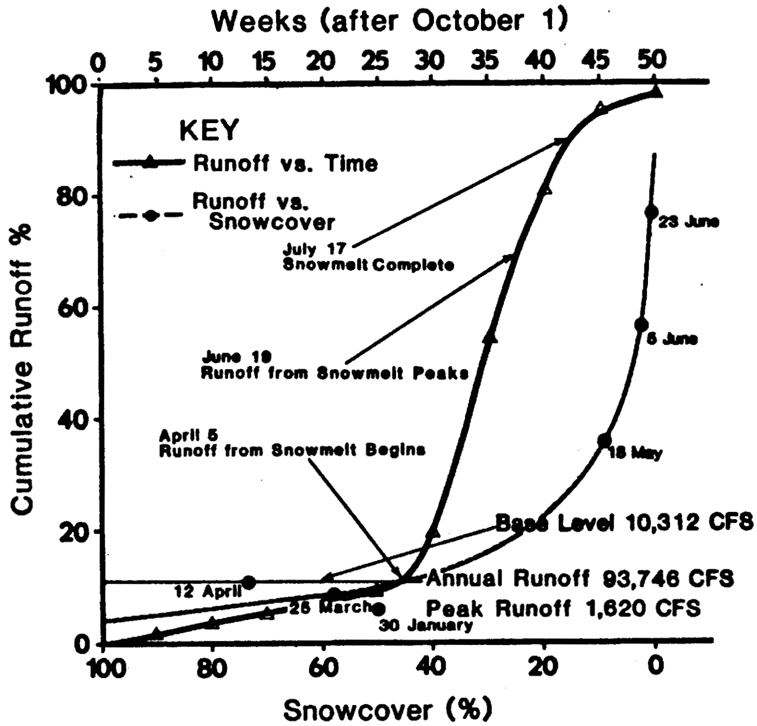
Laramie River above Bosler

RUNOFF VS. TIME AND SNOWCOVER (%) (average)



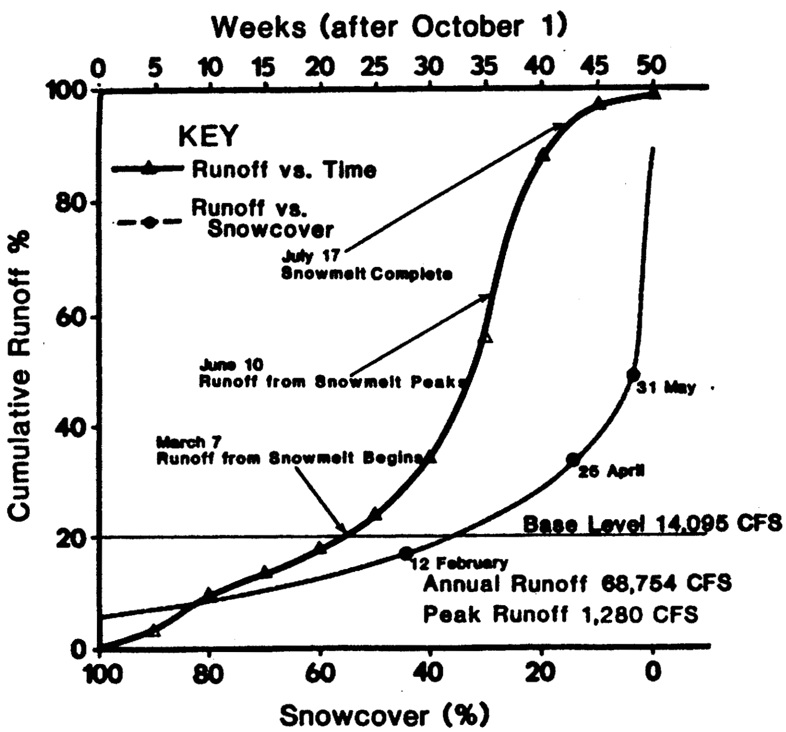
Laramie River above Bosler

RUNOFF VS. TIME AND SNOWCOVER (%), 1973

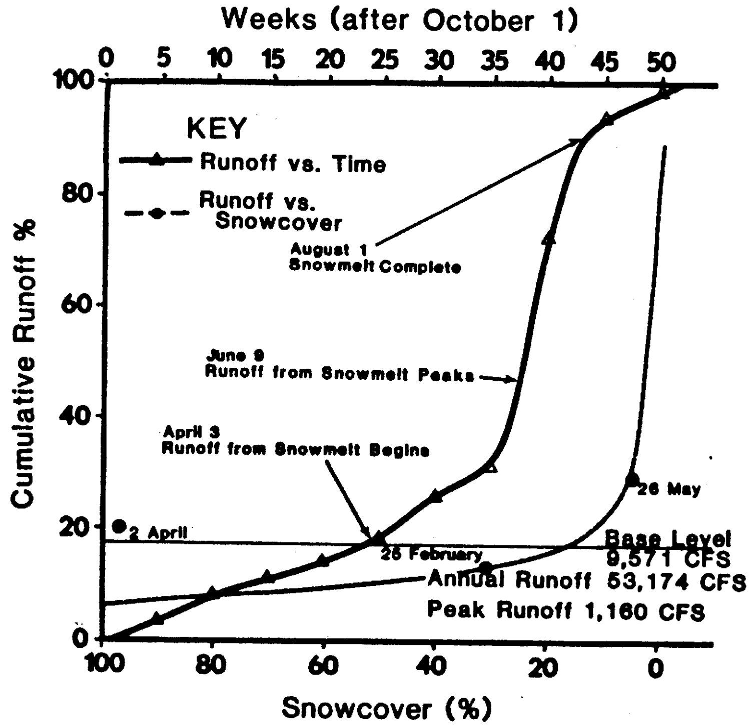


Laramie River above Bosler

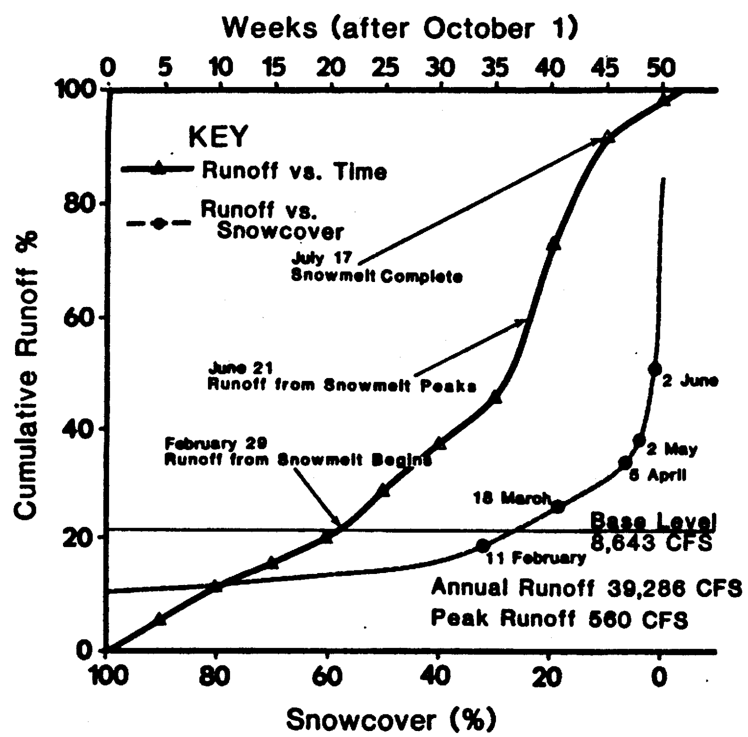
RUNOFF VS. TIME AND SNOWCOVER (%), 1974



Laramie River above Bosler
RUNOFF VS. TIME AND SNOWCOVER (%), 1975



Laramie River above Bosler
RUNOFF VS. TIME AND SNOWCOVER (%), 1976



SNOWMELT AND RUNOFF PATTERNS: HORSE CREEK DRAINAGE AREA ABOVE LYMAN, NEBRASKA

Landsat imagery for 1973, 1974 and 1979 were used to determine the snowmelt-runoff relationship for the Horse Creek drainage, a tributary of the North Platte River. The Laramie Range Landsat images cover this region. The 1973 coverage comprises six scenes and five dates of coverage were available for both 1974 and 1979. No coverage is available for May either in 1974 or 1979; but, otherwise, the data sets are excellent. Stream flow data from station no. 66775.00 on Horse Creek near Lyman, Nebraska, were used to obtain cumulative runoff values. The Horse Creek drainage supplies some agricultural needs, but the runoff pattern does not appear to be strongly influenced by water management.

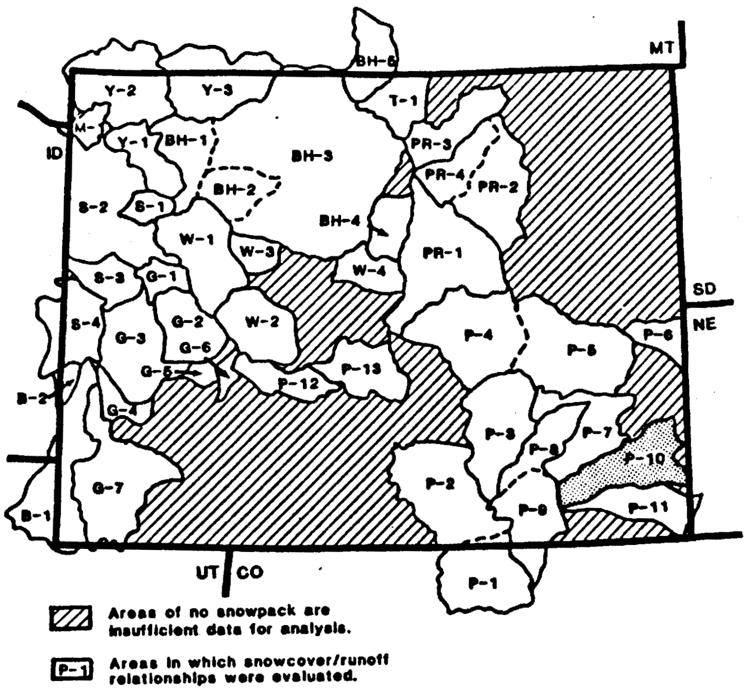
Runoff from snowmelt usually begins in early May with the snowpack area covering only 10-20% of the drainage area. Peak runoffs usually occur in early June. Runoff for the 1973 water year is above average, the 1974 water year was much above average, and 1979 was a near typical year, being very slightly below average. Peak flows as high as 1120 cfs (May 24, 1980) were recorded at this station during the 11-year period used in this evaluation. A typical peak flow rate at this station would be around 376 cfs/day, and should occur about June 7.

Discharge from the Horse Creek drainage was above average for 1973 (41,989 cfs compared to the 11-year average of 34,458 cfs, 22% above average). Runoff for 1974 was much above average at 47,072 cfs (37% above average). The 1979 season was only slightly below average at 33,892 cfs (1.6% below average). Consequently, the 1979 snowmelt curve is expected to represent the normal snowmelt pattern for Horse Creek. The average runoff curve shows runoff from snowmelt beginning about May 1.

The data suggest the water supplied from the melting of the snowpack usually represents about 30% of the total discharge from the Horse Creek drainage. Peak flow rates typically increase by a factor of 4 to 5 during the relatively brief period of rapid snowmelt that occurs between late April and early July. Estimation of the snowmelt-runoff relationship is complicated by the fact that much of the area does not accumulate a snowpack, but provides a large area to gather late shows and rainfall that augment the runoff.

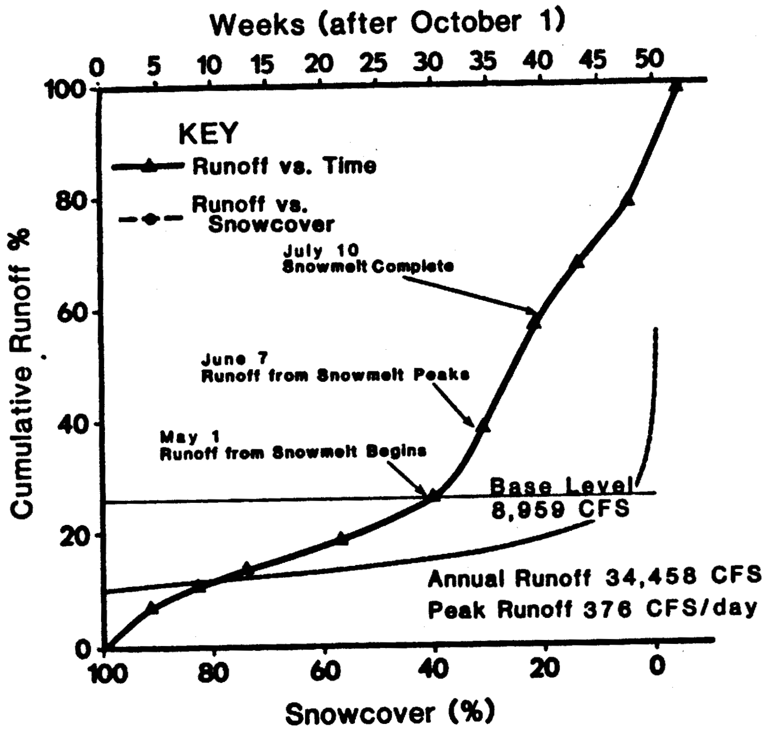
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: May 1
Peak of runoff augmented by snowmelt: June 7
Snowmelt complete (no visible snow): July 10
Percent runoff provided by snowpack: 30%
Peak runoff volume (normal year): 376 cfs
Gauge station used in estimating runoff: #66775.00 near Lyman, Nebraska



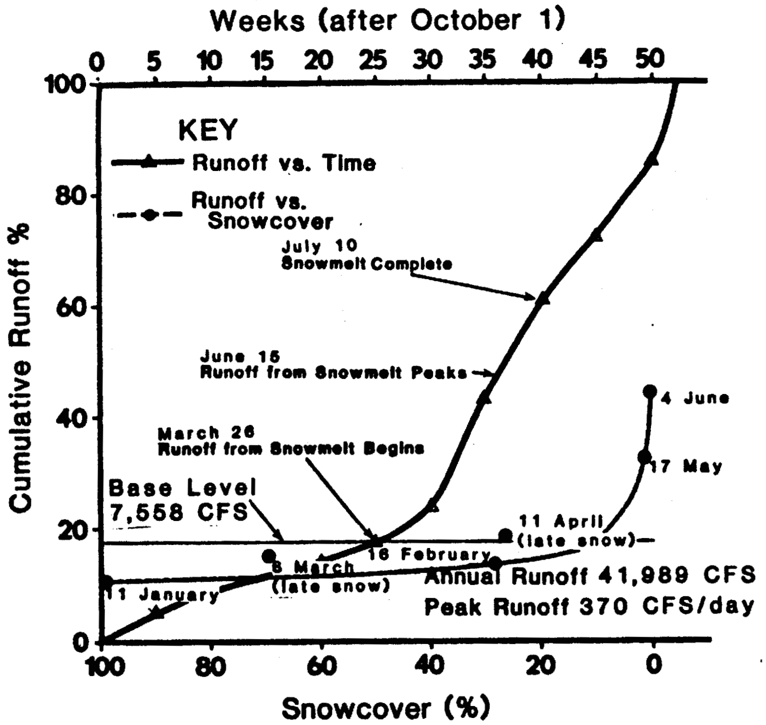
Horse Creek above Lyman,Nebraska

RUNOFF VS. TIME AND SNOWCOVER (%), (average)



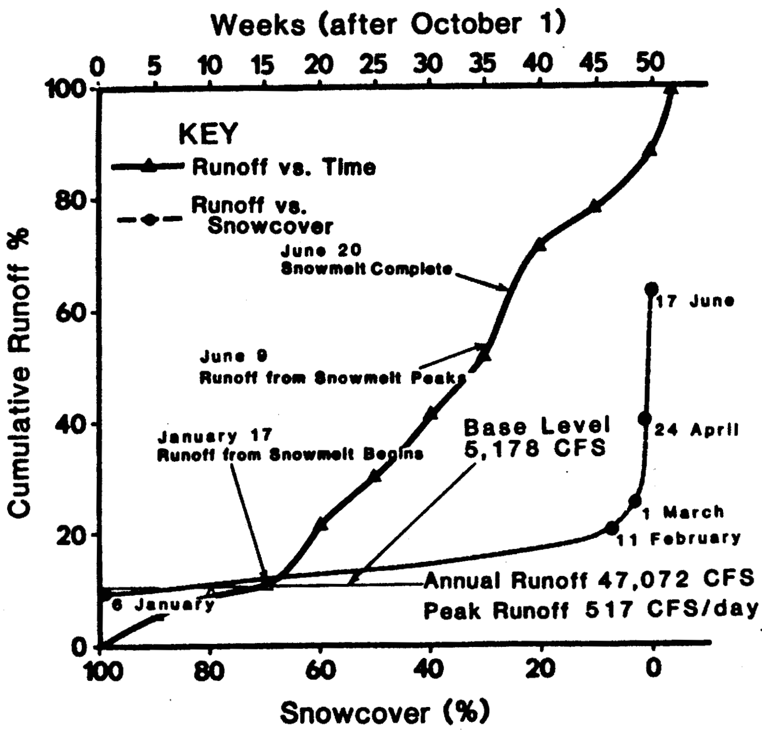
Horse Creek above Lyman, Nebraska

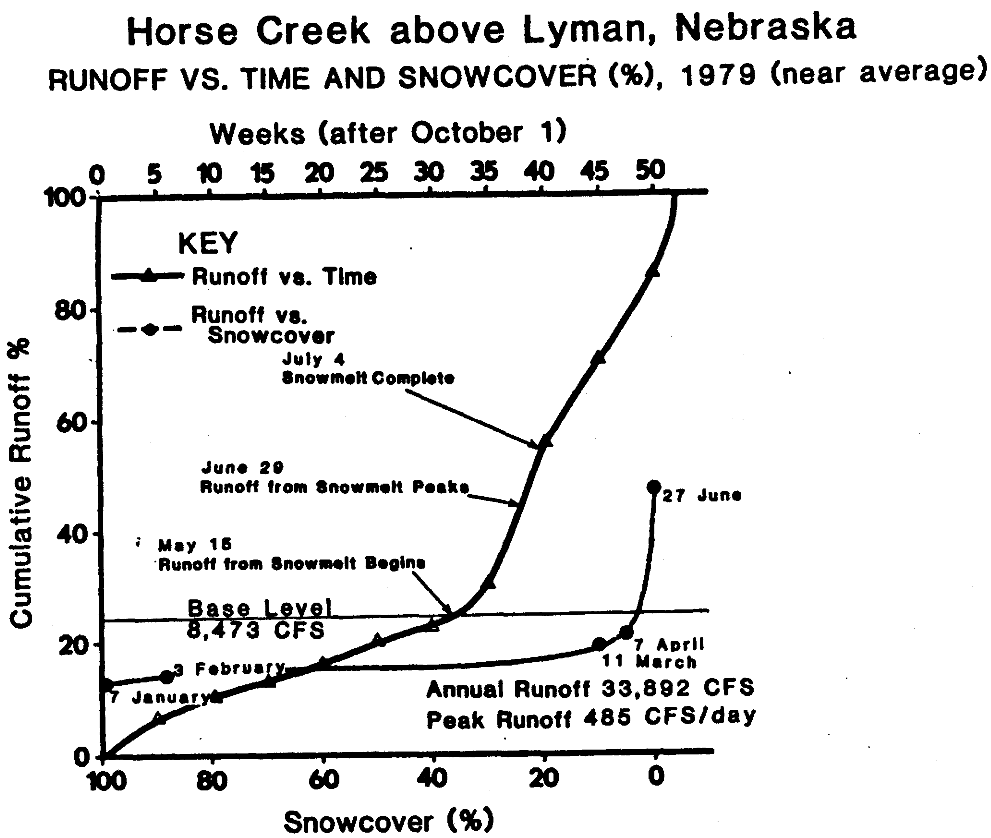
RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



Horse Creek above Lyman, Nebraska

RUNOFF VS. TIME AND SNOWCOVER (%), 1974 (very wet)





Horse Creek above Lyman, Nebraska
RUNOFF VS. TIME AND SNOWCOVER (%), 1979 (near average)
Weeks (after October 1)
0 5 10 15 20 25 30 35 40 45 50
KEY
Runoff vs. Time
Runoff vs. Snowcover
July 4
Snowmelt Complete
June 29
Runoff from Snowmelt Peaks
May 15
Runoff from Snowmelt Begins
27 June
Base Level
8,473 CFS
7 April
11 March
3 February
7 January
Annual Runoff 33,892 CFS
Peak Runoff 485 CFS/day
Cumulative Runoff %
0 20 40 60 80 100
100 80 60 40 20 0
Snowcover (%)

SNOWMELT AND RUNOFF PATTERNS: LODGEPOLE CREEK DRAINAGE AREA (ABOVE BUSHNELL, NEBRASKA)

Landsat imagery of the Laramie Range area for 1973, 1974 and 1979 were used to determine the snowmelt-runoff relationship for the Lodgepole Creek drainage. Coverage consists of six scenes for 1973 and five scenes for 1974 and 1979. The coverage is generally excellent and lacks only the May coverage for 1974 and 1979. Stream flow data from station no. 67625.00 on the Lodgepole Creek at Bushnell, Nebraska, were used to determine cumulative runoff values. The runoff curves show strong influence of water management, but no major storage facilities are upstream from the gauge station. Flow data were available each day for the years evaluated.

Runoff from snowmelt usually begins in early February. The date is difficult to determine exactly because the direct contribution of snowmelt to the normal runoff is relatively small. The snowpack covers 5-30% of the drainage area. Peak runoffs usually occur in early May, but span a wide range of dates. Some peaks may be the result of spring thunderstorms. The 1973 water year shows a much greater than average runoff (135% of normal) and peak flow occurred on March 24 at 20 cfs. The 1974 water year is also above average (110% of normal) and the peak flow occurred on April 6 and 7 at 10 cfs. 1979 was almost a typical year, with slightly below average runoff (94% of normal). Peak flow occurred on February 12 at 23 cfs. The highest flow rate recorded during the 11-year period was 93 cfs on February 21, 1980. A typical peak flow rate at this station would be around 12.8 cfs and should occur on March 15 or May 1.

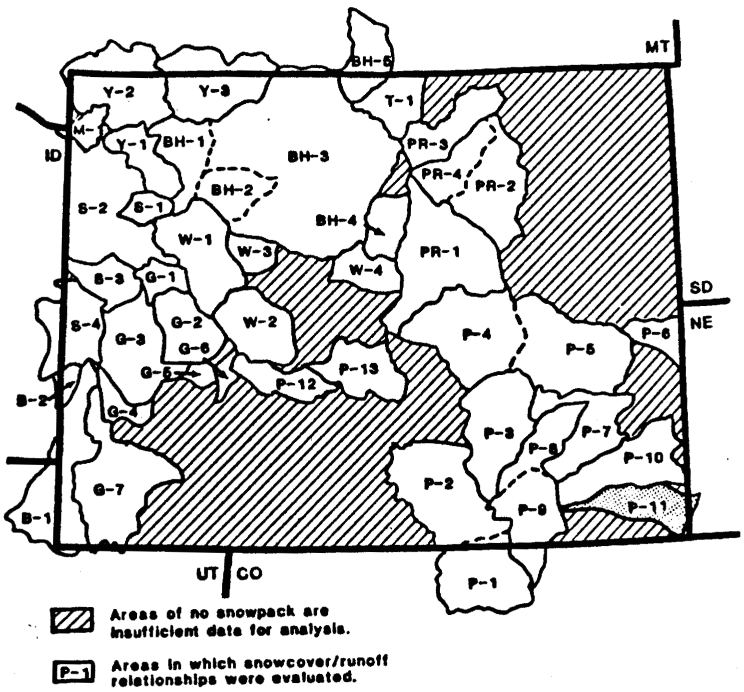
The 1974 and 1979 snowmelt curves most closely represent the normal snowmelt pattern for Lodgepole Creek. The curve for the 1974 year looks fairly similar to the average curve, except the 1974 curve is slightly steeper. The 1979 curve is also quite similar to the average curve, except it has a more gradual slope.

Water supplied directly from the melting of the snowpack usually represents 10% of the total discharge from the Lodgepole Creek drainage. Peak flow rates increase 1.6 to 3.8 times during the relatively brief snowmelt that occurs between late March to late May.

The Lodgepole drainage does not acquire a large snowpack. The straight-line shape of the runoff curve is attributed to the minimal influence of snowmelt. The snowmelt is gradual, and yields no big increase in runoff. Heavy rains in July and August produce extreme peak flows. The 1973 runoff curve, with its above average snowpack, is the only year that shows substantial influence of snowmelt (35% of runoff from snowmelt).

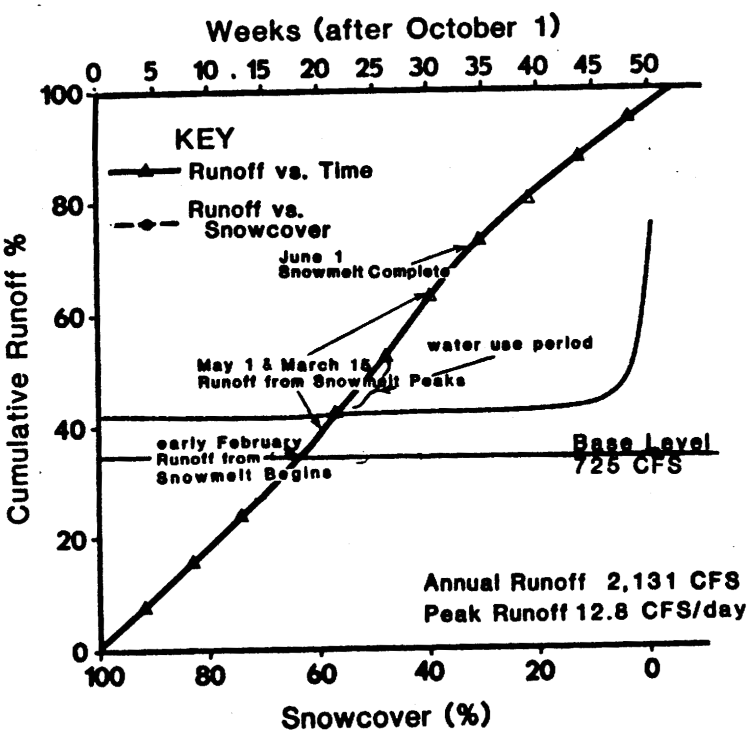
CRITICAL VALUES (approximate for a normal year):

Beginning of runoff from snowmelt: early February
Peak of runoff augmented by snowmelt: March 15 or May 1
Snowmelt complete (no visible snow): early June
Percent runoff provided by snowpack: 10%
Peak runoff volume (normal year): 12.8 cfs
Gauge station used in estimating runoff: #67625.00 at Bushnell, Nebraska



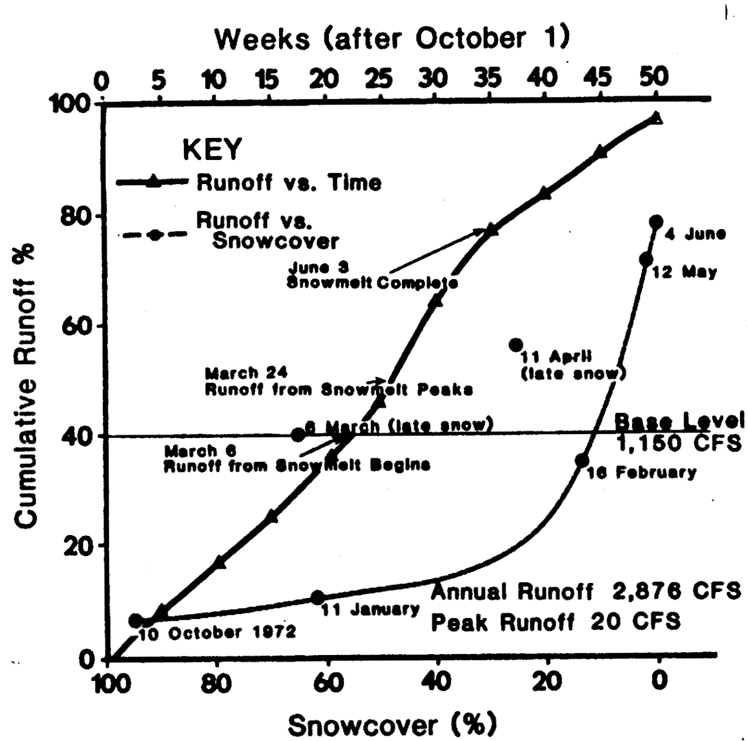
Lodgepole Creek

RUNOFF VS. TIME AND SNOWCOVER (%), (average)



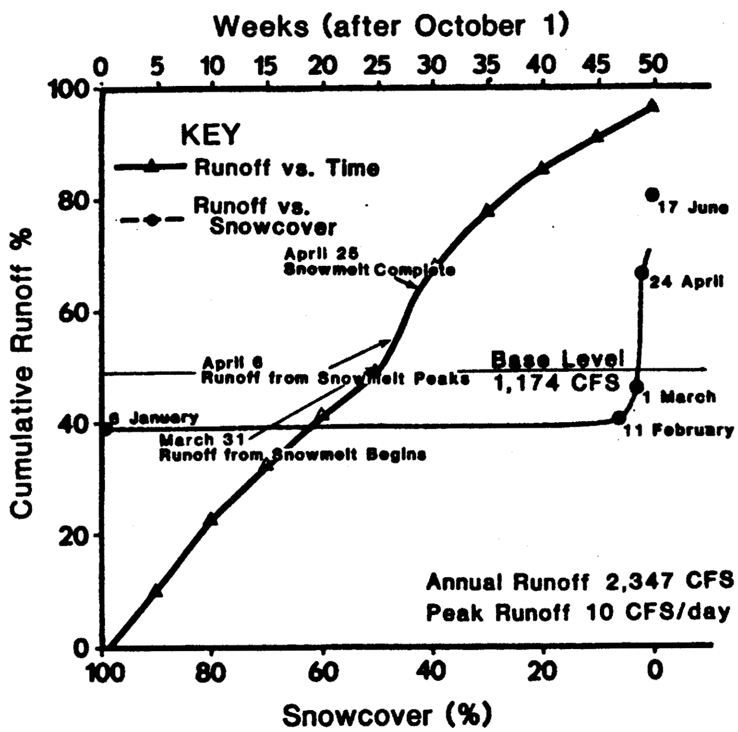
Lodgepole Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



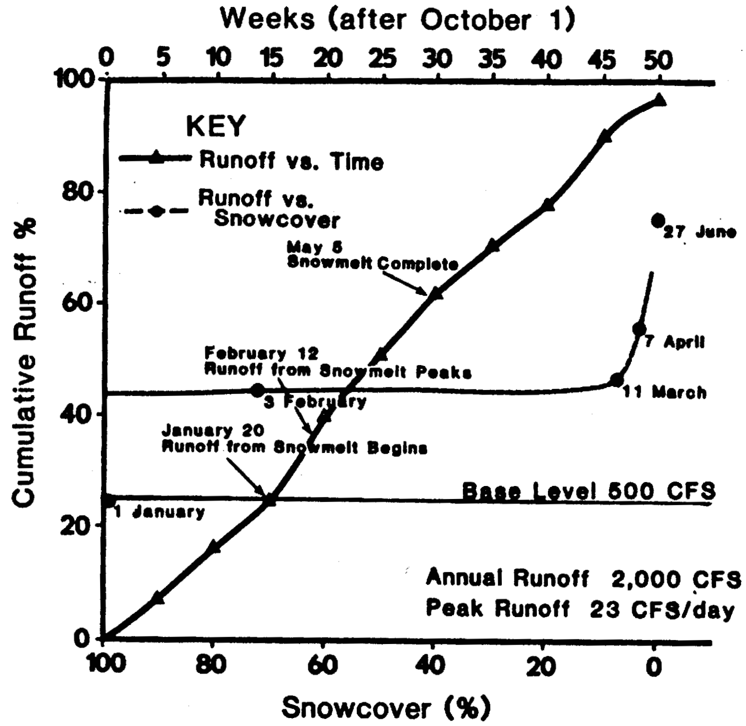
Lodgepole Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1974



Lodgepole Creek

RUNOFF VS. TIME AND SNOWCOVER (%), 1979



AREA P-12

SNOWMELT AND RUNOFF PATTERNS: UPPER SWEETWATER RIVER (SOUTH PASS)

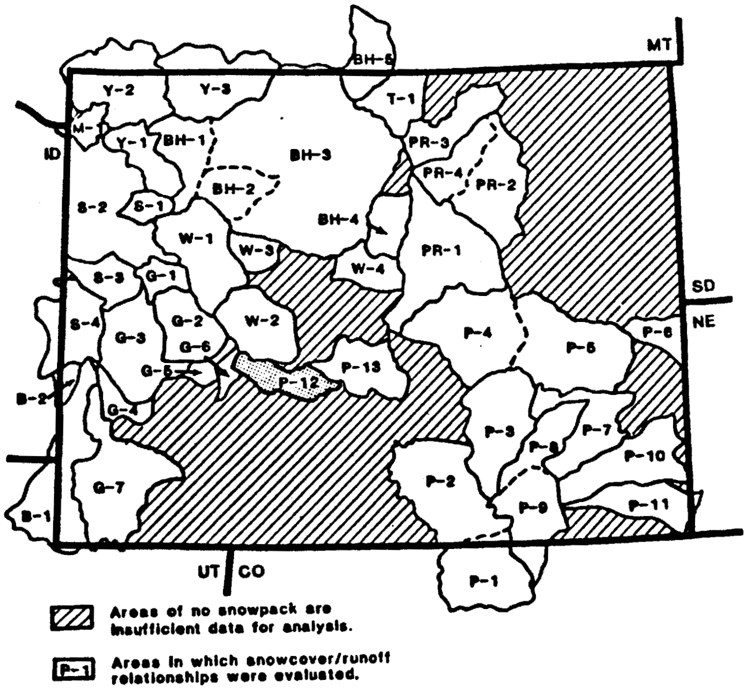
Landsat imagery for the 1976 and 1977 water years was used to define the snowmelt pattern for the upper Sweetwater drainage. Four dates of coverage were available for 1976 and five dates for 1977. However, only three dates of coverage occur during the time of snowmelt. The resultant snowmelt curves are not considered highly reliable. Yet, they provide enough data for an estimate of the relationship between runoff and snowcover.

The 1976 discharge was only 4% below the 1974-82 average of 50,122 cfs. Also, according to snowcourse data, 1976 was approximately an average year. Thus, the 1976 snowmelt curve is considered a fairly representative relationship. The peak values, total runoff values, and melt rates should be very close to expected values for a normal year.

1977 was a drought year according to discharge and snowcourse data. Drought years are defined as years when runoff is 50% or less of the average flow. The snowpack estimate for March 15, 1977, may be slightly in error (too low) or the April 8 estimate might have been somewhat high due to late snowfall. It is unlikely that the estimates for both dates are correct. We have chosen to honor the April 8 value for the 1977 runoff-snowpack curve.

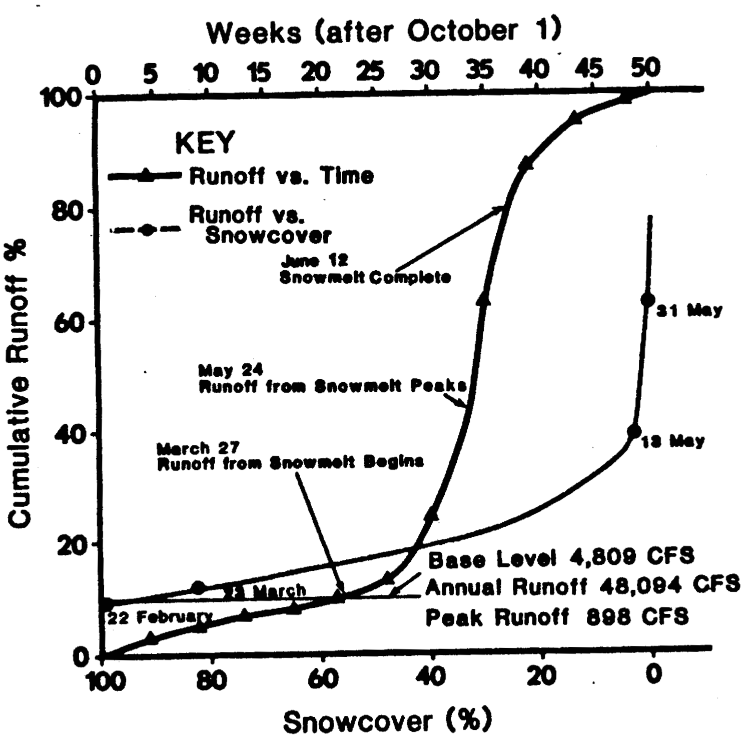
CRITICAL VALUES (for 1976, a near normal year):

Beginning of runoff from snowmelt: March 27
Peak of runoff augmented by snowmelt: May 24
Snowmelt complete (no measureable snowcover): June 12
Percent runoff provided by snowpack: 57%
Peak runoff volume (normal year): 898 cfs/day
Gauge station used in estimating runoff: #066380.9 Sweetwater River near Sweetwater Station, Wyo.



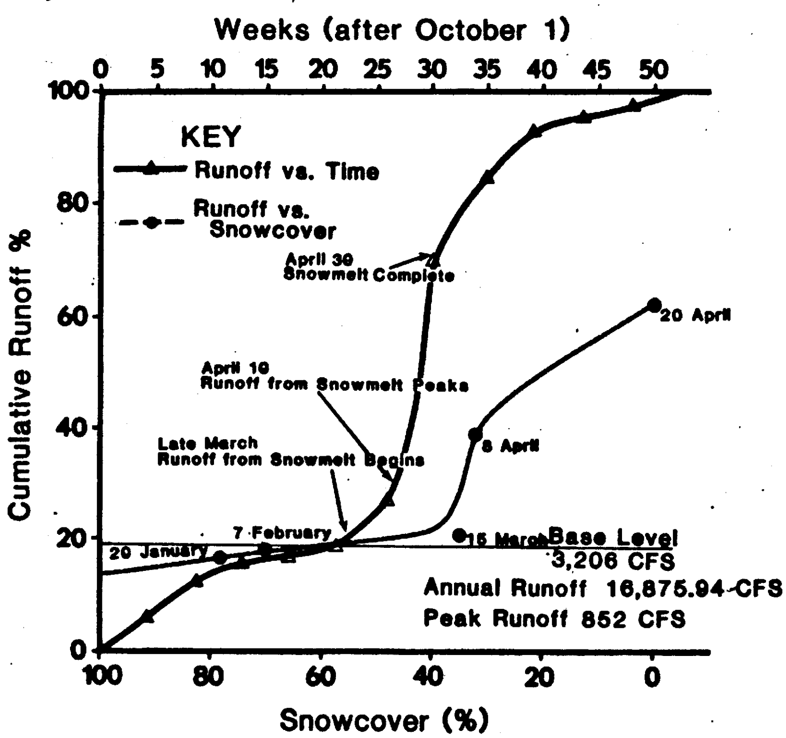
Upper Sweetwater (South Pass)

RUNOFF VS. TIME AND SNOWCOVER (%), 1976 (near average)



Upper Sweetwater (South Pass)

RUNOFF VS. TIME AND SNOWCOVER (%), 1977



SNOWMELT AND RUNOFF PATTERNS: LOWER SWEETWATER RIVER (ABOVE ALCOVA)

The lower Sweetwater drainage is an area of isolated mountain blocks and intervening basins. It does not develop a continuous snowpack in the basin areas. Snowmelt-runoff curves were constructed for the 1973 and 1976 water years. Constructed from five dates of coverage, the 1973 snowmelt curve represents the best available estimate of the snowmelt pattern for the lower Sweetwater River. Unfortunately, only three of the 1973 satellite coverage dates fall within the actual period of snowmelt. The 1976 snowmelt curve is derived from only two dates of satellite coverage and is not considered reliable.

A complete daily record of discharge was available for the three water years of 1972, 1973 and 1976. The remaining seven water years of the 1972-81 period were represented by an incomplete annual record. In order to calculate the ten-year average flow, the annual flow was estimated for each of the 7 years of incomplete data by adding a fixed discharge increment to represent the runoff during the six months from October through March when discharge was not recorded. The value added each year varies, depending upon a preliminary estimate of whether the season was relatively dry or wet. Both 1972 and 1973 appear to be years of high precipitation. Relatively speaking, 1976 is a year of low precipitation. Thus, the October through March discharge recorded in 1976 is added to the annual runoff total for dry years, while the October through March flow values for 1972 or 1973 are added to complete the record for wet years.

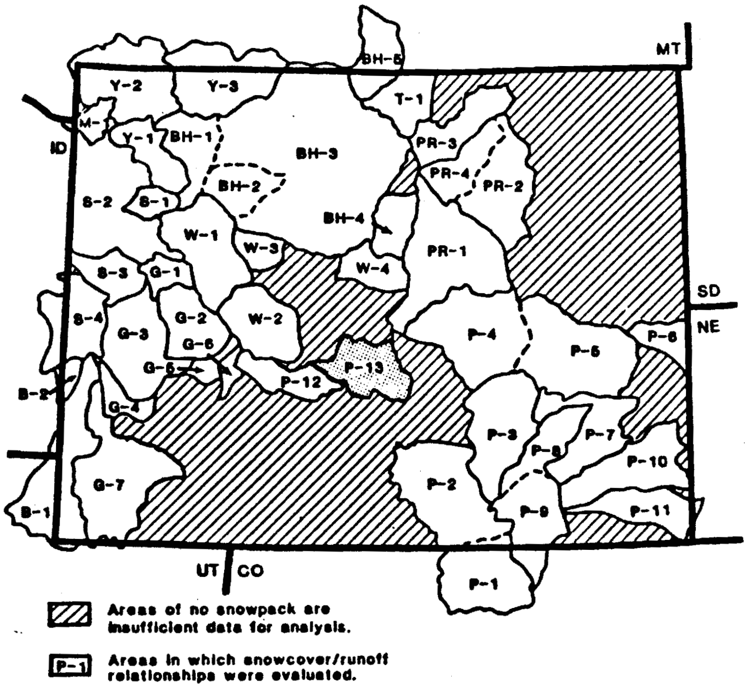
Relative to the 1972-81 estimate of average annual discharge (55,924 cfs), the 1973 water supply was 33% above average and the 1976 flows were 18% below average. No snowcourse data is available for this area, so this estimation can not be confirmed by correlation with snowcourse data.

A major problem in using the snowcover pattern to predict runoff is that much of the flow of the Sweetwater River is derived from snowmelt and runoff along the upper Sweetwater River; yet, the records of discharge are not sufficiently complete to allow determination of volume of flow into the lower Sweetwater by computing differences of gauge readings.

The snowmelt data for 1976 suggest that, in dry years, very little snowpack actually accumulates in the lower Sweetwater area; but, the discharge curve shows a strong influence of snowmelt due to the contribution of snowmelt on the upper Sweetwater. In 1973, a wet year, a substantial snowpack does accumulate in the mountains flanking the lower Sweetwater River and the melt pattern correlates well with the runoff curve. Because the data are marginal for this area, average runoff and snowcover curves are considered only a rough approximation of a representative snowmelt season. Yet, they provide a fairly good idea of some of the major parameters of the snowmelt pattern.

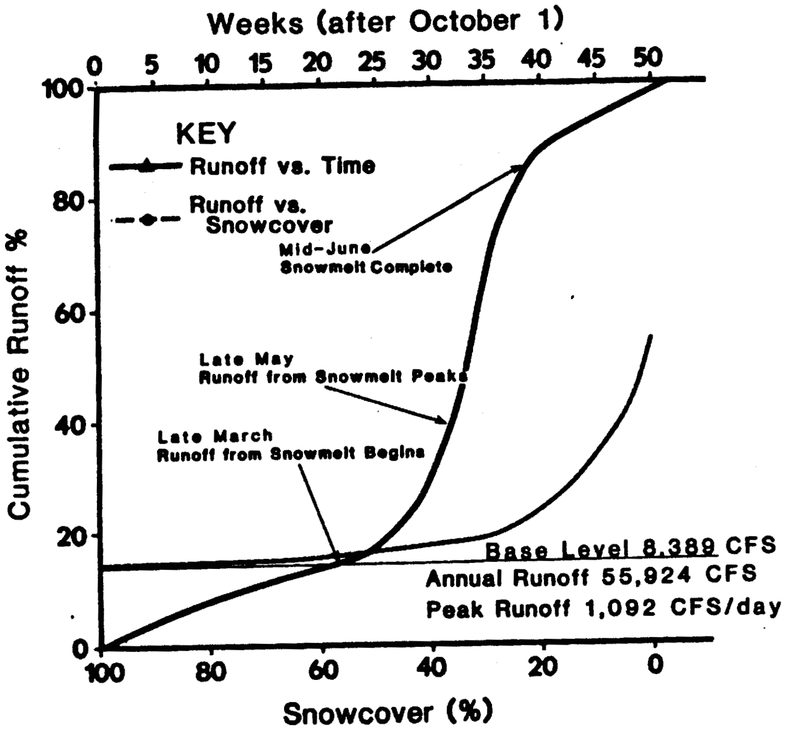
CRITICAL VALUES (estimated averages):

Beginning of runoff from snowmelt: Late March
Peak of runoff augmented by snowmelt: May 30
Snowmelt complete (no measureable snow): mid-June
Percent of runoff provided by snowpack: 60%
Peak runoff volume: 1092 cfs/day
Gauge station used in estimating runoff: #066390 Sweetwater River near Alcova



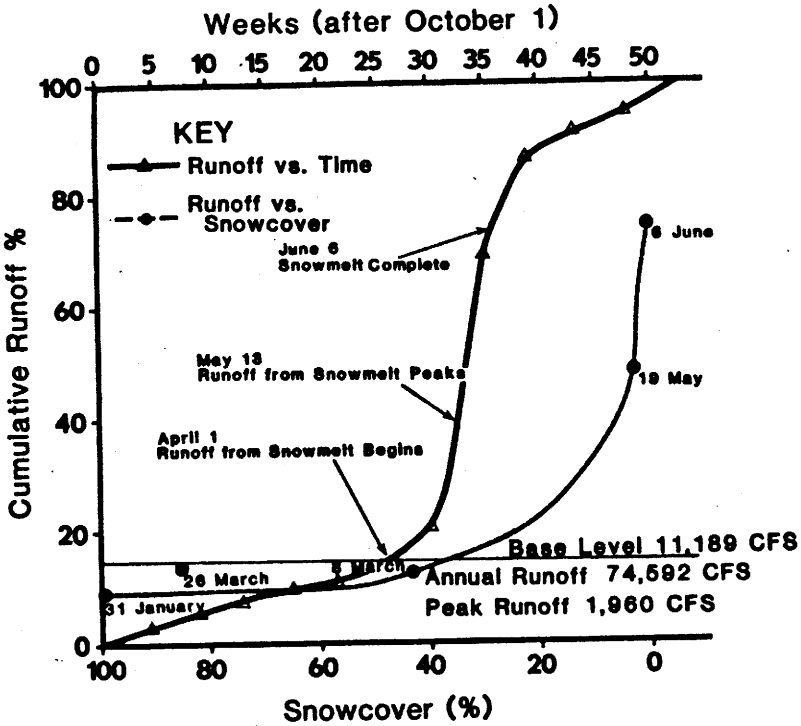
Lower Sweetwater River

RUNOFF VS. TIME AND SNOWCOVER (%), (average)



Sweetwater River

RUNOFF VS. TIME AND SNOWCOVER (%), 1973 (wet)



Sweetwater River

RUNOFF VS. TIME AND SNOWCOVER (%), 1976 (dry)