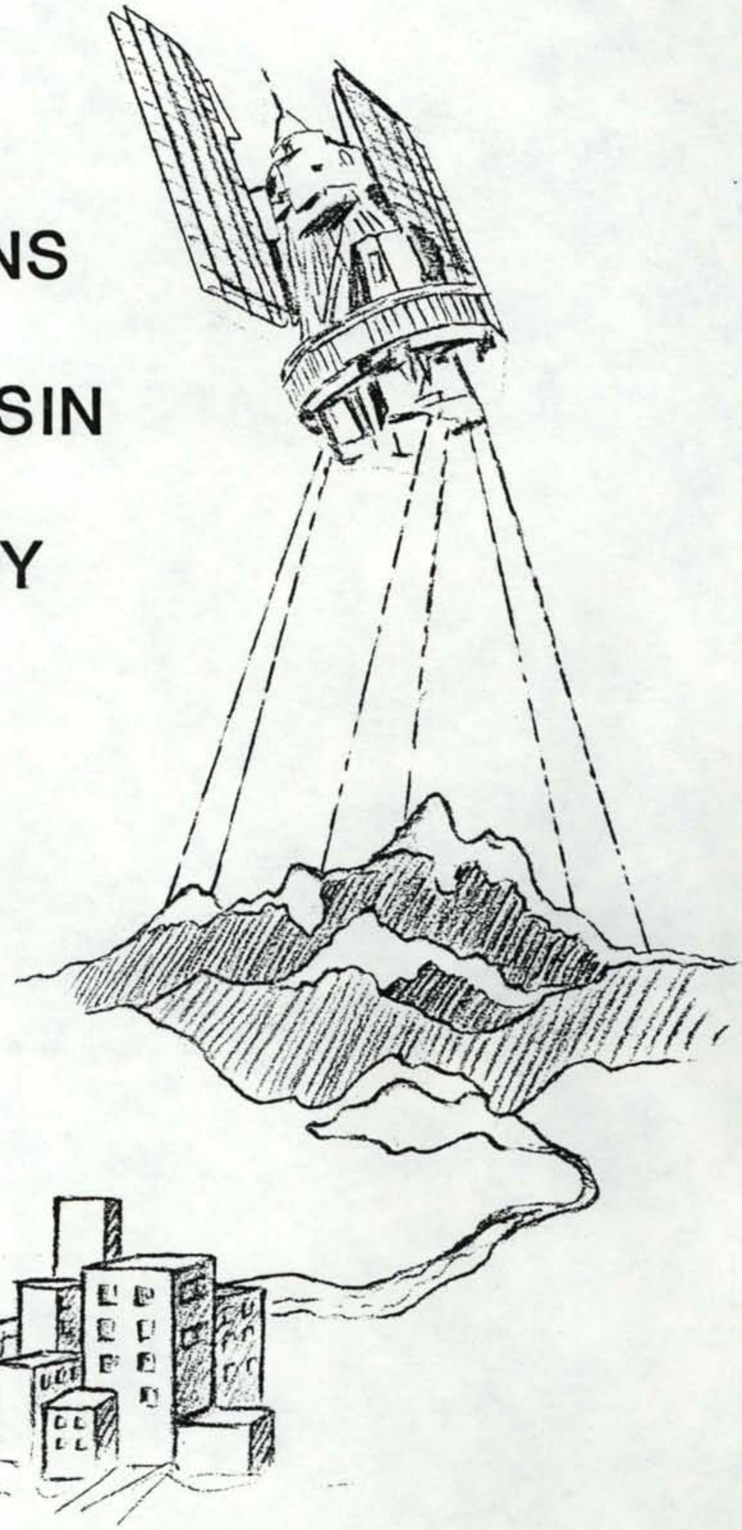
IDENTIFICATION OF SNOW COVER DEPLETION PATTERNS IN THE BOISE RIVER BASIN USING SATELLITE IMAGERY

PHASE II



by

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June, 1986

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ABSTRACT

The purpose of this research was to investigate methods of enhancing the runoff prediction capabilities for the Boise River Basin through the use of low level Landsat satellite imagery. The major topics that were addressed are:

1. Development and comparison of simplistic and typical snow covered area maps.
2. Determination of the distribution of slope aspect within and between subbasins.
3. Determination of average snow line elevations.
4. Investigation of the relationship between heat input, snow covered area, and runoff.

The development and comparison of the simplistic and typical snow covered area maps revealed that there were differences between the two representations. Since the SSARR model, which is presently used for runoff forecasting by the Corps of Engineers uses the simplistic representation of snow depletion, these difference could lead to some possible problems in the models snowmelt prediction routines.

The slope aspects studies revealed that the distribution of slope aspects within and between subbasins was not equal. Since slope aspect can affect snow melt patterns, this unequal distribution could present problems to the runoff modeling process if these distributions are not accounted for in the model.

The average snow line studies revealed that snow lines were not at constant elevations for given snow covered areas as is assumed in the present modeling scheme. Graphs are provided to help determine a realistic snow covered area after estimates of snow line are determined from snow flight data.

The heat input studies were made as preliminary investigations into development of a simpler model to describe the runoff process. Due to constraints in time, no rigorous statistical analysis were performed but some promising prediction schemes were presented.

INTRODUCTION

The Walla Walla District of the U.S. Army Corps of Engineers, along with other agencies, is responsible for reservoir operations in the Boise Basin. District personnel presently uses a sophisticated runoff model to predict snow melt runoff into the river system. This model named Streamflow Synthesis and Reservoir Regulation (SSARR) is extremely valuable in determining reservoir operation plans (U.S. Army Corps of Engineers, 1972). In the past there appeared to be certain areas within the basin where the actual patterns of snow cover depletion did not follow that which was predicted by the SSARR model. These discrepancies between model and real world caused the model to predict flows that were unrealistic when compared to observed values.

These erroneous predictions usually are most troublesome during the critical final reservoir refill period. Prediction errors during this period of time could result in the reservoirs of the system under filling or having to resort to possible reservoir surcharging or unnecessarily high flows in the lower portions of the Boise River system. Each of these could result in undesirable economic and political effects.

The purpose of this project was to investigate the snow cover depletion patterns in the Boise River Basin to determine what possible modifications to existing prediction procedures could be made so that more accurate flow predictions can be made during the critical final refill period. This report will briefly describe the first phase of this work which dealt with gathering snow covered area satellite imagery and developing this imagery into snow covered area maps. This part of the project was completed in June of 1984 and is covered in a previous completion report (Heitz, 1984). Detailed description of work accomplished using the previously described snow covered area maps will also be presented in this report.

The first major effort of this study was to develop a set of "simplistic" snow covered area maps. These maps were developed using area elevation information. The maps show the extent of area covered for certain percents of area of the total basin or subbasin. These maps were developed for 10, 15, 20, 25, and 35 percent area of each of four subbasins and for the total Boise Basin. The maps show how the existing models represents the snow depletion process.

The next effort was to develop "typical" snow covered area maps. These typical maps were developed from the snow covered area maps created in the first phase of this project. Again, a set of maps was developed depicting the 10, 15, 20, 25, and 35 percent snow covered area conditions but this time the maps were based on past snow cover conditions. Typical snow covered area maps were developed for each of four subbasin and for the entire basin.

Comparisons were made between the typical and simplistic maps to see if there were any differences in the maps. Any identified differences between the simplistic and typical maps could indicate areas where the simplified approach, which is used in the existing prediction techniques was in error. Some differences were identified. The most important of these centered around two different areas in the basin. The simplified area coverage maps consistently showed larger snow covered areas than the typical snow covered area maps in the Smokey Creek Drainage of the South Fork of the Boise River. The simplified area coverage maps consistently showed smaller snow covered areas than those shown on the typical snow covered area maps in the upper reaches of the North Fork and Queens River Basins.

The next major effort came in the development of a geographic information system (GIS) model of each of the subbasins. This model is an elevation location model which was used to compute average snow line elevations and to predict the distribution of slope exposures in all of the subbasins.

Results of applying the GIS model indicated that there were no significant differences in North, South, East and West slope snow line elevations at the precision which the GIS was based. There is, although quite a difference between the distributions of slope aspects between basins. Certain of the basins have higher components of one or more of the slope directions than do others. This might also contribute to inaccuracies experienced with the SSARR model which has no way to account for slope exposure within a basin or within an elevation band.

The last major emphasis area of the study was to investigate the relationships between temperature, runoff, and snow covered area. The effect of temperature was accounted for by using a degree day approach. Four different temperature recording locations in the basin were examined. No reliable relationship between degree day and snow covered area could be established from the available data, although it was found that the percent of total 1 April thru 1 July degree days is nearly constant for every location in the basin.

A regression of percent of total degree days vs percent runoff shows promise as a basis for a simple runoff predicting tool. A procedure for making runoff prediction using the volume forecasts and the degree day runoff relationships is suggested. It is also noted that no rigorous statistical analysis was made of the prediction procedure and use of this technique should be made only after more rigorous studies have been made.

PREVIOUS STUDIES

In August of 1983, the Walla Walla District of the U. S. Army Corps of Engineers entered into a contract with the University of Idaho to provide snow covered area maps of the Boise River Basin in Idaho. The snow covered area maps that were drawn for this project were developed from satellite imagery collected by the Landsat series of satellites. The Landsat satellite series has consisted of four satellites, Landsat 1 thru Landsat 4. Landsat 1, the first in the series became operational in July 1971. Since that time there has been at least one or two of the Landsat platforms operational at any one time.

The U.S. Geological Survey is in charge of managing the image information that is gathered by these satellites. The EROS Data Center at Sioux Falls, South Dakota has the primary responsibility of creating usable imagery from the satellite gathered data. They are also charged with the dissemination of this information to the public. The EROS Data Center is an extremely well organized information dissemination organization, and if a systematic approach is applied, those wishing to use satellite imagery should be favorably impressed with this organization. The steps outlining the procedures for identifying the desired imagery are contained in the completion report for phase I of this study (Heitz, 1984). Similar steps should be taken by anyone wishing to use satellite imagery for any reason.

Once the desired imagery was identified, the next step was to determine what type of image product was desired and which band or bands would be the most useful for this particular project. Both black and white and color imagery is available. This imagery can be purchased in various formats such as film positive or negative and also printed on paper. It was determined that black and white film positives would be most usable for the snow covered area mapping. Which multi spectral scanner (MSS) band to order was also an important consideration. A review of previous work in this area revealed that band 5 was probably the best for delineating snow covered area with band 4 being the second best for this type of task. (Foster, 1983).

Table 1 shows a listing of the scene dates of the imagery that was purchased. Figure 1 shows the imagery dates plotted on time lines so that comparisons can be made of data availability for different years.

In order for the information on snow cover to be useful, it had to be transferred to maps of standard U.S. Geological Survey topographic map scale. It was determined that maps of 1-250,000 scale would be used for this project. These maps represented a scale that was both large enough so that the entire basin could be drawn on a workable size sheet, yet the scale was small enough so that details in the basin would not be lost.

The imagery available from the Landsat series of satellites is not geometrically to the same scale on all points of the scene. In order to achieve a scale adjustment of the imagery to a constant 1 to 250,000 scale, the zoom transfer scope was used. The zoom transfer scope is an optical projection devise that allows the projection of one image onto another. In this case the satellite imagery was projected on to a standard 1-250,000 scale U.S. Geological Survey topographic map of the Boise Basin.

The inconsistent scale of the satellite imagery was corrected by using the stretch feature of the zoom transfer scope. This feature allows the scale of the projected image to be changed in two different axis directions. This stretching was continued until physiographic features such as streams or mountain tops on the projected image matched those on the topographic map. While the procedure sounds relatively simple, the actual process of matching map scales is very tedious and time consuming.

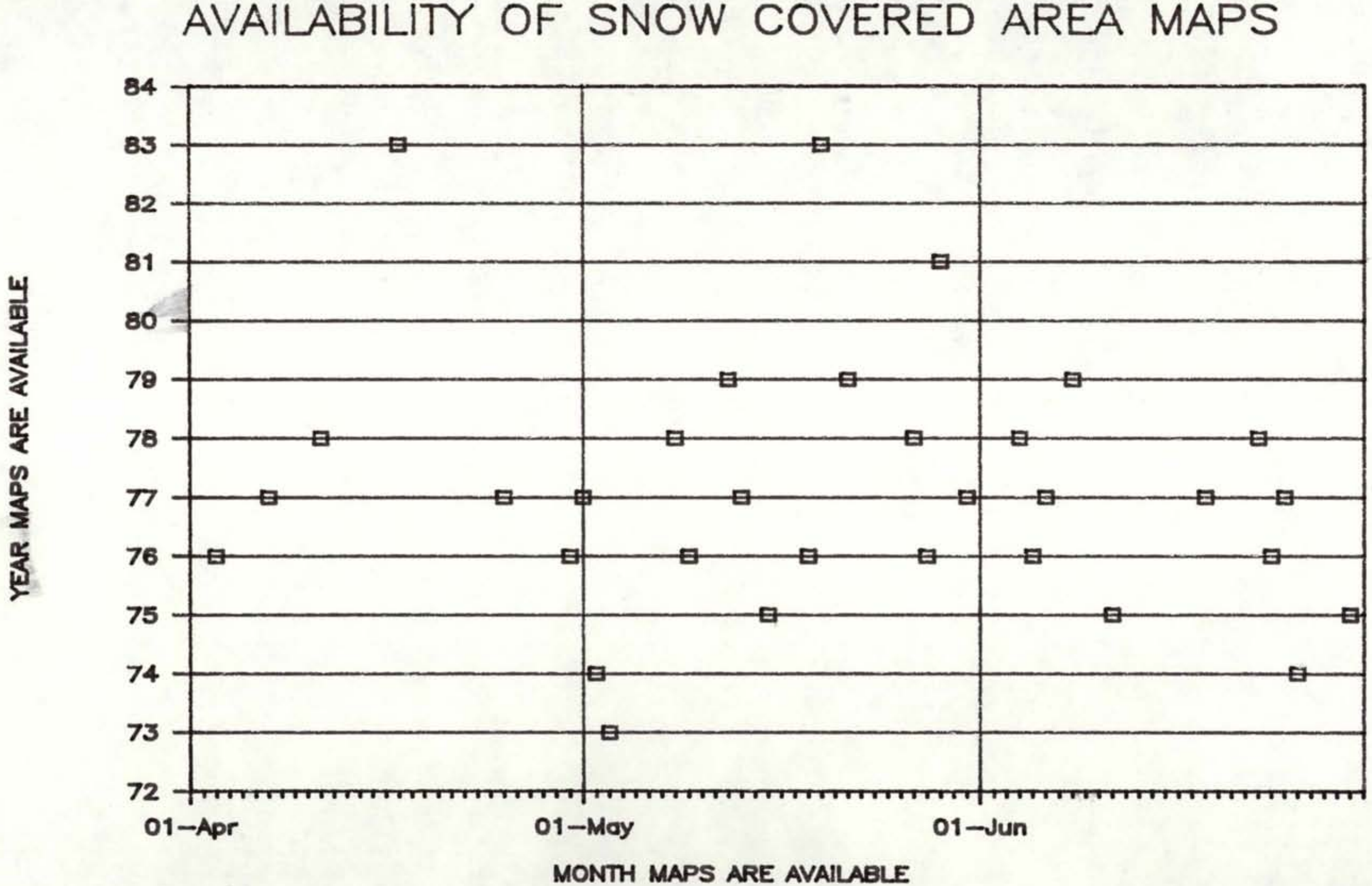
After the scales of the satellite imagery and the topographic map were made to coincide, the next step was to actually draw the location of the snow line. This was accomplished by simply tracing the projected snow line location on to the topographic map. The tracing was done on a mylar overlay.

In most cases the high contrast between snow covered and snow free areas made the snow line tracing task relatively simple. In some cases, though, cloud cover obscured portions of the snow line. In these cases the obscured snow line was estimated and shown as a dotted line on the tracing. Another problem that arose was trying to differentiate between

TABLE 1
DATES WHEN SNOW COVERED AREA
MAPS ARE AVAILABLE

* * * * * * 1983 * * * * * *	
1.	19 MAY
2.	17 APR
* * * * * * 1981 * * * * * *	
3.	28 MAY
* * * * * * 1979 * * * * * *	
4.	08 JUN
5.	21 MAY
6.	12 MAY
* * * * * * 1978 * * * * * *	
7.	22 JUN
8.	04 JUN
9.	26 MAY
10.	08 MAY
11.	11 APR
* * * * * * 1977 * * * * * *	
12.	24 JUN
13.	18 JUN
14.	06 JUN
15.	31 MAY
16.	13 MAY
17	01 MAY
18.	25 APR
19.	07 APR
* * * * * * 1976 * * * * * *	
20.	23 JUN
21.	05 JUN
22.	27 MAY
23.	18 MAY
24.	09 MAY
25.	30 APR
26.	03 APR
* * * * * * 1975 * * * * * *	
27.	29 JUN
28.	11 JUN
29.	15 MAY
* * * * * * 1974 * * * * * *	
30.	25 JUN
31.	02 MAY
* * * * * * 1973 * * * * * *	
32.	02 MAY

FIGURE 1


AVAILABILITY OF SNOW COVERED AREA MAPS
YEAR MAPS ARE AVAILABLE
84
83
82
81
80
79
78
77
76
75
74
73
72
01-Apr
01-May
01-Jun
MONTH MAPS ARE AVAILABLE

snow covered and snow free area when the snow covered area contained patches of partially snow free areas. In these cases the best estimate of complete cover snow line was estimated. A complete set of snow covered area tracings for the dates shown in Table 1 and Figure 1 was furnished to the U.S. Army Corps of Engineers as agreed in the contract for phase 1 of this project.

SIMPLISTIC SNOW COVERED AREA MAPS

The first major effort of this project was to develop a set of what was termed "Simplistic" snow covered area maps. These maps were developed assuming the following two constraints.

1. Snow cover always starts at the highest elevation in the basin.
2. Snow cover extends continuously and completely from higher elevation areas to areas of lower elevation.

These constraints represent very closely how the Streamflow Synthesis and Reservoir Regulation (SSARR) model, that the Corps uses in their streamflow forecasting procedure, represents the distribution of snow throughout the basin.

The first step in the process of developing these simplistic snow covered area maps was to divide the total Boise Basin into subbasins corresponding to those used by the Corps in their streamflow forecasting efforts.

The four subbasins used by the Corps are South Fork at Anderson Ranch Dam, Middle fork at Twin Springs, South Fork Local, and Lucky Peak Local. The South Fork at Anderson Ranch Dam includes all contributing areas to the South Fork above Anderson Ranch Dam. The Middle Fork at Twin Springs includes all of the contributing area to the Middle Fork lying above Twin Springs. South Fork local includes that area contributing to flows in the South Fork between Anderson Ranch Dam and Arrowrock Dam, and contributing areas between Arrowrock Dam and Twin Springs on the Middle Fork. Lucky Peak Local includes all area contributing to Lucky Peak Reservoir between Lucky Peak Dam and Arrowrock Dam.

The next step in the process was to gather information on the distribution of basin area with elevation within the total Boise Basin and within each of the subbasins. This information was provided by the Walla Walla District of the U.S. Army Corps of Engineers. They developed this information by measuring and tabulating the basin areas above various elevations in each of the basins. This area elevation information was provided for the four major subbasins that the corps uses in their streamflow forecasting efforts and also for the total basin. Table 2 contains a tabulations of the elevation versus corresponding percent of basin area above that particular elevation for all of the basins studied.

It was determined thru conferences with officials of the Corps that maps would be generated with snow covered areas covering 10, 15, 20, 25, and 35 percent of each of the subbasins and the total basin. These snow covered area values correspond to the snow covered area that would be expected during the later parts of the melt season. These later stages of melt have been particularly difficult to predict accurately using the present forecasting models and are critical to the final reservoir refill period.

To construct a 10 percent snow covered area map, first the elevation corresponding to the 10 percent area value was interpolated from values shown in table 2 for each subbasin and for the total basin. Next the particular elevation corresponding to the 10 percent area was traced on an overlay of the subbasin or total basin. The area lying in portions of the basin above the traced elevation line is the area that would be covered by snow under the simplistic viewpoint of snow covered area. This procedure was repeated for the other values of percent snow covered area, and a complete set of these simplistic snow covered area maps were provided to the Corps for each of the percentages described above for each subbasin and for the total basin. The elevations corresponding to the appropriate percentage area values is also shown on each of the maps and in table 3 of this report.

TABLE 2
BOISE BASIN
ELEVATION VS PERCENT AREA
ABOVE THAT ELEVATION
FROM CORPS OF ENGINEERS DATA

ELEVATION	S.F. AND. 980.00 SQ MI	M.F. TWIN 830.00 SQ MI	S.F. LOCAL 405.00 SQ MI	L.P. LOCAL 470.00 SQ MI	TOT BASIN 2685.00 SQ MI
10,500	0.00				0.00
10,250					0.00
10,200					0.00
10,000	0.34	0.00			0.12
9,750	0.72	0.25			0.34
9,500	1.12	0.50			1.00
9,250	1.90	1.00			1.31
9,000	3.70	2.50			2.12
8,750	5.80	5.00			3.66
8,500	9.20	7.50			5.68
8,250	12.60	12.50	0.00		8.46
8,000	16.20	17.00	1.00	0.00	11.32
7,750	20.20	20.00	2.00	0.90	14.01
7,500	25.80	23.00	3.00	1.70	17.28
7,250	30.60	26.00	4.00	2.60	20.26
7,000	36.60	30.00	5.00	3.40	23.98
6,750	43.00	35.00	6.00	4.70	28.24
6,500	49.70	42.00	7.50	6.40	33.37
6,250	56.70	50.00	9.00	9.40	39.15
6,000	62.40	62.00	12.00	12.90	46.01
5,750	71.30	69.50	15.00	17.70	52.87
5,500	78.20	75.50	20.00	23.60	59.03
5,250	85.40	81.00	25.00	30.90	65.39
5,000	92.50	86.00	32.00	39.50	72.09
4,750	96.30	90.50	40.00	48.40	77.63
4,500	98.20	94.00	50.00	60.10	82.96
4,250	99.30	97.00	65.00	67.20	87.80
4,220	99.80				17.47
4,196	100.00				36.50
4,000	100.00	99.00	83.00	84.80	94.47
3,750	100.00	99.50	92.00	91.40	97.13
3,500	100.00	99.80	97.00	95.80	98.75
3,250	100.00	100.00	99.00	97.90	99.48
3,216	100.00	100.00	100.00	99.40	99.89
3,120	100.00	100.00	100.00		82.50
3,055	100.00	100.00	100.00	100.00	100.00

TABLE 3
ELEVATIONS FOR 10, 15, 20, 25,
AND 35 PERCENT AREA

PERCENT AREA	TOTAL BASIN ELEVATION FT	SOUTH FORK BASIN ELEVATION FT	SOUTH FORK LOCAL BASIN ELEVATION FT	MIDDLE FORK BASIN ELEVATION FT	LUCKY PEAK LOCAL BASIN ELEVATION FT
10	8115	8440	6166	8375	6200
15	7675	8085	5750	8111	5890
20	7250	7750	5500	7750	5650
25	6940	7500	5250	7330	5452
35	6430	7066	4900	6750	5130

The next major effort in this project was to develop a set of what is termed "Typical" snow covered area maps. These maps were to represent what typical real snow packs would look like for 10, 15, 20, 25, and 35 percent snow covered areas. These maps were developed from the snow covered area maps that were constructed for phase 1 of this project (Heitz, 1984).

The first step in this portion of the project was to measure the snow covered areas on the phase 1 snow covered area maps. The percentage of area covered for the total basin and for each of the subbasins was then computed. Values of snow covered area for each of the phase 1 snow covered area maps are shown in Table 4. A more detailed listing of percent snow covered area, snow covered area in square miles and other variables affecting the snowmelt runoff process is shown in Tables 6 thru 10.

The next step was to identify which snow covered area maps contained percent snow covered area values similar to the 10 thru 35 percent values of interest for each of the subbasins and the total basin. A snow covered area map was then generated for each of the particular percent snow covered area values by interpolating and extrapolating from the phase 1 maps having similar snow covered area percent values. This was a very tedious and time consuming job which required the use of considerable judgement. The resulting maps should be a good representation of what an average snow line condition would be for the particular snow covered area values. These typical snow covered area maps should be a valuable tool to use during and after snow flights in order to determine what values of snow covered area were actually observed in the field.

TABLE 4
SNOW COVERED AREA DATA
BOISE BASIN
CHRONOLOGICAL LISTING

DATE	S.F. AND SCA %	S.F. LOC. SCA %	M.F. TWIN SCA %	L.P. LOC. SCA %	TOTAL BASIN SCA %
5-07-73	54.98	8.50	66.48	10.75	43.71
5-02-74	79.29	18.58	85.06	28.34	62.89
6-25-74	18.72	1.85	30.11	1.48	16.67
5-15-75	88.80	24.00	89.18	37.21	69.99
6-11-75	36.38	6.19	45.16	6.25	29.22
6-29-75	22.21	3.31	33.76	3.19	19.59
4-03-76	100.00	98.54	100.00	90.20	98.05
4-30-76	86.09	20.31	87.80	34.22	67.50
5-09-76	---	11.19	74.33	16.80	27.84
5-18-76	49.92	9.00	67.88	14.10	42.99
5-27-76	32.86	6.50	47.17	6.84	28.73
6-05-76	30.23	4.19	68.40	8.48	34.35
6-23-76	46.12	2.19	43.39	0.00	30.47
4-07-77	---	13.77	84.95	29.65	33.82
4-25-77	13.13	1.50	---	1.31	5.19
5-01-77	---	0.00	---	0.00	0.00
5-13-77	18.26	0.73	18.19	0.72	12.48
5-31-77	7.04	0.42	12.83	0.56	6.70
6-06-77	2.65	0.00	---	0.00	0.95
6-18-77	---	---	---	0.00	0.00
6-24-77	8.64	0.88	22.25	0.00	10.18
4-11-78	97.06	47.65	94.22	50.79	80.52
5-08-78	87.63	32.85	84.83	20.55	66.60
5-26-78	49.18	15.50	54.32	7.53	38.32
6-04-78	45.38	6.81	55.79	9.50	36.45
6-22-78	29.43	5.73	---	6.48	12.61
5-12-79	49.66	8.69	59.32	14.10	40.18
5-21-79	25.51	4.46	38.31	9.43	23.47
6-08-79	9.05	1.12	13.56	0.20	7.69
5-28-81	17.04	1.46	27.03	2.93	15.30
4-17-83	100.00	29.12	88.32	51.05	76.98
5-19-83	72.91	16.31	68.85	19.20	53.58

Dashed line indicates discontinuous snow lines unable to make calculations.

COMPARISON OF TYPICAL AND SIMPLISTIC SNOW COVERED AREA MAPS

The SSARR model, which is used by the Corps for runoff prediction, largely uses the simplistic viewpoint for area coverage of snow within the subbasins. For this reason, it is important to observe just how this simplistic view of runoff compares with what is actually happening in the basins. Visual comparisons of the simplified and typical snow covered area maps were made with some interesting results.

For the most part the typical and simplistic maps compared fairly well when considering the resolution of the original satellite photography and the processes required to bring all the maps to a common scale. So in general the basins seem to behave as expected as far as snow cover depletion following fairly equal lines of elevation in a particular basin.

There were some areas, though that departed rather markedly from the simplistic viewpoint of snow covered area. The first of these areas was the West facing slopes of Big and Little Smokey Creeks in the South Fork Drainage. These areas consistently showed more snow covered area (lower snow line elevations) on the simplistic maps than did the maps developed from the satellite photography. This would indicate that these areas tend to either have less snow accumulations than other equal elevation areas in the basin or tend to melt off quicker than other equal elevation areas in the South Fork. This discrepancy should be accounted for in any modeling that is done in the South Fork Drainage.

There are also large differences in snow covered areas between the simplistic and typical snow covered area maps in the upper North Fork and upper portions of the Queens River Basin. These basins consistently show larger snow covered areas (lower snow lines) on the typical maps than on the simplistic maps. This indicates that these areas either tend to accumulate much deeper snow packs during the snowfall season or that these areas tend to hold their melt back longer than what is typical for other areas at similar elevation in the basin. Either of these circumstances must be accounted for in any modeling effort in the Middle Fork Drainage.

There are also some differences, although not as great as those in the Queens and upper North Fork, in the upper Grimes Creek Basin around Placerville. The East facing slopes of this basin consistently show larger snow covered areas (lower snow lines) on the typical snow covered area maps than what is shown on the simplified maps. This also indicates either areas of higher accumulation or areas where snow melt is retarded somewhat compared to other areas of similar elevation.

The above three areas are the only areas where consistent variability between the typical and simplistic snow covered area representations were noted. Since the SSARR model basis much of its melt computation on more or less a simplistic view of snow depletion it may be beneficial to isolate those areas where the relationship between snow depletion and elevation seem to be somewhat different than those exhibited in the rest of a particular basin.

SLOPE DISTRIBUTIONS
WITHIN THE SUBBASINS

In order to better understand the snow depletion process, a series of studies were made to determine the distribution of slope aspect (the direction a slope is facing) and to determine average elevations of the snow line within the subbasins. These two problems were attacked using what is called a Geographic Information System (GIS) model. The model was used to simulate the topography of the basin in such a way that slope aspect and average snow line elevations could be determined. The rest of this chapter will be devoted to describing the development and use of the GIS model on the Boise Basin.

A Geographic Information System is a computer model used to store and manipulate spatially varied values. A good example of a spatially varied value is ground elevation in a drainage basin. This value varies with location within the basin. The GIS model stores values for the variable being modeled in locations called grid cells. Therefore, each cell in the model can be assigned a unique value of the stored variable. For example, each cell could have a unique value of elevation. A grid work is laid over the area to be studied, and the location of each grid cell represents an area in the real world system being modeled. In this case it would be an area of ground within the study basin.

The resolution of the model is determined by the number of grid cells that are used, to describe the area being modeled. If a large number of cells are used then higher resolution is obtained than if a smaller number of cells are used to describe the same area. In the case of the Boise Basin the GIS model titled PMAP (Tomlin,1980) was used, and the maximum size map array of 100 X 100 cells was used for each of the four subbasins. This resulted in a cell size of approximately .5 miles on a side or an area of approximately .25 square miles per cell. While this cell size certainly did not define every small change in topography in the basin, it did provide some ideas about trends in aspects of slopes and elevations of snow lines.

The first step in developing the topographic GIS model was to input the elevations in the basin into the model. This was done by tracing elevation contours using an electronic digitizing tablet connected to a personal computer. Actual 1-250,000 scale contour maps were used as the data base, and personal computer software was used to change the digitizer coordinates for points along each contour line to cell coordinates corresponding to a 100 X 100 rectangular grid laid over each basin. Too maintain maximum resolution the smallest size 100 X 100 grid that would encompass each of the subbasins was used. Therefore, the scale of each grid cell was not the same between basins.

Coordinate location values were gathered for points along each topographic line using automatic input mode on the digitizing tablet. This means that data was being gathered for each point whose location was more that 1/500 of an inch different from the previous point in the vertical or horizontal direction. Therefore, a very accurate description of each topographic line was obtained. The lowest contour elevation in each subbasin was input along with all other contours at even 1000 foot intervals.

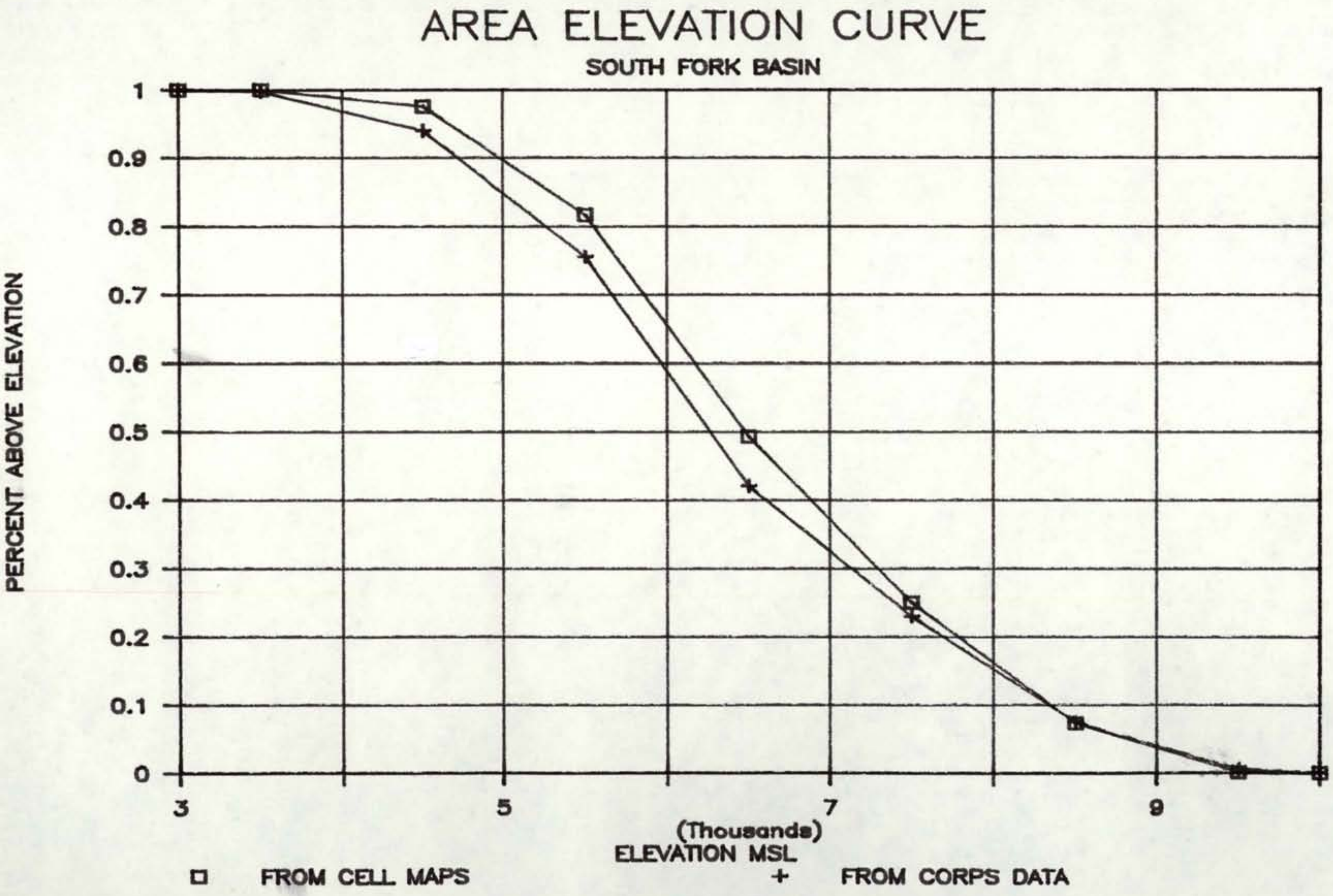
The next step in the process involved assigning each cell an elevation. If a contour line passed through any part of a grid cell, then that grid was assigned the value of that elevation contour. A separate grid map was developed for each elevation contour that was digitized. An averaging technique was used to assign the cell elevations to those cells on which more than one contour line passed. This was accomplished by a straight average of the multiple elevations that had been assigned to any individual cell. The averaging was accomplished by using the compute facility of the PMAP GIS.

Even after inputting all of the elevation contours into the cell data base, it turned out that some cells were not crossed by any contours. This meant that that cell had not been assigned an elevation. To fill in the data for those cells a weighted distance averaging method was used. This procedure is built into the PMAP GIS, and it allows for different scan diameters in the averaging process. In order to maintain a high order of precision, a scan distance of only one cell was used in the averaging process. This meant that the interpolated elevation was determined by looking at cells that were no more than one cell unit away from the cell whose value was being computed. In certain cases some cells were not within one cell diameter from know values. In these cases known elevation values were determined from the topographic maps and manually input into the grid cell. After each input of new topographic information, the entire data set was re-interpolated to insure that interpolations were done using all of the available known elevation data. This procedure was repeated for each of the subbasins.

A new set of area elevation data was developed for each subbasin using the GIS model elevation data. Figures 2 thru 5 show how these values compare with those provided by the Corps which were measured directly from the topographic maps. Comparatively speaking the two sets of curves are quite similar. There are some differences, but considering the accuracies of the measuring equipment for both the Corps and GIS data and the resolution of the GIS model, the comparisons are surprisingly good.

Next the elevation map was processed to determine the slope aspect of each cell in the 100 X 100 grid. This was done using the Orient command in the PMAP GIS. The Orient command outputs a new map with the aspect orientation in degrees from North for each cell. The degree aspects were concentrated into four categories; North, East, South, and West. North constituted all aspects from 315 to 45 degrees. East constituted all aspects from 45 thru 135 degrees. South constituted all aspects from 135 thru 225 degrees and West constituted all aspects from 225 thru 315 degrees. Table 5 shows the comparative areas in each of the four aspect directions for each of the subbasins. Figures 6 thru 13 show how the aspects are distributed within and between subbasins. The horizontal values listed on the table and graphs

FIGURE 2



AREA ELEVATION CURVE
SOUTH FORK BASIN
PERCENT ABOVE ELEVATION
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
5
7
9
(Thousands)
ELEVATION MSL
FROM CELL MAPS
FROM CORPS DATA

FIGURE 3

AREA ELEVATION CURVE

MIDDLE FORK BASIN

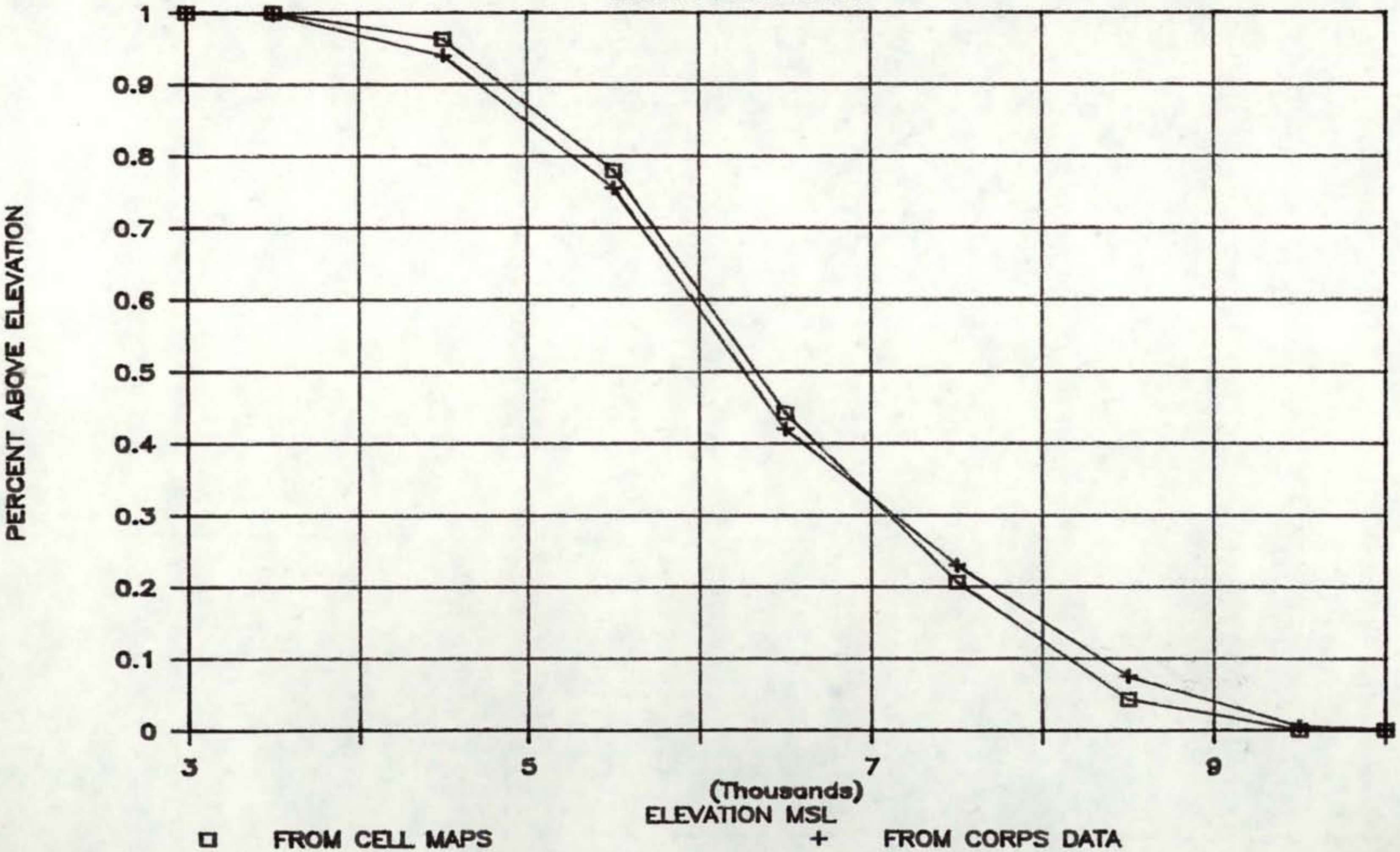


FIGURE 4

AREA ELEVATION CURVE

SOUTH FORK LOCAL BASIN

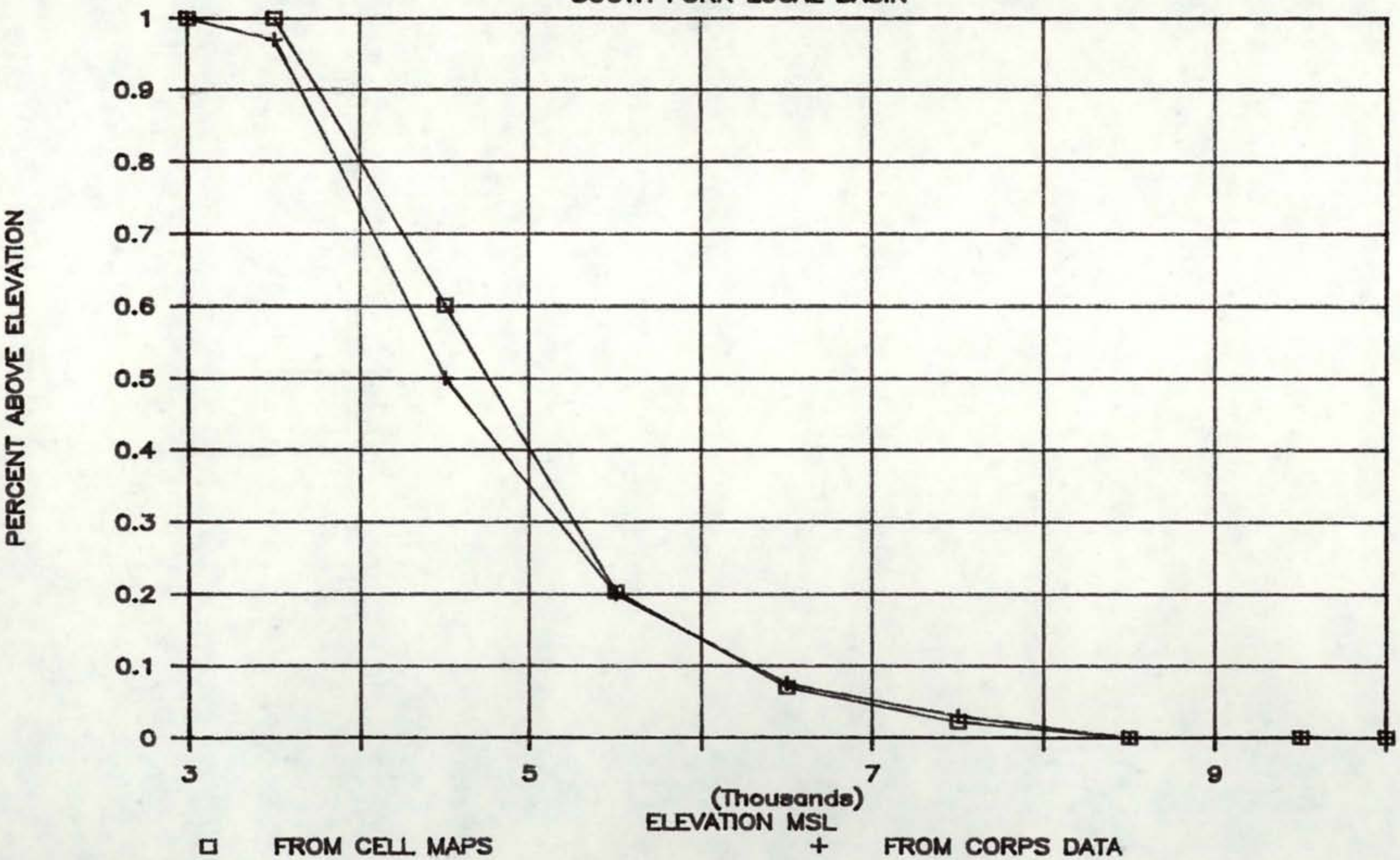


FIGURE 5

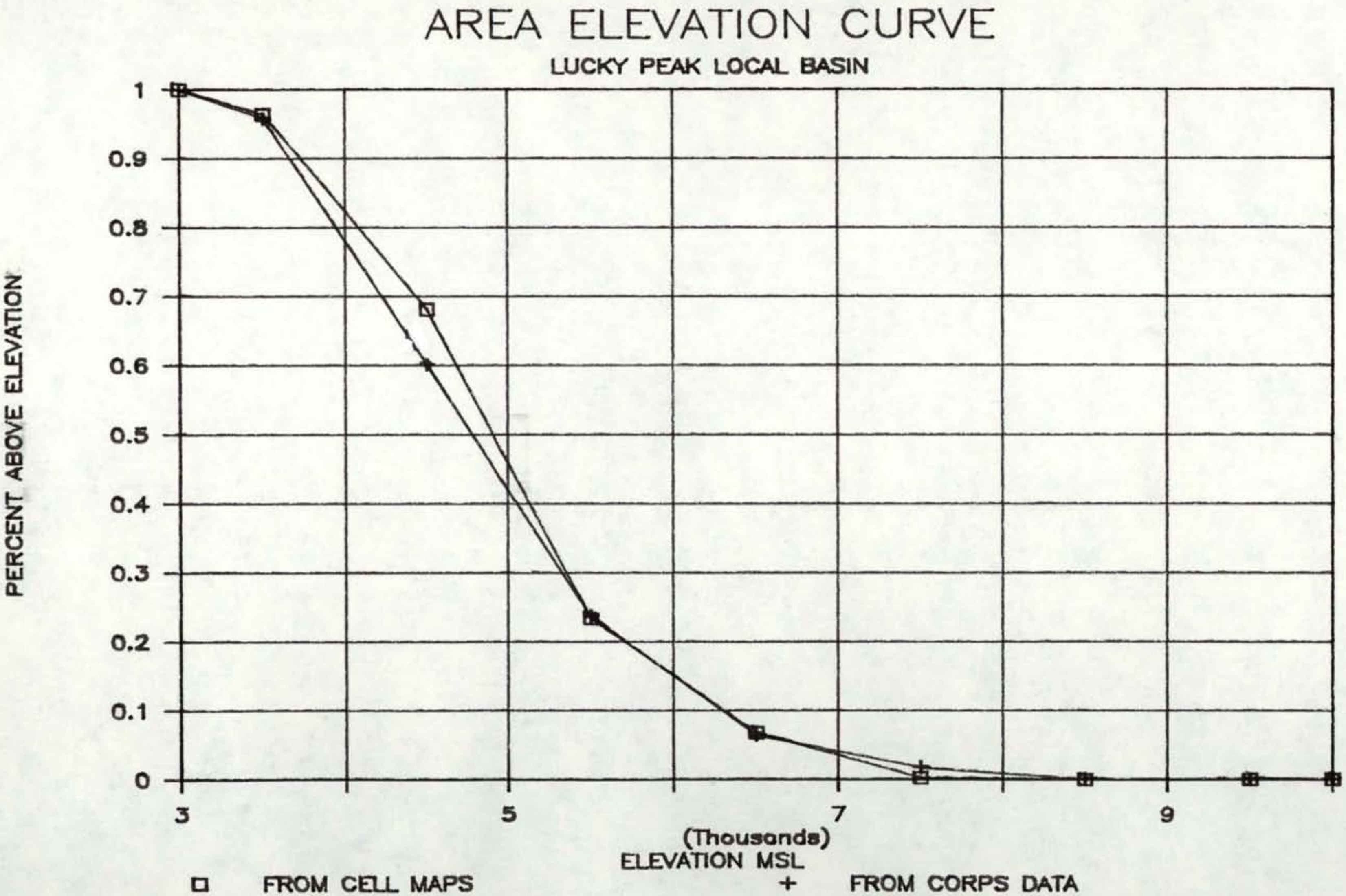

AREA ELEVATION CURVE
LUCKY PEAK LOCAL BASIN
PERCENT ABOVE ELEVATION
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
5
7
9
(Thousands)
ELEVATION MSL
FROM CELL MAPS
+ FROM CORPS DATA

TABLE 5
PERCENT AREAS IN
DIFFERENT ASPECT DIRECTIONS

ORIENTATION	SOUTH FORK PERCENT OF BASIN	MIDDLE FORK PERCENT OF BASIN	SOUTH FORK LOCAL PERCENT OF BASIN	LUCKY PEAK LOCAL PERCENT OF BASIN
NORTH	25.0%	24.4%	23.1%	13.8%
EAST	19.0%	18.0%	18.1%	16.8%
SOUTH	34.6%	25.0%	24.1%	21.7%
WEST	21.4%	23.5%	22.5%	19.9%
HORIZONTAL	8.8%	9.1%	12.1%	27.7%
TOTAL	100.0%	100.0%	100.0%	100.0%

FIGURE 6

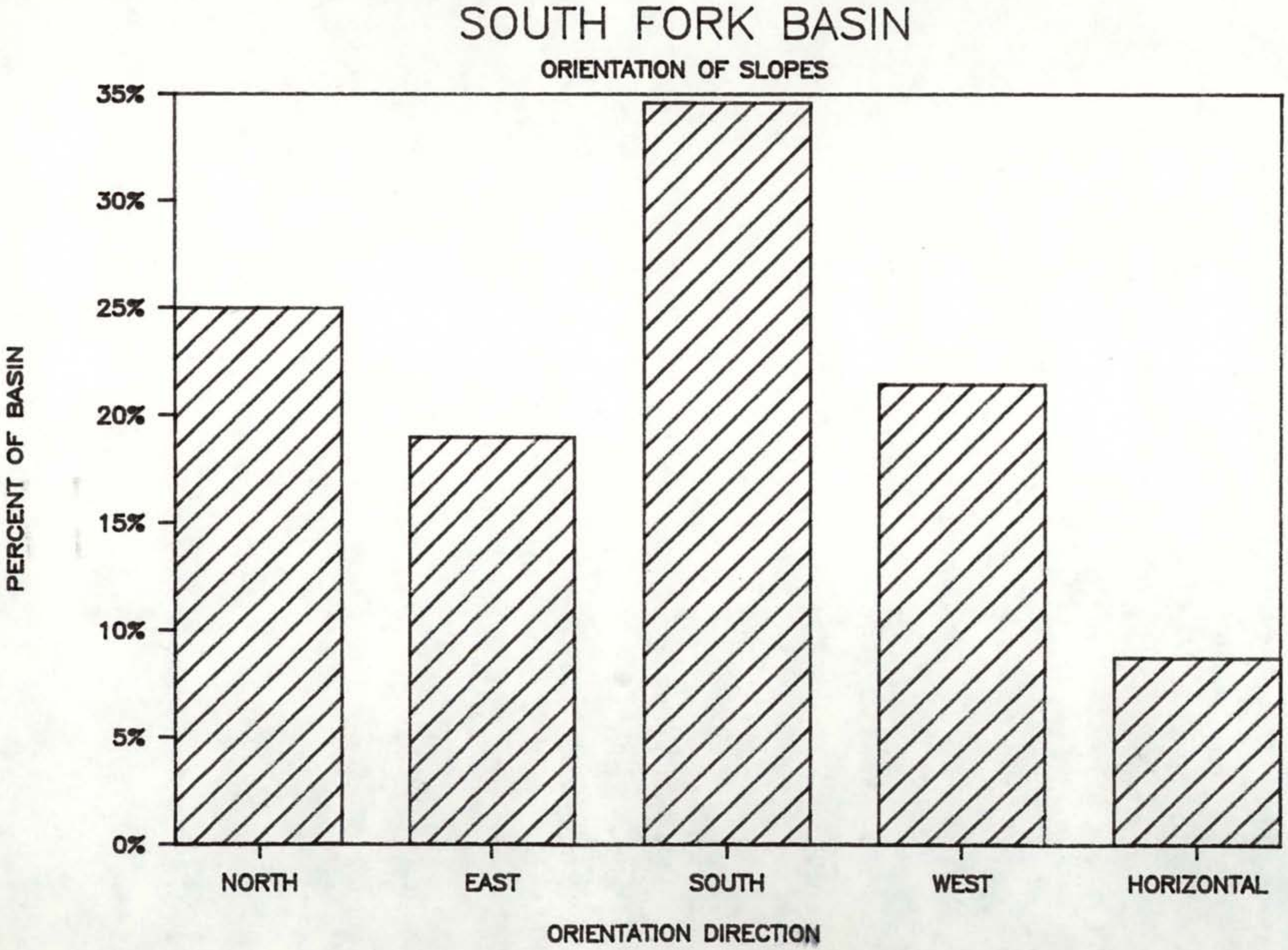

SOUTH FORK BASIN
ORIENTATION OF SLOPES
PERCENT OF BASIN
35%
30%
25%
20%
15%
10%
5%
0%
NORTH
EAST
SOUTH
WEST
HORIZONTAL
ORIENTATION DIRECTION

FIGURE 7

MIDDLE FORK BASIN

ORIENTATION OF SLOPES

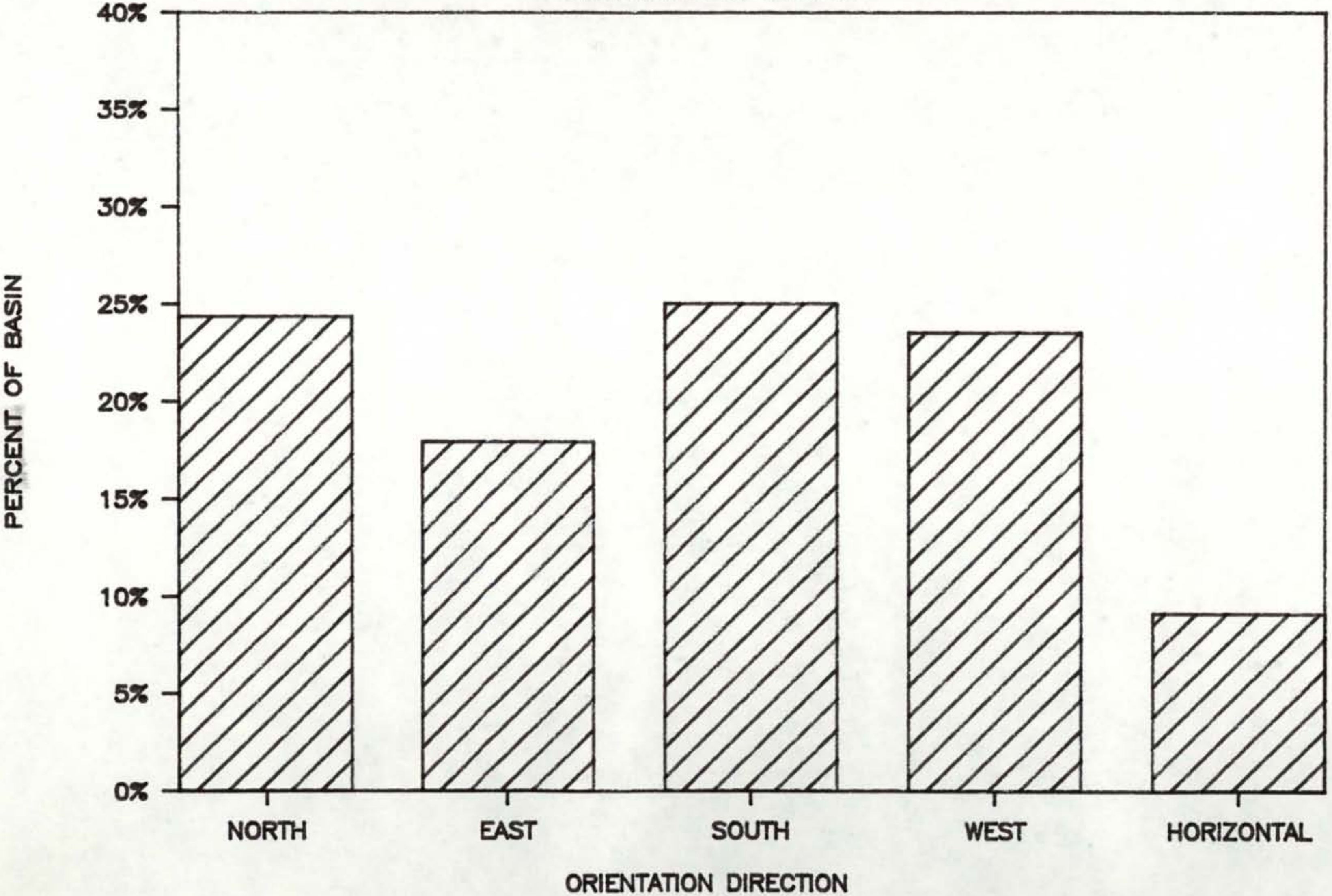


FIGURE 8

SOUTH FORK LOCAL BASIN

ORIENTATION OF SLOPES

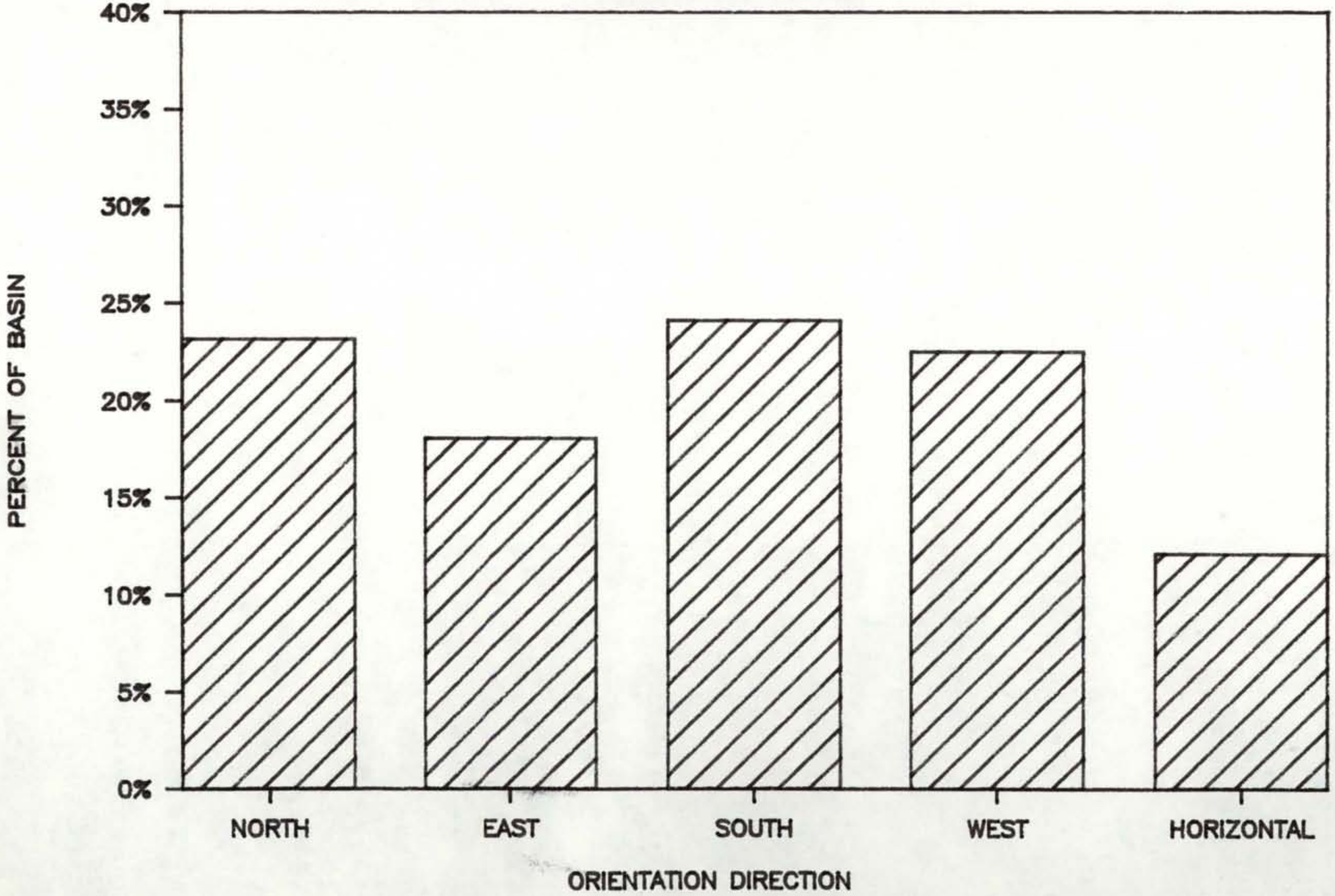


FIGURE 9

LUCKY PEAK LOCAL BASIN

ORIENTATION OF SLOPES

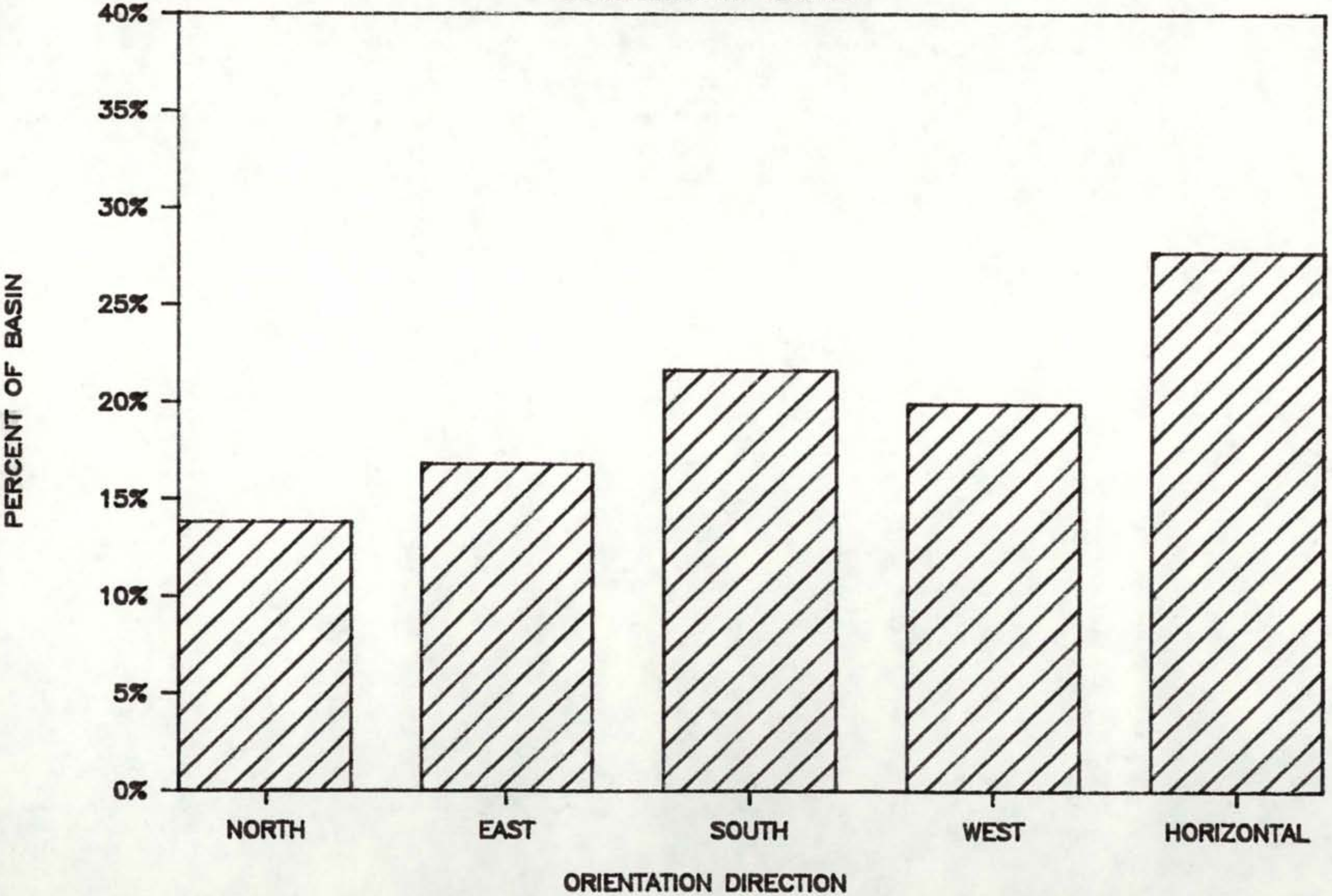
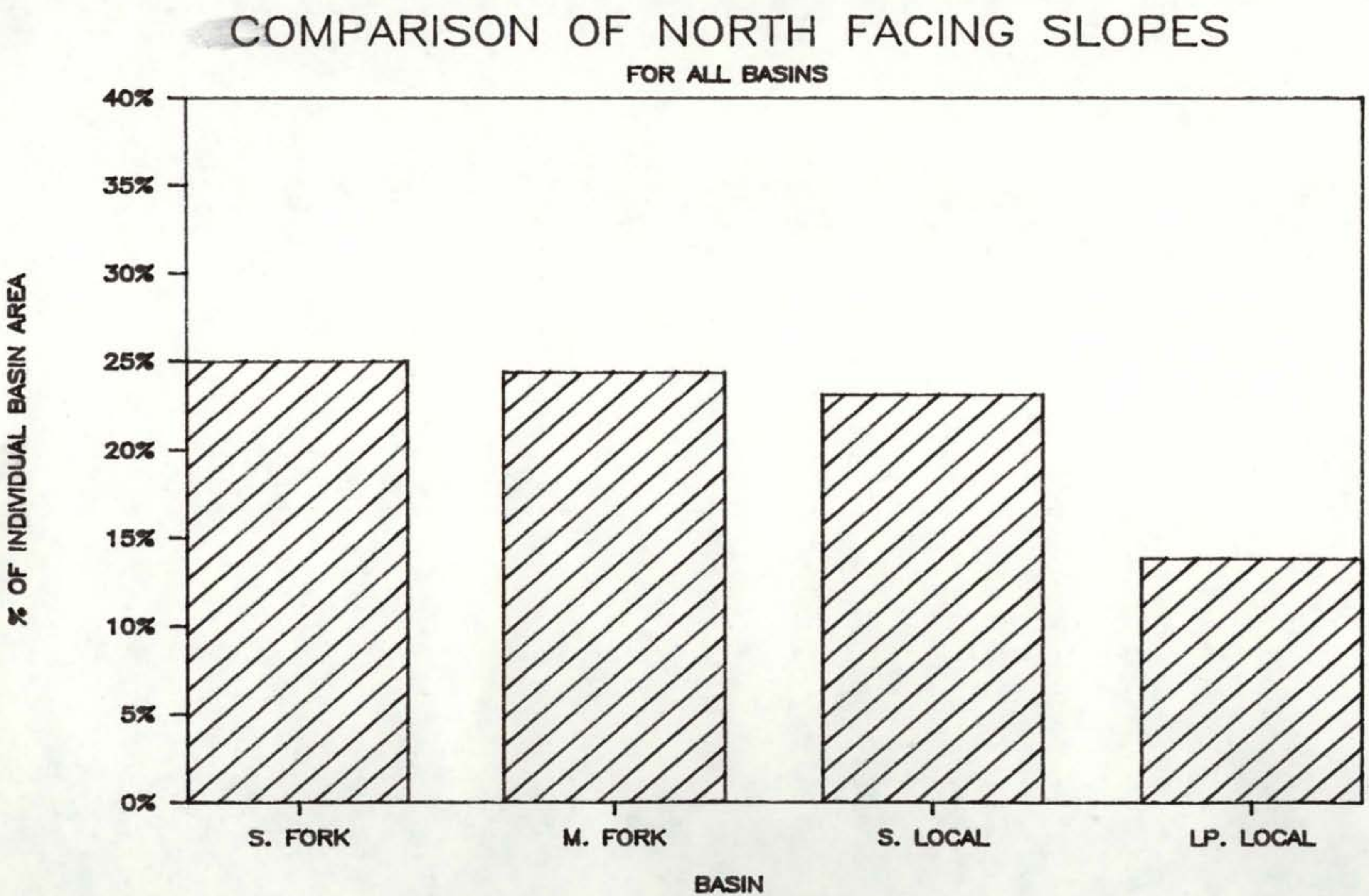


FIGURE 10



COMPARISON OF NORTH FACING SLOPES
FOR ALL BASINS
40%
35%
30%
25%
20%
15%
10%
5%
0%
% OF INDIVIDUAL BASIN AREA
S. FORK
M. FORK
S. LOCAL
LP. LOCAL
BASIN

FIGURE 11

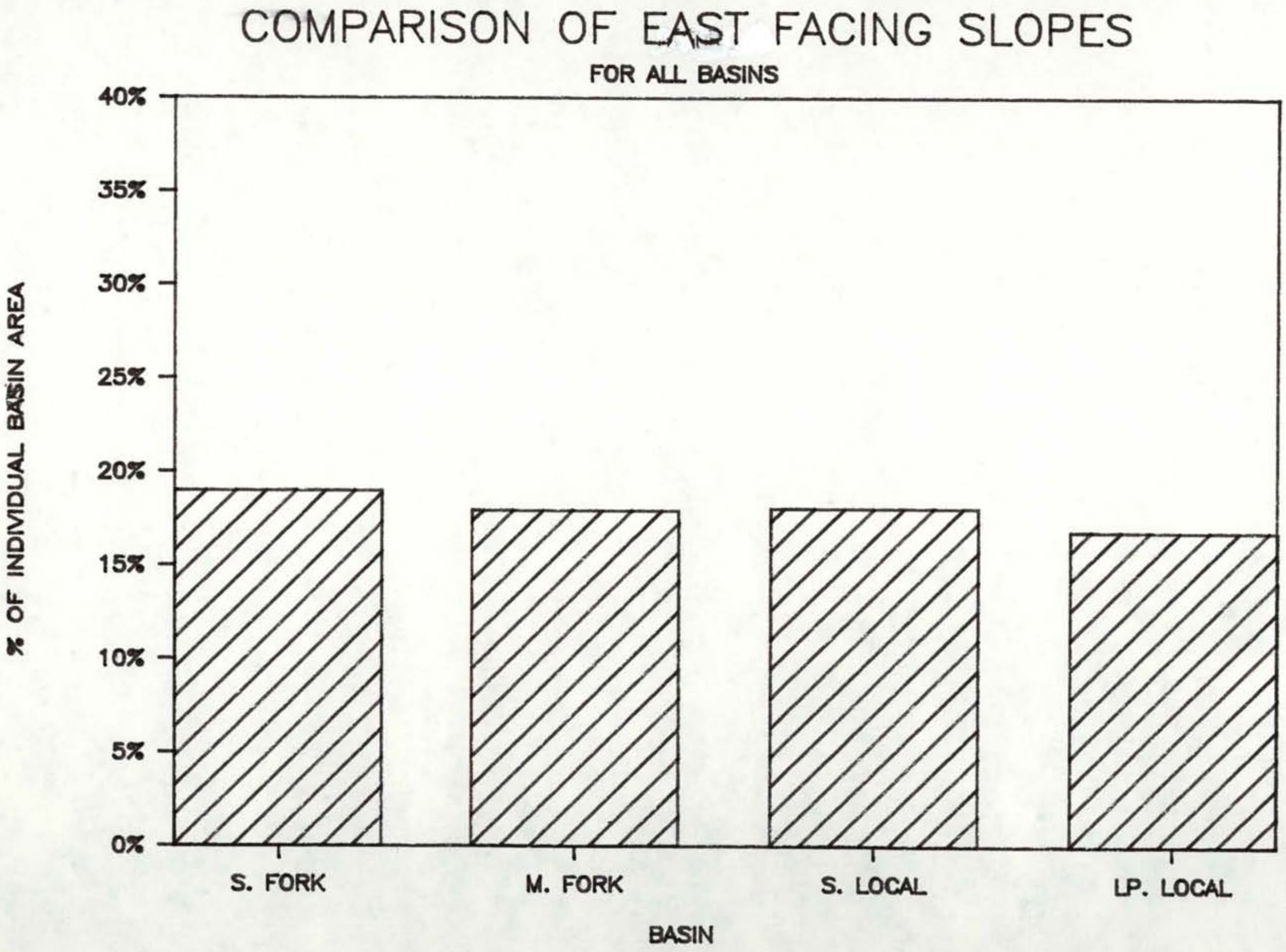

COMPARISON OF EAST FACING SLOPES
FOR ALL BASINS
40%
35%
30%
25%
20%
15%
10%
5%
0%
% OF INDIVIDUAL BASIN AREA
S. FORK
M. FORK
S. LOCAL
LP. LOCAL
BASIN

FIGURE 12

COMPARISON OF WEST FACING SLOPES

FOR ALL BASINS

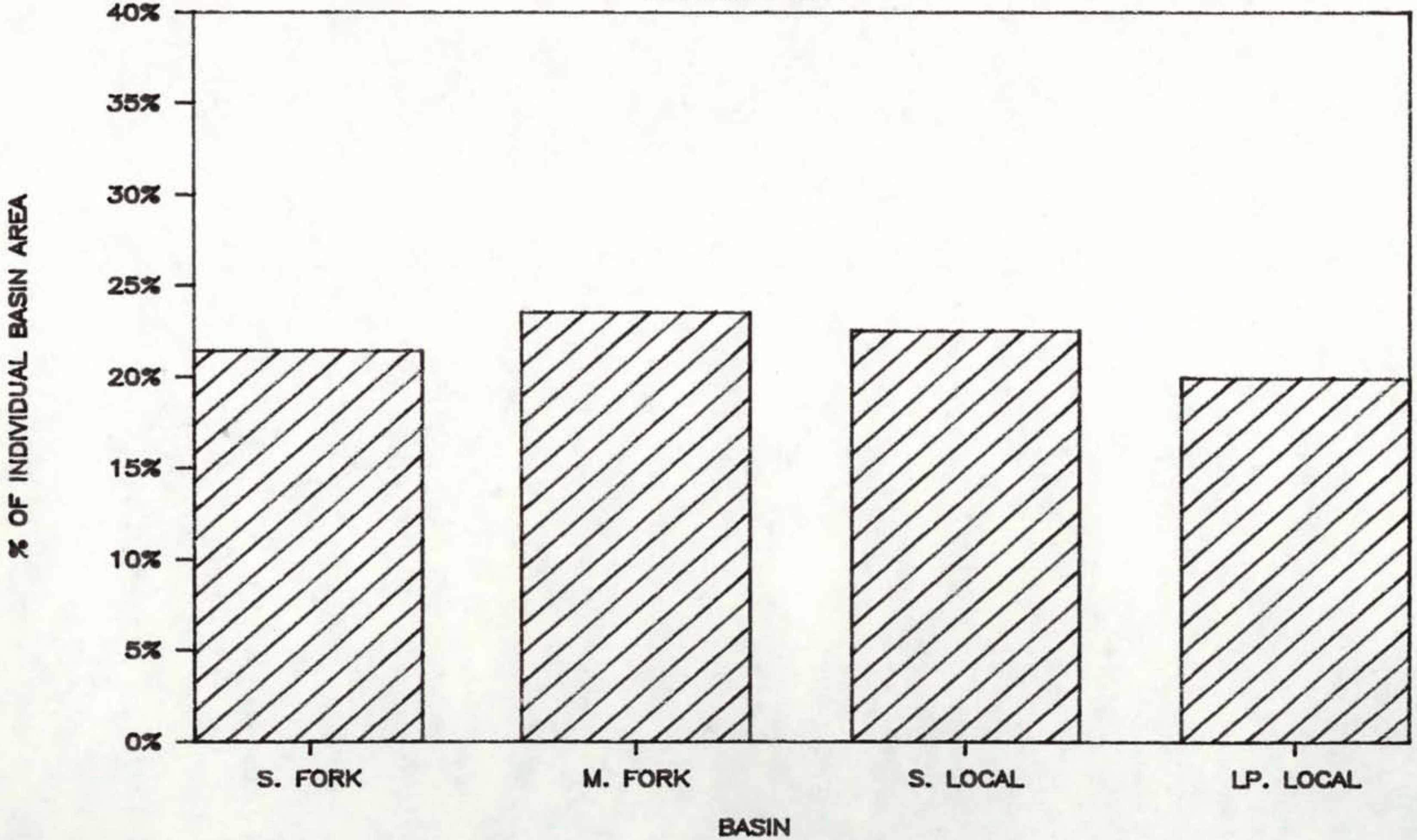
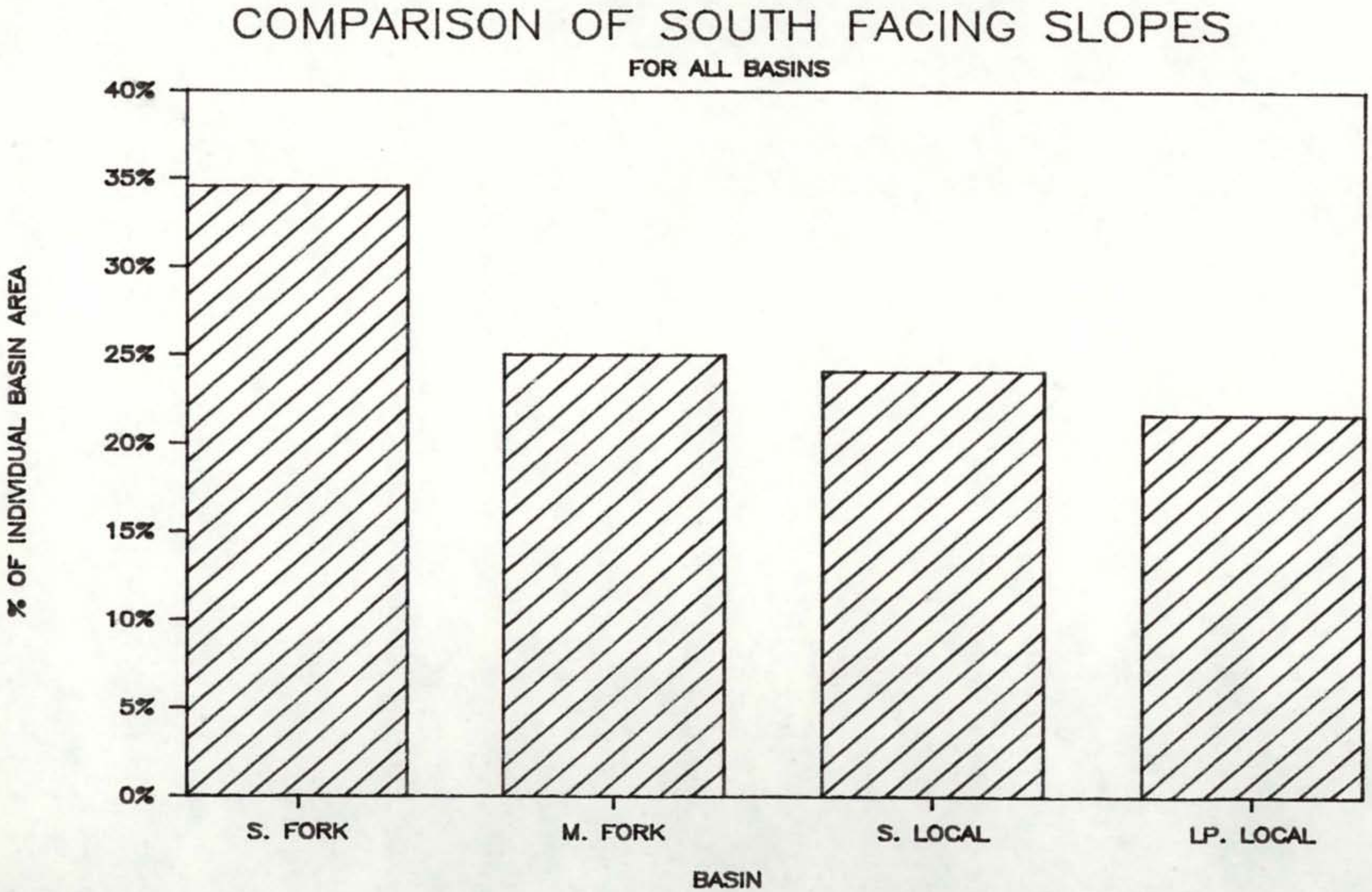


FIGURE 13


COMPARISON OF SOUTH FACING SLOPES
FOR ALL BASINS
40%
35%
30%
25%
20%
15%
10%
5%
0%
% OF INDIVIDUAL BASIN AREA
S. FORK
M. FORK
S. LOCAL
LP. LOCAL
BASIN

does not mean that some cells were precisely horizontal, but that the elevation changes between cells were so small that due to the resolution of the cells and the distance between the 1000 foot contours no appreciable change in elevation was found.

In looking at Figures 6 thru 9, it is apparent that each basin has its own characteristic distribution of slope aspects. The South Fork Basin has a very high percentage of South exposures. There is nearly 10 percent more basin area facing South than in the next highest area of exposure which is North slopes. These South facing slopes are probably more susceptible to high early season runoff.

The Middle Fork Basin seems to have a pretty even distribution of slope exposures with the East slopes being slightly smaller than those areas with other slope exposure directions. The South Fork Local Basin has a distribution of slopes quite similar to those in the Middle Fork. Again the different slope aspects are fairly well distributed with East facing slopes occupying a slightly smaller area than the other directions.

The Lucky Peak Local Basin is quite different from the other Basins as for as slope aspect is concerned. Large areas of the Basin in the Placerville Centerville area are much less steep than in other parts of the Boise Basin. In these areas a very large percentage of horizontal aspect was predicted meaning that there was no dominating slope direction in those areas. Also this subbasin has a much smaller proportion of North facing slopes than the other subbasins. This indicates that this basin is probably one that would have high early-season runoff. This is indicated both from the slope aspect distributions and from the relatively low elevation of this subbasin.

In analyzing Figures 10 thru 13 it is apparent that there are differences in percentage of areas with the same slope aspects between the subbasins. North facing slopes are fairly evenly distributed between subbasins at about 25 percent, with the exception of Lucky Peak Local, which has only about 15 percent of it's area on North slopes. East and West facing slopes are fairly evenly distributed between the subbasins. South facing slopes are fairly evenly distributed except for the South Fork which has 35 percent South slope areas as compared to 25 percent area for the other basins.

The aspect distribution analyses indicate that portions of certain of the basins have much higher or much lower percent of area in certain slope aspect directions than others. This may cause problems in the runoff modeling process if these nontypical values are not accounted for in the modeling. Lucky Peak Local Basin and South Fork Basin both should be watched closely in regard to these slope aspect peculiarities.

AVERAGE SNOW LINE ELEVATIONS

The average elevation of the snow line and its relationship with snow covered area can be important factors in trying to predict runoff. Since the SSARR model uses a fairly simplistic area elevation approach to the snow depletion process, it is important to know if this simplistic constant snow line approach is adequately representing what is really happening in the basin. Some shortcomings in this simplistic representation have already been described in chapter three in discussions of the simplistic and typical snow covered area maps.

To obtain a better understanding of the correspondence between snow covered area and average snow line elevation, studies were made to compare actual snow line elevations with those predicted using basin area elevation curves. The average elevation of the snow line was obtained using the gridded elevation maps in the GIS model discussed in the previous chapter. A grid representation of each snow map was developed by identifying all cells which contained segments of the snow line. Next the elevation maps and the snow line maps were cross tabulated in order to get a list of elevations for each segment of the snow line. The list of elevations were averaged to obtain the average elevation of the snow line. Therefore, the average snow line values computed were the actual on the ground average of the snow line around the perimeter of the snow covered area.

The next step in the process was to compare the average snow line elevations obtained from the gridded elevation maps with the average snow line elevation that would be expected from a simplistic area elevation viewpoint. This simplistic view point would represent the snow line as a constant elevation corresponding to the value of elevation that would be obtained from the area elevation curve for the basin. The value of elevation assigned would be that value of elevation corresponding to the area which had been directly measured from the snow covered area maps. Since the snow line on the snow covered area maps were not at constant elevation, there was a difference between the two snow line elevation values. In comparing the two snow line values, we are comparing actual snow depletion conditions with conditions that are quite similar to those assumed in the SSARR model.

Table 6 thru 10 contain tabulations of the comparisons of the snow line elevations. Those areas that are left blank are due to insufficient data available to do the appropriate averaging. Figures 14 thru 18 are plots comparing the two snow line elevations. Perfect correspondence between the two snow line elevations would cause all points to fall on the straight line plotted on each set of curves.

The usefulness of Figures 14 thru 18 comes when examining the points on the curve that depart from the plotted line. These are points where the simplistic snow line elevation (from the area elevation curve) do not agree with the value averaged from the snow covered area maps. In examining the higher elevation segments of the plots, it can be seen that for most of the basins the points lie above the plotted line. This means that the actual snow line elevation is somewhat lower than that which would be obtained from the area elevation curve for the same area as covered by the snow.

This discrepancy in snow line elevation means that the actual average snow line is some what less than that using the simplistic area elevation approach. This could lead to a number of problems in the runoff predicting process. One problem could occur if snow line elevations are used to predict snow covered area. For example, assume a snow flight revealed an elevation of say 8500 feet as the estimated actual snow line elevation in the South Fork Basin. If we go to the area elevation curve, we would determine a snow covered area of approximately 8 percent. But if we examine the curve comparing the two different types of snow line elevations, we would see that the actual elevation to use with the area elevation curve would be approximately 8800 feet which would result in a smaller actual coverage in snow covered area. This trend seems to hold for all of the sub basins. Some with more or

TABLE 6
ENTIRE BOISE BASIN
2685 SQ MILES
SNOW DELPLETION DATA

DATE	SNOW COVERED AREA MI^2	AVERAGE SNOW LINE ELEVATION FT MSL	ELEVATION FROM AREA-ELV CURVE FT MSL	PERCENT SNOW COVERED AREA %
5-07-73	1159.11	6352	6100	43.17
5-02-74	1688.60	5616	5300	62.89
6-24-74	447.59	7422	7500	16.67
5-15-75	1879.23	5150	5100	69.99
6-11-75	784.56	6709	6700	29.22
6-29-75	525.99	7298	7300	19.59
4-03-76	2632.64	3600	3600	98.05
4-30-76	1812.38	5463	5200	67.50
5-09-76	747.50		6800	27.84
5-18-76	1154.28	6266	6100	42.99
5-27-76	771.40	6765	6700	28.73
6-05-76	922.30		6500	34.35
6-23-76	818.12	6826	6600	30.47
4-07-77	908.07		6700	33.82
4-25-77	139.35		8600	5.19
5-01-77		10000	10000	0.00
5-13-77	335.09	7686	7900	12.48
5-31-77	179.90	8107	8400	6.70
6-06-77	25.51	9500	9500	0.95
6-18-77		10000	10000	0.00
6-24-77	273.33	7717	8100	10.18
4-11-78	2161.96	4815	4600	80.52
5-08-78	1788.21	5388	5200	66.60
5-26-78	1028.89	6340	6300	38.32
6-04-78	978.68	6381	6400	36.45
6-22-78	338.58		7900	12.61
5-12-79	1078.83	6317	6200	40.18
5-21-79	630.17	7090	7000	23.47
6-08-79	206.48	7971	8300	7.69
5-28-81	410.81	7551	7700	15.30
4-17-83	2066.91		4800	76.98
5-19-83	1438.62	5840	5700	53.58

TABLE 7
SOUTH FORK BASIN
980 SQ MILES
SNOW DEPLETION DATA

DATE	SNOW COVERD AREA MI^2	AVERAGE SNOW LINE ELEVATION FT MSL	AVERAGE SOUTH SLOPE SNOW LINE ELEVATION FT MSL	AVERAGE NORTH SLOPE SNOW LINE ELEVATION FT MSL	ELEVATION FROM AREA-ELV CURVE FT MSL	PERCENT SNOW COVERED AREA %
5-07-73	538.80	6454	6441	6454	6300	54.98
5-02-74	777.04	5865	5909	5573	5500	79.29
6-24-74	183.46	7746	7782	7672	7800	18.72
5-15-75	870.24	5302	5271	5366	5100	88.80
6-11-75	356.52	6934	6915	6962	7000	36.38
6-29-75	217.66	7600	7494	7569	7700	22.21
4-03-76	980.00	4200	4200	4200	4200	100.00
4-30-76	843.68	5644	5529	5415	5200	86.09
5-09-76						
5-18-76	489.22	6484	6591	6458	6500	49.92
5-27-76	322.03	7064			7200	32.86
6-05-76	296.25	7220			7300	30.23
6-23-76	451.98	6864	6919	6860	6600	46.12
4-07-77						
4-25-77	128.67	8086	7999	8120	8200	13.13
5-01-77						
5-13-77	178.95	7770	7618	7843	7900	18.26
5-31-77	68.99	8406	8267	8498	8700	7.04
6-06-77	25.97	8536	8350	8663	9000	2.65
6-18-77						
6-24-77	84.67	8110	8035	8018	8500	8.64
4-11-78	951.19				4700	97.06
5-08-78	858.77	5469	5557	5322	5200	87.63
5-26-78	481.96	6624			6500	49.18
6-04-78	444.72	6727	6872	6548	6700	45.38
6-22-78	288.41	7241	7488	7213	7300	29.43
5-12-79	486.67	6585	6594	6613	6500	49.66
5-21-79	250.00	7387	7318	7343	7500	25.51
6-08-79	88.69	8213	8237	8211	8500	9.05
5-28-81	166.99	7865	7727	7929	7900	17.04
4-17-83	980.00	4200	4200	4200	4200	100.00
5-19-83	714.52	5929	5919	5806	5700	72.91

TABLE 8
MIDDLE FORK TWIN SPRINGS
830 SQ MILES
SNOW DEPLETION DATA

DATE	SNOW COVERD AREA MI^2	AVERAGE SNOW LINE ELEVATION FT MSL	ELEVATION FROM AREA-ELV CURVE FT MSL	PERCENT SNOW COVERED AREA %
5-07-73	219.38	6244	5900	66.48
5-02-74	280.70	5370	5000	85.06
6-24-74	99.36	7045	7000	30.11
5-15-75	294.29	5054	4800	89.18
6-11-75	149.03	6409	6400	45.16
6-29-75	111.41	6859	6800	33.76
4-03-76	830.00		3300	100.00
4-30-76	289.74	5389	4900	87.80
5-09-76	245.29	5679	5500	74.33
5-18-76	224.00	5955	5800	67.88
5-27-76	155.66	6385	6300	47.17
6-05-76	225.72		5800	68.40
6-23-76	143.52	6705	6500	43.49
4-07-77	280.34	5378	5100	84.95
4-25-77				
5-01-77				
5-13-77	60.03	7590	7900	18.19
5-31-77	42.34	7812	8300	12.83
6-06-77				
6-18-77				
6-24-77	73.43	7215	7600	22.25
4-11-78	310.93	4854	4500	94.22
5-08-78	279.94	5295	5100	84.83
5-26-78	179.26	6045	6200	54.32
6-04-78	184.11	6042	6100	55.79
6-22-78				
5-12-79	195.76	6031	6000	59.32
5-21-79	126.42	6833	6600	38.31
6-08-79	44.75	7580	8200	13.56
5-28-81	89.20	7235	7200	27.03
4-17-83	291.46	5151	4900	88.32
5-19-83	227.20	5823	5800	68.85

TABLE 9
SOUTH FORK LOCAL BASIN
405 SQ MILES
SNOW DEPLETION DATA

DATE	SNOW COVERD AREA MI^2	AVERAGE SNOW LINE ELEVATION FT MSL	ELEVATION FROM AREA-ELV CURVE FT MSL	PERCENT SNOW COVERED AREA %
5-07-73	34.43	6067	6300	8.50
5-02-74	75.25	5519	5600	18.58
6-24-74	7.49	7457	7800	1.85
5-15-75	97.20	5163	5300	24.00
6-11-75	25.07	6479	6700	6.19
6-29-75	13.41	7054	7500	3.31
4-03-76	399.09	3390	3300	98.54
4-30-76	82.26	5404	5500	20.31
5-09-76	45.32	6125	6100	11.19
5-18-76	36.45	6120	6300	9.00
5-27-76	26.33	6414	6700	6.50
6-05-76	16.97	6857	7200	4.19
6-23-76	8.87	7222	7700	2.19
4-07-77	55.77	5866	5900	13.77
4-25-77	6.08	7600	7900	1.50
5-01-77	0.00		8300	0.00
5-13-77	2.96	8000	8100	0.73
5-31-77	1.70	8000	8200	0.42
6-06-77	0.00		8300	0.00
6-18-77				
6-24-77	3.56	7690	8000	0.88
4-11-78	192.98	4731	4600	47.65
5-08-78	133.04	4907	5000	32.85
5-26-78	62.78	5609	5700	15.50
6-04-78	27.58	6205	6600	6.81
6-22-78	23.21	6634	6800	5.73
5-12-79	35.19	6172	6300	8.69
5-21-79	18.06	6947	7100	4.46
6-08-79	4.54	8000	8000	1.12
5-28-81	5.91	7633	7900	1.46
4-17-83	117.94	5057	5100	29.12
5-19-83	66.06	5658	5700	16.31

TABLE 10
LUCKY PEAK LOCAL BASIN
470 SQ MILES
SNOW DEPLETION DATA

DATE	SNOW COVERD AREA MI^2	AVERAGE SNOW LINE ELEVATION FT MSL	ELEVATION FROM AREA-ELV CURVE FT MSL	PERCENT SNOW COVERED AREA %
5-07-73	50.53	6065	6200	10.75
5-02-74	133.20	5284	5300	28.34
6-24-74	6.96	6941	7600	1.48
5-15-75	174.89	5004	5100	37.21
6-11-75	29.38	6513	6500	6.25
6-29-75	14.99	7000	7400	3.19
4-03-76	423.94	3909	380	90.20
4-30-76	160.83	5138	5200	34.22
5-09-76	78.96	5873	5800	16.80
5-18-76	66.27	6000	5900	14.10
5-27-76	32.15	6530	6500	6.84
6-05-76	39.86		6300	8.48
6-23-76	0.00		8000	0.00
4-07-77	139.36	5340	5300	29.65
4-25-77	6.16	7629	7600	1.31
5-01-77	0.00		8000	0.00
5-13-77	3.38	7000	7800	0.72
5-31-77	2.63	7125	7800	0.56
6-06-77	0.00		8000	0.00
6-18-77	0.00		8000	0.00
6-24-77	0.00		8000	0.00
4-11-78	238.71	4947	4700	50.79
5-08-78	96.59	5688	5600	20.55
5-26-78	35.39	6250	6400	7.53
6-04-78	44.65	6255	6200	9.50
6-22-78	30.46	6558	6400	6.48
5-12-79	66.27	6007	5900	14.10
5-21-79	44.32	6127	6200	9.43
6-08-79	0.94	6800	7900	0.20
5-28-81	13.77	6800	7200	2.93
4-17-83	239.93	5075	4700	51.05
5-19-83	90.24	5625	5700	19.20

FIGURE 14

COMPARISON OF SNOWLINE ELEVATIONS

TOTAL BOISE BASIN

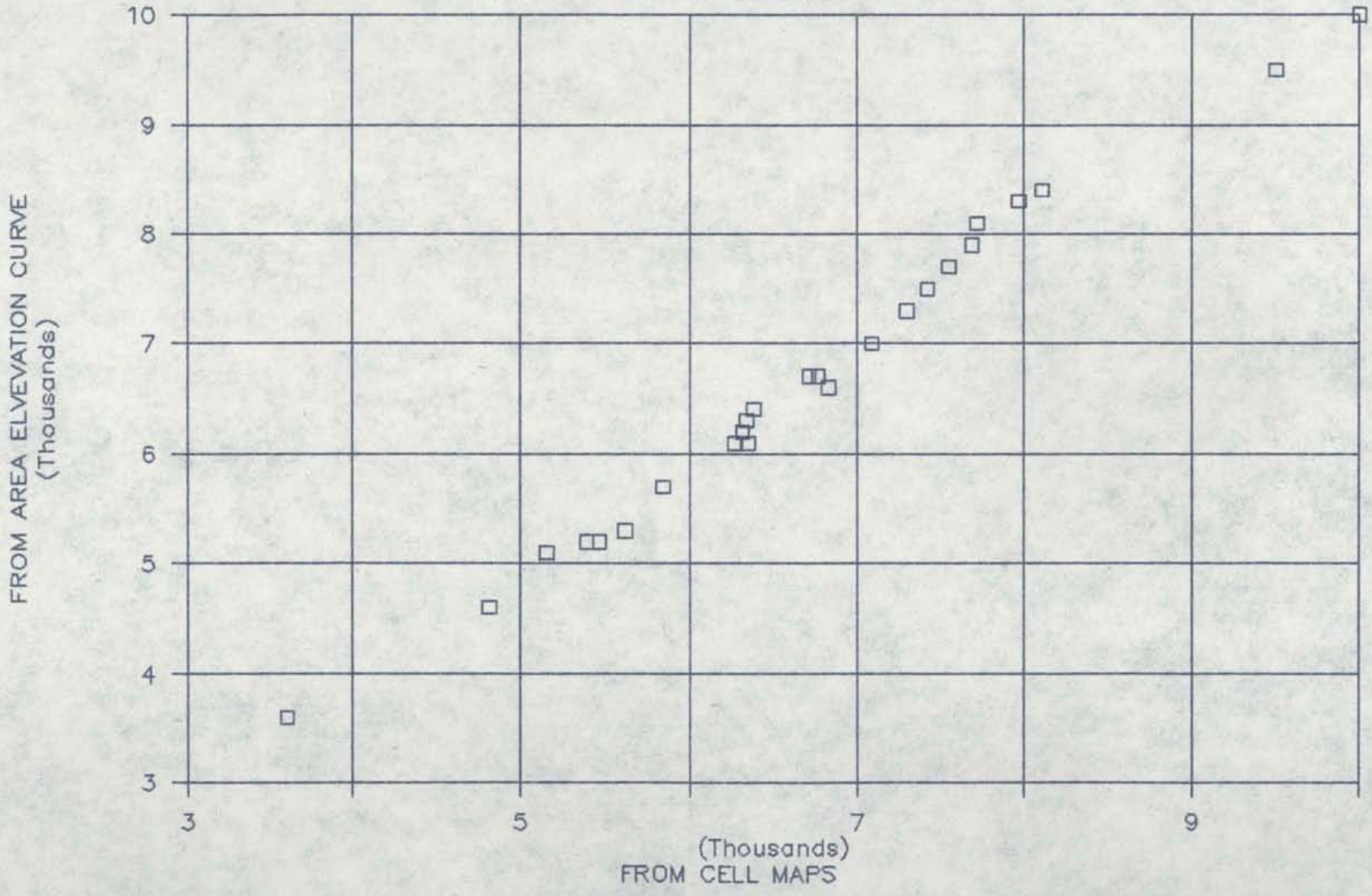


FIGURE 15

COMPARISON OF SNOWLINE ELEVATIONS

SOUTH FORK BASIN

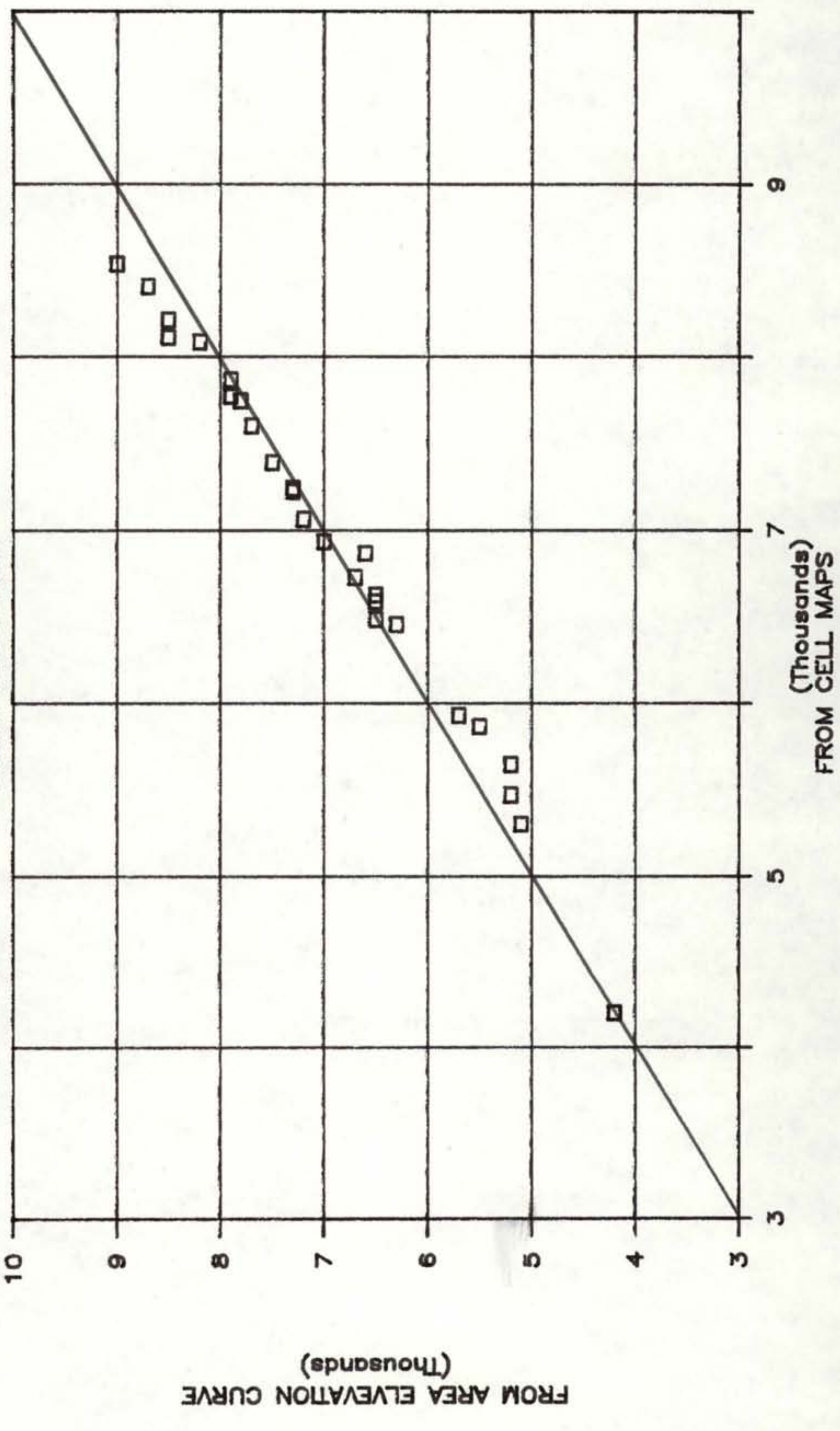


FIGURE 16

COMPARISON OF SNOWLINE ELEVATIONS

MIDDLE FORK BASIN

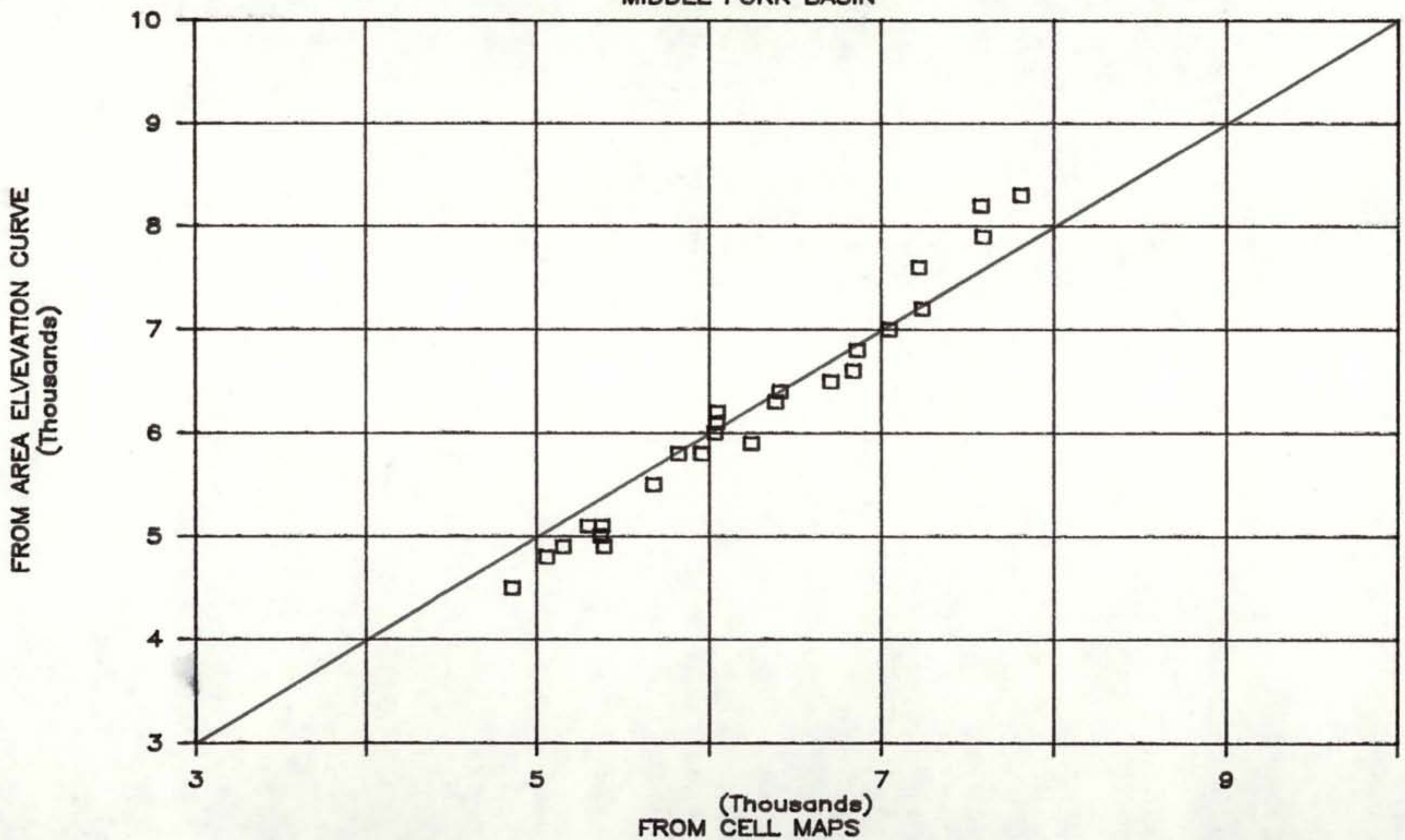
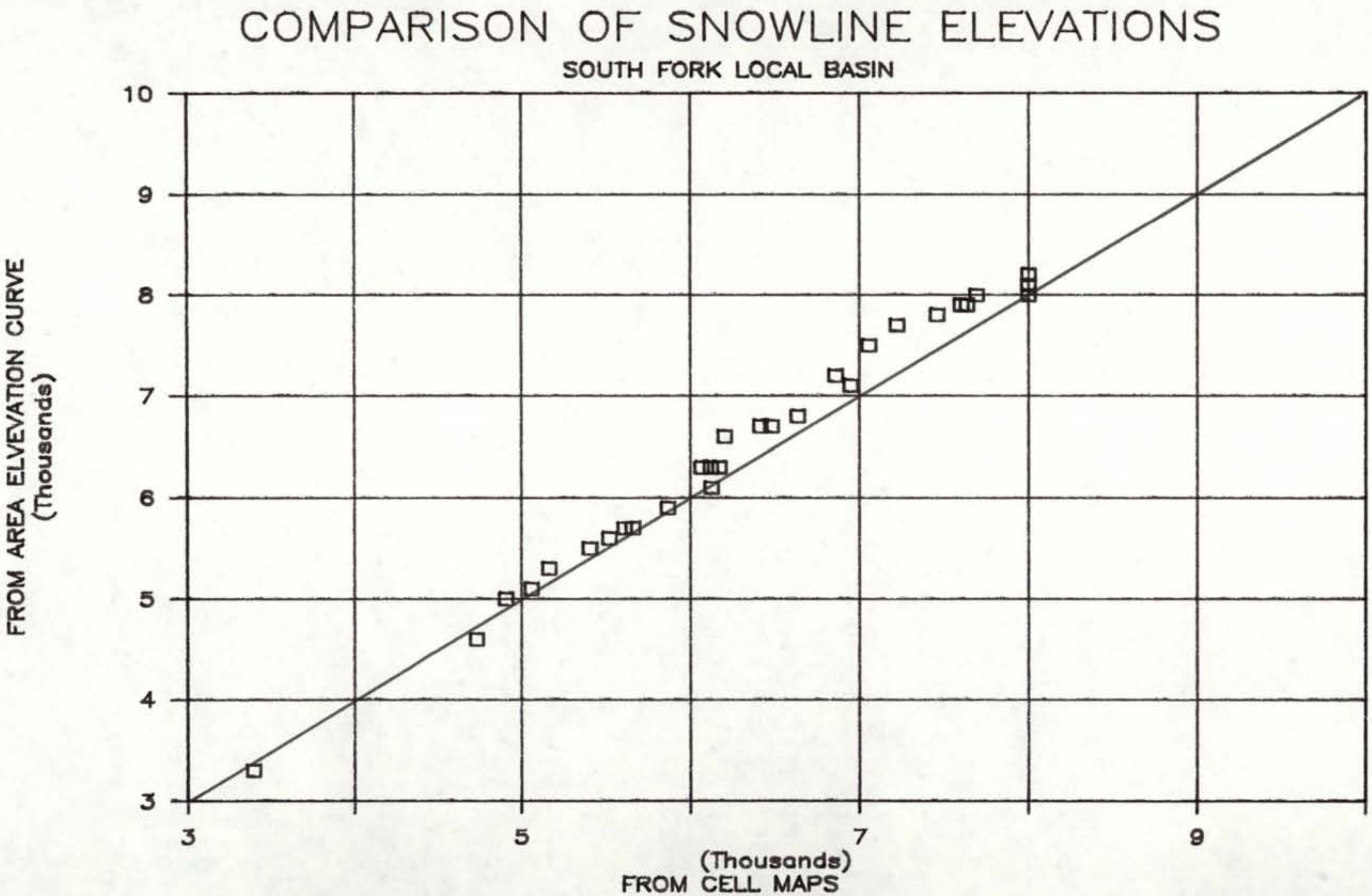


FIGURE 17

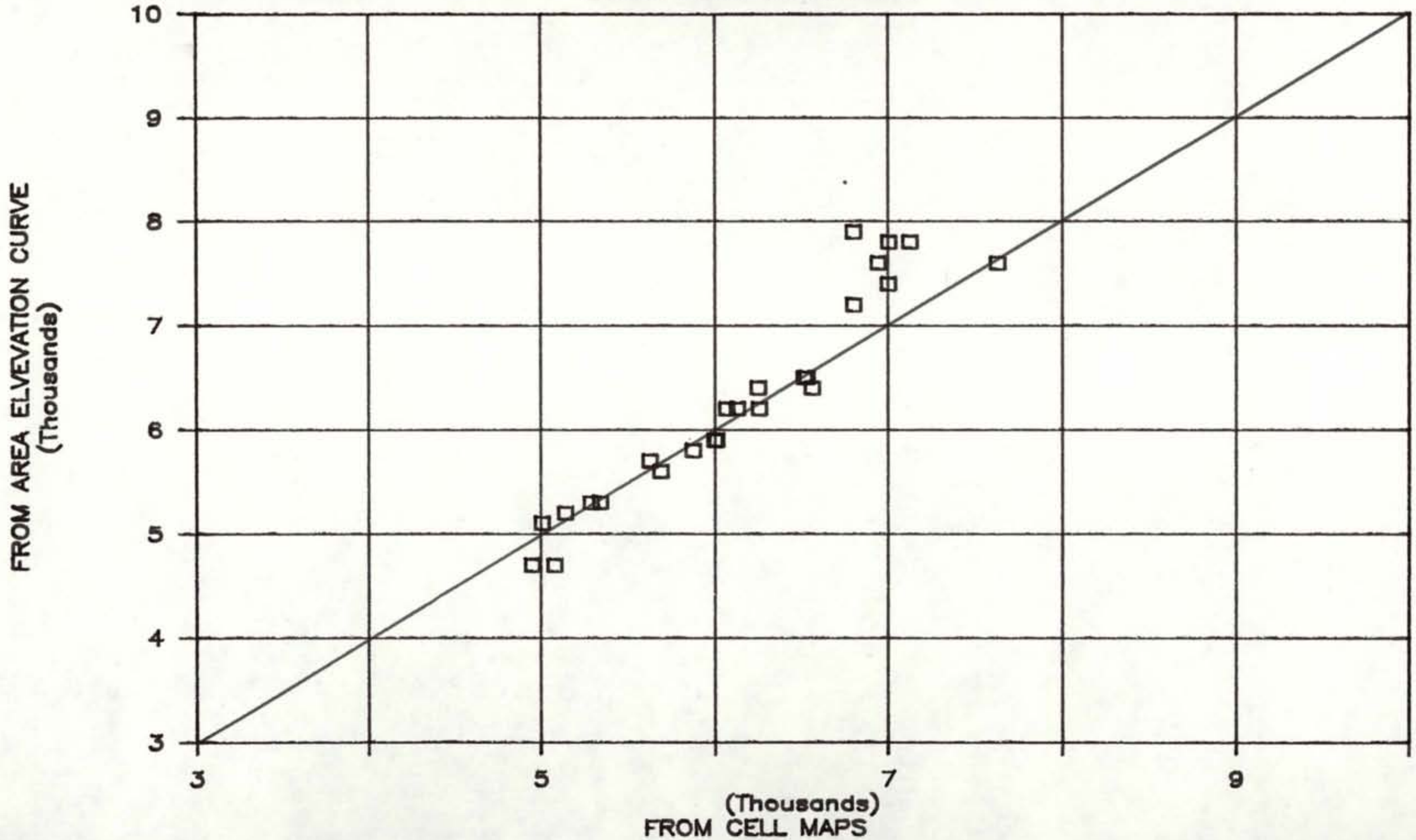


COMPARISON OF SNOWLINE ELEVATIONS
SOUTH FORK LOCAL BASIN
FROM AREA ELVEVATION CURVE
(Thousands)
10
9
8
7
6
5
4
3
3
5
7
9
(Thousands)
FROM CELL MAPS

FIGURE 18

COMPARISON OF SNOWLINE ELEVATIONS

LUCKY PEAK LOCAL BASIN

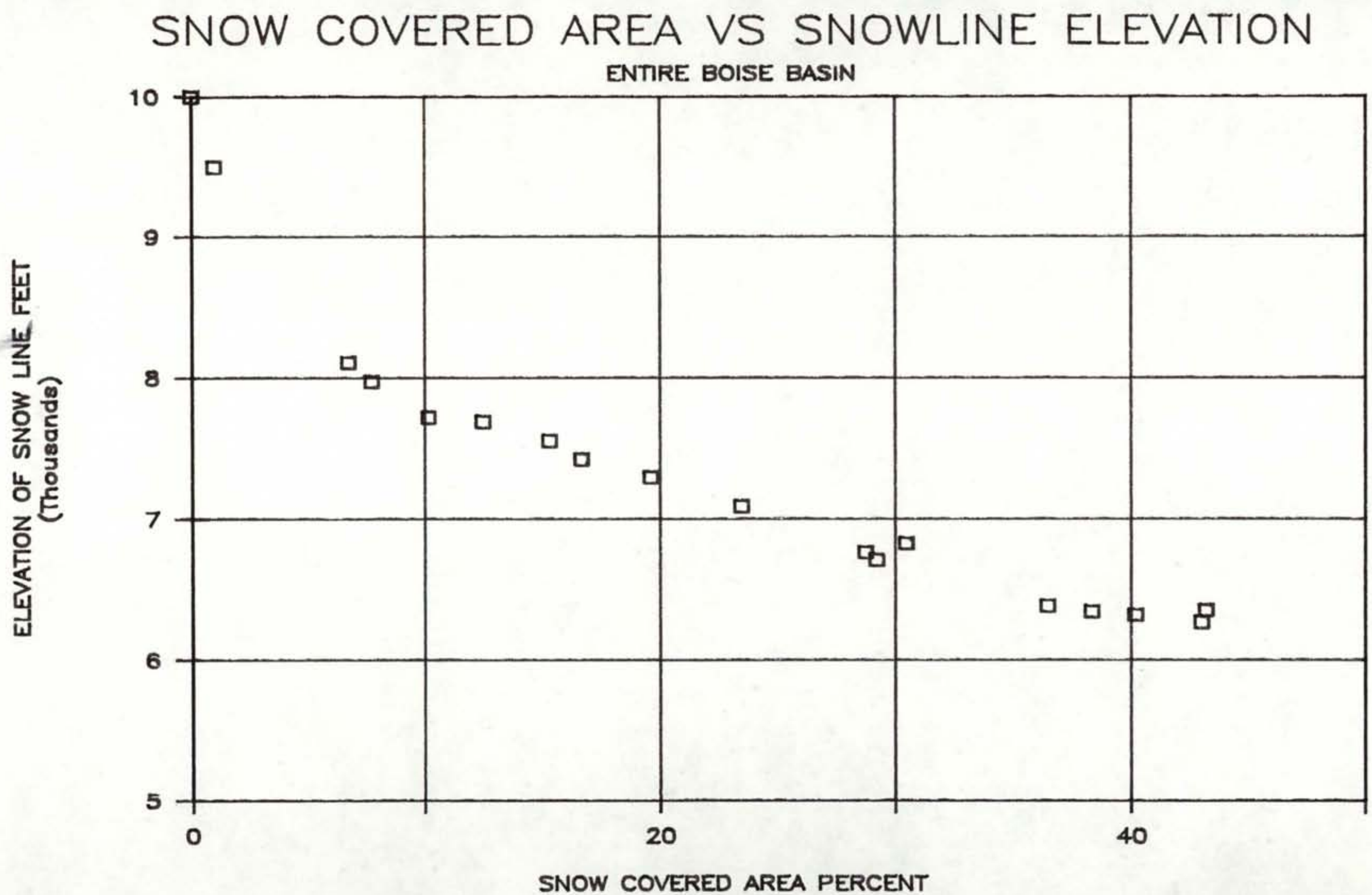


less effect. Figures 19 thru 23 show plots of what might be considered more realistic values of area vs snow line elevation for the total basins and the subbasins. These plots would be useful for finding a snow covered area for a corresponding snow line elevation or for estimating what the average snow line elevation might be for a particular snow covered area.

Another aspect of the snow line elevation phenomena that was investigated is the variability of snow line between North and South facing slopes in the subbasins. In order to investigate this phenomena, average North slopes and South slope snow line elevations were computed. The South Fork Basin was designated as the test basin for this part of the study. Again the PMAP GIS model was used to determine what the average snow line elevation conditions were on the North and South slopes. This time cross tabulations were made between the maps containing the elevation cells and a set of maps with cells containing snow lines on either North or South slopes. The cross tabulations yielded a list of elevations that were averaged to determine the average snow line elevations on the particular slopes. Table 11 shows a listing of the snow line elevations obtained.

Intuitively it is expected that normally the North slope elevations would be the lowest followed by the average elevation condition followed next by the South slope elevation. Upon inspection of the table it appears that for most cases there is no appreciable difference in elevations. In some cases the expected trend is followed and in other cases a reversal of the expected trend occurs. After analysis of the results of this part of the study, it was determined that the resolution of the GIS model used was not adequate to individually isolate North and South segments of the snow line and therefore none of the other basins were analyzed for variability in North and South slope elevations.

FIGURE 19



SNOW COVERED AREA VS SNOWLINE ELEVATION
ENTIRE BOISE BASIN
10
9
8
7
6
5
0
20
40
SNOW COVERED AREA PERCENT
ELEVATION OF SNOW LINE FEET
(Thousands)

FIGURE 20

SNOW COVERED AREA VS SNOWLINE ELEVATION

SOUTH FORK BASIN

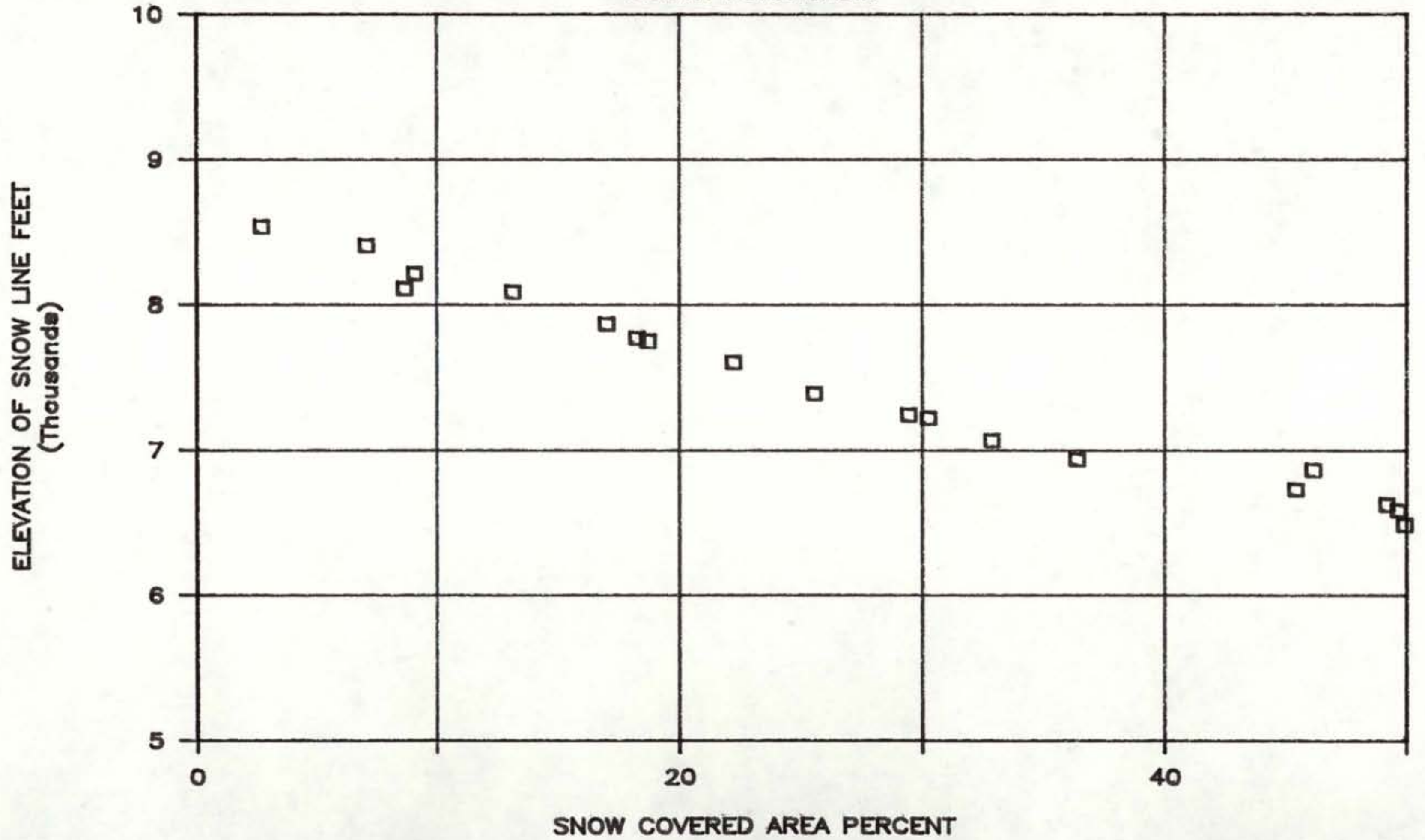
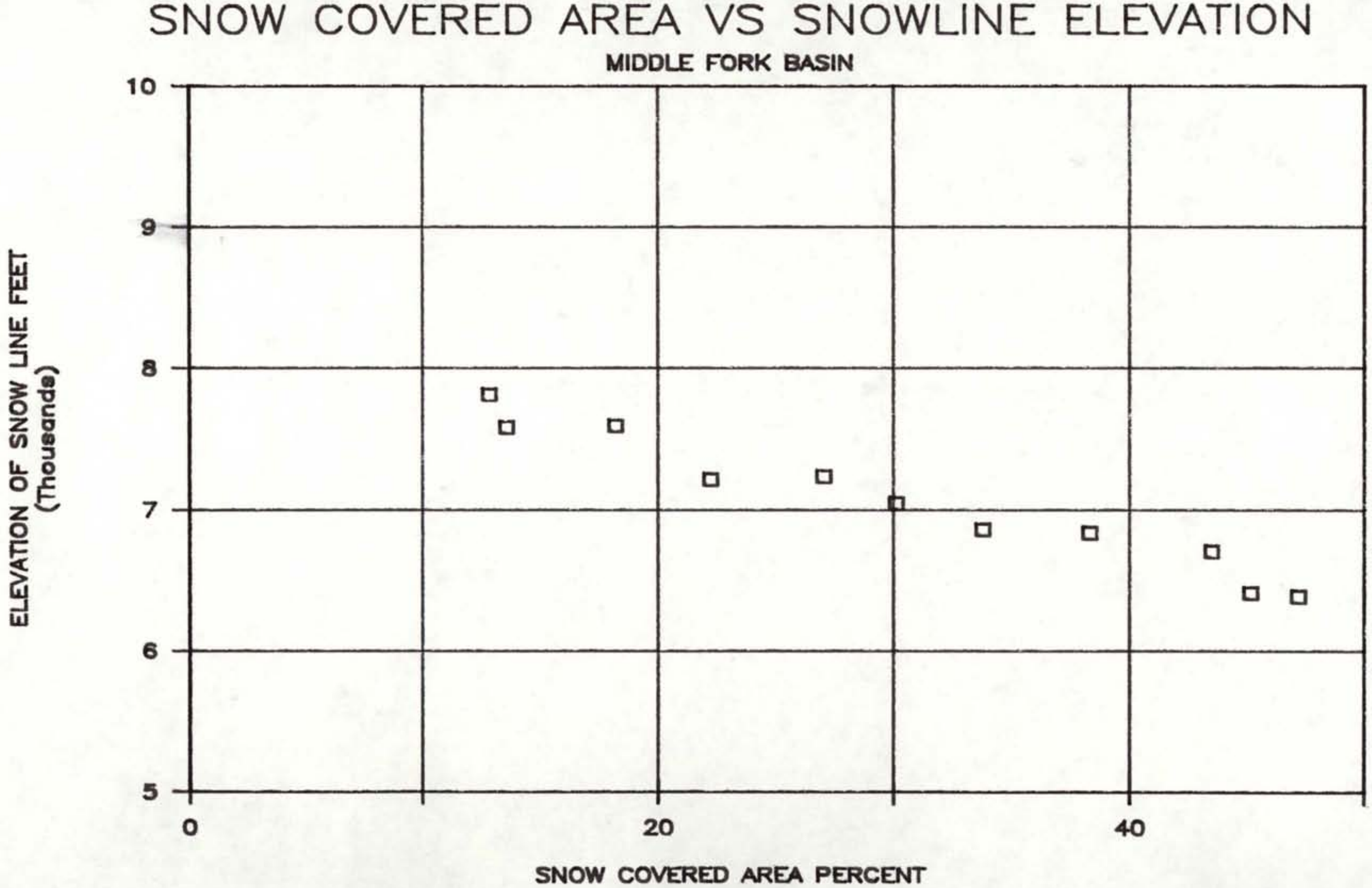


FIGURE 21



SNOW COVERED AREA VS SNOWLINE ELEVATION
MIDDLE FORK BASIN
ELEVATION OF SNOW LINE FEET
(Thousands)
10
9
8
7
6
5
0
20
40
SNOW COVERED AREA PERCENT

FIGURE 22

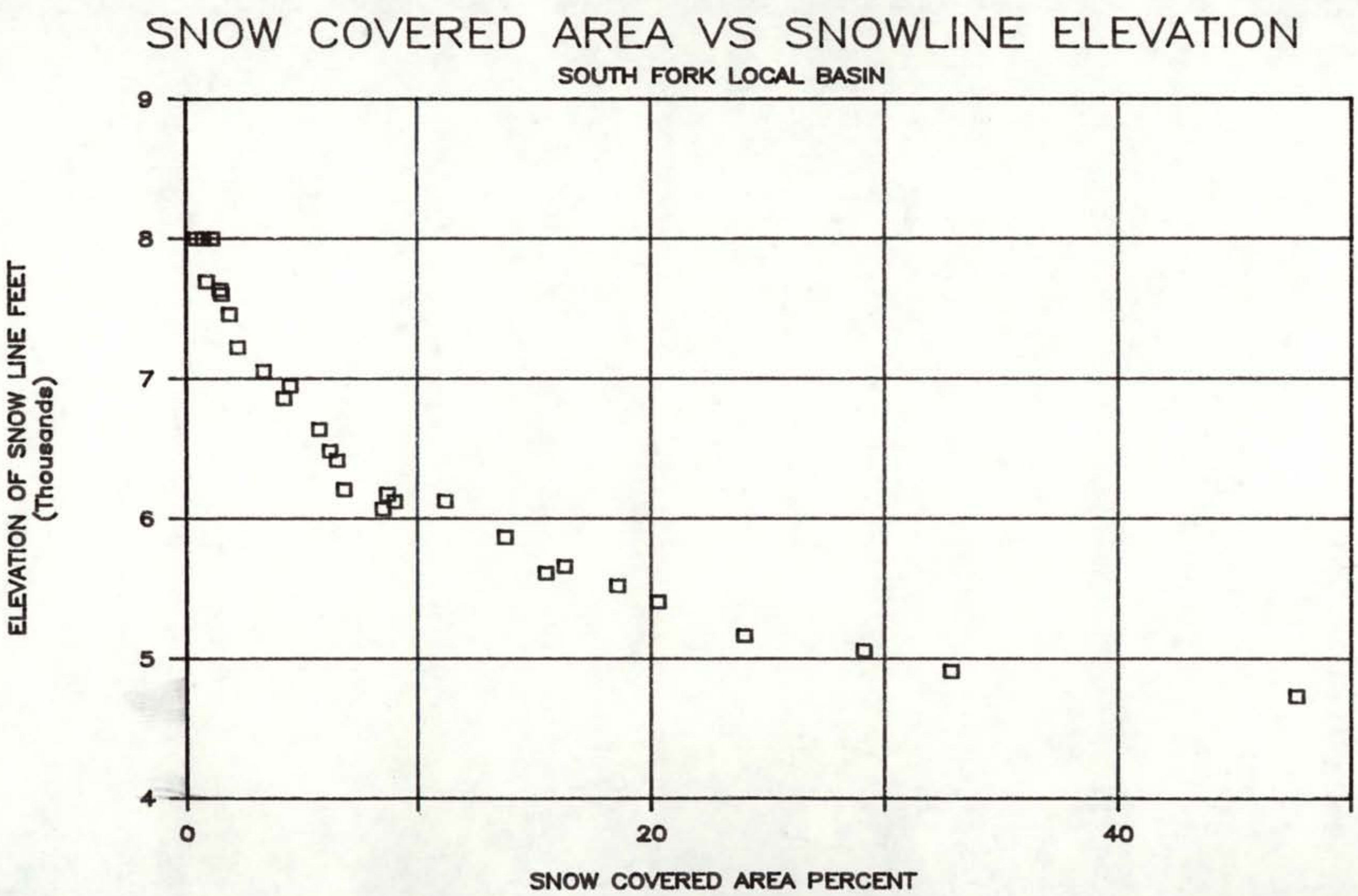

SNOW COVERED AREA VS SNOWLINE ELEVATION
SOUTH FORK LOCAL BASIN
ELEVATION OF SNOW LINE FEET
(Thousands)
9
8
7
6
5
4
0
20
40
SNOW COVERED AREA PERCENT

FIGURE 23

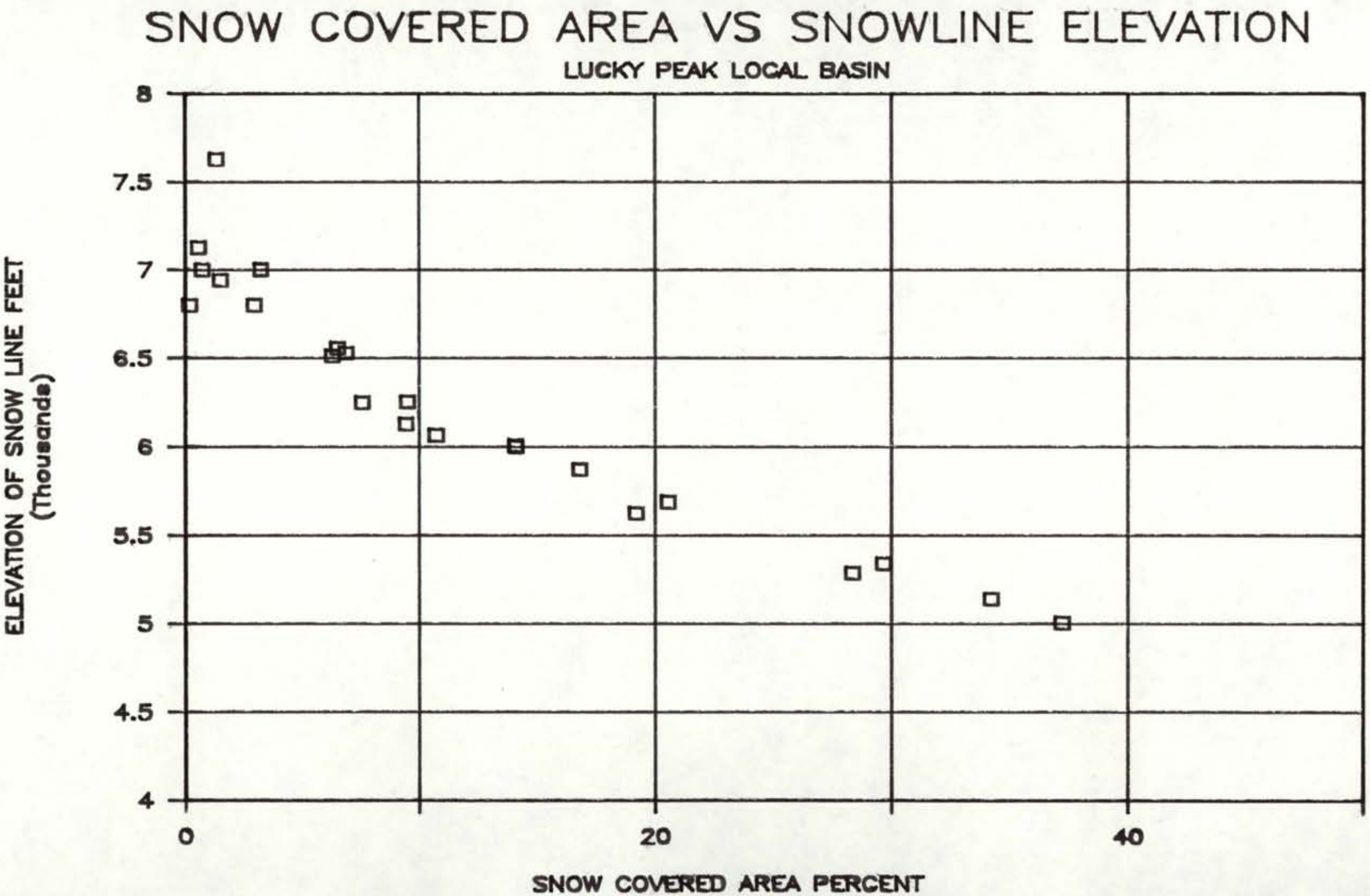

SNOW COVERED AREA VS SNOWLINE ELEVATION
LUCKY PEAK LOCAL BASIN
8
7.5
7
6.5
6
5.5
5
4.5
4
ELEVATION OF SNOW LINE FEET
(Thousands)
0
20
40
SNOW COVERED AREA PERCENT

TABLE 11
TOTAL NORTH SLOPE AND SOUTH SLOPE
SNOW LINE ELEVATIONS
FOR SOUTH FORK BASIN

DATE	AVERAGE TOTAL SNOWLINE	AVERAGE NORTH SLOPE SNOWLINE	AVERAGE SOUTH SLOPE SNOWLINE
5-7-73	6427	6441	6454
5-2-74	5735	5909	5573
6-25-74	7727	7782	7672
5-15-75	5309	5271	5366
6-11-75	6941	6915	6962
6-29-75	7577	7494	7569
4-3-76	4196	4196	4196
4-30-76	5492	5529	5415
5-18-76	6488	6591	6458
6-23-76	6869	6919	6860
4-25-77	8051	7999	8120
5-13-77	7754	7618	7843
5-31-77	8349	8267	8498
6-6-77	8493	8350	8663
6-24-77	8046	8035	8018
4-11-78	6561	7038	5933
5-8-78	5459	5557	5322
6-4-78	6683	6872	6548
6-22-78	7212	7488	7213
5-12-79	6571	6594	6613
5-21-79	7367	7318	7343
6-8-79	8210	8237	8211
5-28-81	7845	7727	7929
4-17-83	7310	7890	6547
5-19-83	5881	5919	5806

RELATIONSHIPS BETWEEN HEAT INPUT, SNOW COVERED AREA, AND STREAMFLOW

The purpose of this particular portion of the study was to investigated the possible relationships between heat input, snow covered area and stream flow. Officials from the Corps of Engineers, the sponsors of this study, felt that because of the availability of more and more temperature information in the basin it would be wise to investigate if ties could be made between temperature, snow covered area, and streamflow.

It has been firmly established that heat is the driving force for the snow melt process. Many process models such as the SSARR model use various snow melt equations involving temperature and other climatic conditions to determine the amount of snowmelt in a given time period. The main difficulty with these process model equations comes in determining: 1. What is the correct temperature to be applying in the equations, and 2. What are the correct coefficients to apply with the temperature in the snowmelt equations.

Temperatures are only known at established temperature recording sights and are not available in sufficient numbers throughout the basin. The problem is how to take the temperatures at known points and transfer them to the points where the snow pack is located. This has been done in the past with various lapsing equations which involve elevation changes between the known temperature location and the snow pack, and lapse coefficients. This method can be coupled with a weighting technique so that lapsing and averaging can be done on several stations to determine a snow pack temperature. Which lapse rates to use and which weighting parameters are appropriate become a very difficult calibration problem.

Officials with Walla Walla District of the Corps of Engineers felt that there might be some simpler relationships between heat input, snow covered area, and runoff. If these simpler relationships could be established another tool might become available in the runoff predicting process. Their thought was not that a simpler tool might eliminate the need for the more sophisticated SSARR model, but that a simpler tool might help in identifying times when the more sophisticated model might be headed for trouble in its predicting processes.

In order to investigate relationships of heat input with other runoff parameters, some means of measuring heat input needed to be established. The degree day approach was adopted. This simple method gives a quick and easy reference to the heat input available to drive the snow melt process. The basic degree day equations used is as shown below:

$$DD = (T_{max} - T_{base})$$

where

DD = computed degree days

T_{max} = maximum daily temperature

T_{base} = base temperature

The base temperature used in the degree day calculation for snow melt computations is commonly around 32 degrees F. or 0 degrees C. Adjustments are sometimes made to this base temperature depending on snow pack conditions and other climatic factors. For consistency throughout this study, a base temperature of 32 degrees was used.

Although there has been new temperature stations installed in the recent past, only four temperature recordings stations were available in the Boise Basin for the entire 1973 thru 1983 period. These stations were Anderson Ranch Dam, Arrowrock Dam, Lucky Peak Dam, and Idaho City. In examining the degree day values computed from the four stations, it was determined that the stations were very consistent in value between stations if percent of 1 April thru 1 July degrees days were computed rather that just the degree day values for each station. For this reason the various studies that were made to try to establish a correlation between heat input, snow covered area and runoff were made using the percent of total seasonal degree days instead of just degree day values.

Table 12 contains a listing of the percent of total seasonal degree days versus measured snow covered areas for the dates which snow maps were available. The data in this table was used to try to develop some relationships between heat input and snow covered area. Upon inspection of the various percent degree day values, one can easily see that there is a very strong intercorrelation between the various stations. Therefore, doing a multiple regression using more than one of the stations would tend to break the rule of nondependence between independent variables. Nonetheless, no matter what kind of correlations relationship was investigated no really significant correlation could be established between the percent of degree days and the snow covered area for the data available.

Figure 24 shows a scatter plot of percent degree day vs snow covered area for the South Fork Basin. The wide scattering of data is indicative of the poor correlation that is present between percent of total degree days and snow covered area. Plots from the other basins showed similar wide scattering.

Another approach that was explored was to investigate the relationship between the percent of total 1 April thru 30 June flow and the percent of total 1 April thru 30 June degree days. Figures 25 and 26 are plots of the percent flow vs percent degree day relationship. Simple linear correlations analysis yielded values of R^2 of 0.9832 for the Middle Fork at Twin Springs data and R^2 of 0.9786 for the South Fork data. The prediction equations for the two data sets are shown below:

MIDDLE FORK AT TWIN SPRINGS

PERCENT FLOW = -2.804 + 1.0920 X PERCENT DEGREE DAY

SOUTH FORK AT ANDERSON RANCH DAM

PERCENT FLOW = -2.156 + 1.0994 X PERCENT DEGREE DAY

TABLE 12
PERCENT OF TOTAL DEGREE DAYS VS BASIN SNOW COVERED AREA
1 APRIL THRU 30 JUNE
BASE TEMP = 32 F

DATE	ANDERSON RANCH DAM %DD	ARROW-ROCK DAM %DD	LUCKY PEAK DAM %DD	IDAHO CITY %DD	SOUTH FORK SCA %	TWIN SPRINGS SCA %	LUCKY PEAK LOCAL SCA %	SOUTH FORK LOCAL SCA %	TOTAL BASIN SCA %
07-May-73	28.71	29.38	28.71	28.94	54.98	66.48	10.75	8.50	43.71
02-May-74	25.04	24.34	25.04	24.90	79.29	85.06	28.34	18.58	62.89
25-Jun-74	92.09	91.98	92.09	92.07	18.72	30.11	1.48	1.85	16.67
15-May-75	34.71	34.05	34.71	35.20	88.80	89.18	37.21	24.00	69.99
11-Jun-75	72.21	71.89	72.21	72.27	36.38	45.16	6.25	6.19	29.22
29-Jun-75	98.13	98.19	98.13	98.18	22.21	33.76	3.19	3.31	19.59
03-Apr-76	1.50	1.58	1.50	1.86	100.00	100.00	90.20	98.54	98.05
30-Apr-76	22.57	22.12	22.57	23.34	86.09	87.80	34.22	20.31	67.50
09-May-76	32.74	32.19	32.74	33.70		74.33	16.80	11.19	
18-May-76	44.96	43.80	44.96	45.52	49.92	67.88	14.10	9.00	42.99
27-May-76	56.93	55.39	56.93	57.25	32.86	47.17	6.84	6.50	28.73
05-Jun-76	68.50	66.26	68.50	67.89	30.23	68.40	8.48	4.19	34.35
23-Jun-76	91.74	89.53	91.74	89.58	46.12	43.39	0.00	2.19	30.47
07-Apr-77	5.59	5.03	5.59	4.74		84.95	29.65	13.77	
25-Apr-77	23.35	22.63	23.35	23.09	13.13		1.31	1.50	
01-May-77	30.66	30.18	30.66	31.10			0.00	0.00	
13-May-77	40.40	39.38	40.40	39.84	18.26	18.19	0.72	0.73	12.48
31-May-77	56.52	55.45	56.52	55.20	7.04	12.83	0.56	0.42	6.70
06-Jun-77	66.26	64.85	66.26	64.81	2.65		0.00	0.00	
18-Jun-77	82.35	81.29	82.35	81.37			0.00		
24-Jun-77	90.93	90.29	90.93	90.15	8.64	22.25	0.00	0.88	10.18
11-Apr-78	7.04	6.87	7.04	8.07	97.06	94.22	50.79	47.65	80.52
08-May-78	30.48	30.68	30.48	32.06	87.63	84.83	20.55	32.85	66.60
26-May-78	50.73	50.57	50.73	51.06	49.18	54.32	7.53	15.50	38.32
04-Jun-78	61.44	61.46	61.44	62.27	45.38	55.79	9.50	6.81	36.45
22-Jun-78	87.59	87.19	87.59	88.11	29.43		6.48	5.73	
12-May-79	34.93	34.95	34.93	35.37	49.66	59.32	14.10	8.69	40.18
21-May-79	47.46	47.77	47.46	48.16	25.51	38.31	9.43	4.46	23.47
08-Jun-79	72.22	73.00	72.22	72.62	9.05	13.56	0.20	1.12	7.69
28-May-81	53.18	56.80	53.18	56.12	17.04	27.03	2.93	1.46	15.30
17-Apr-83	9.02	10.76	9.02	10.50	100.00	88.32	51.05	29.12	76.98
19-May-83	34.62	40.20	34.62	38.69	72.91	68.85	19.20	16.31	53.58

FIGURE 24

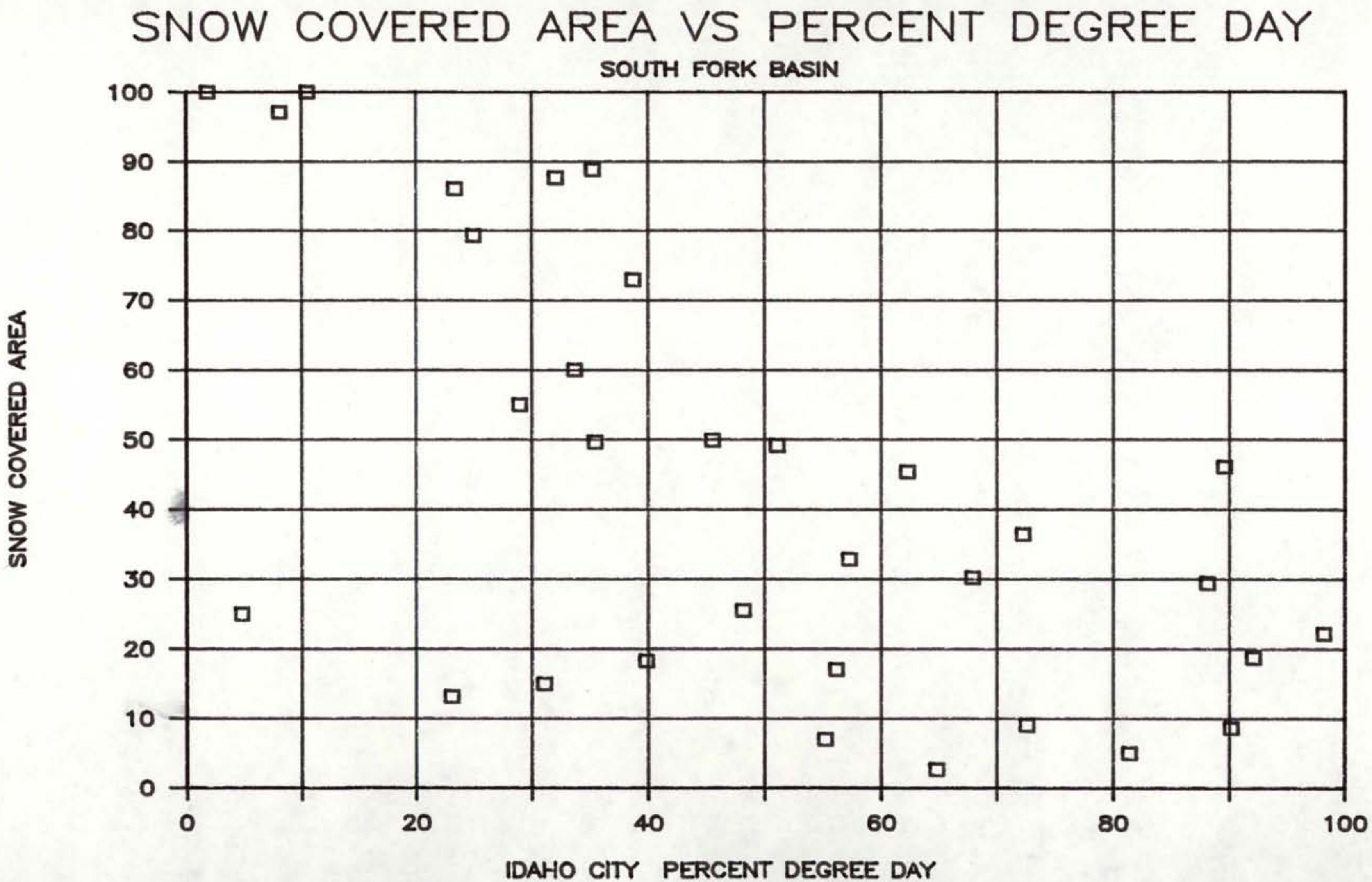

SNOW COVERED AREA VS PERCENT DEGREE DAY
SOUTH FORK BASIN
100
90
80
70
60
50
40
30
20
10
0
SNOW COVERED AREA
0
20
40
60
80
100
IDAHO CITY PERCENT DEGREE DAY

FIGURE 25

PERCENT FLOW VS PERCENT DEGREE DAYS

MIDDLE FORK AT TWIN SPRINGS

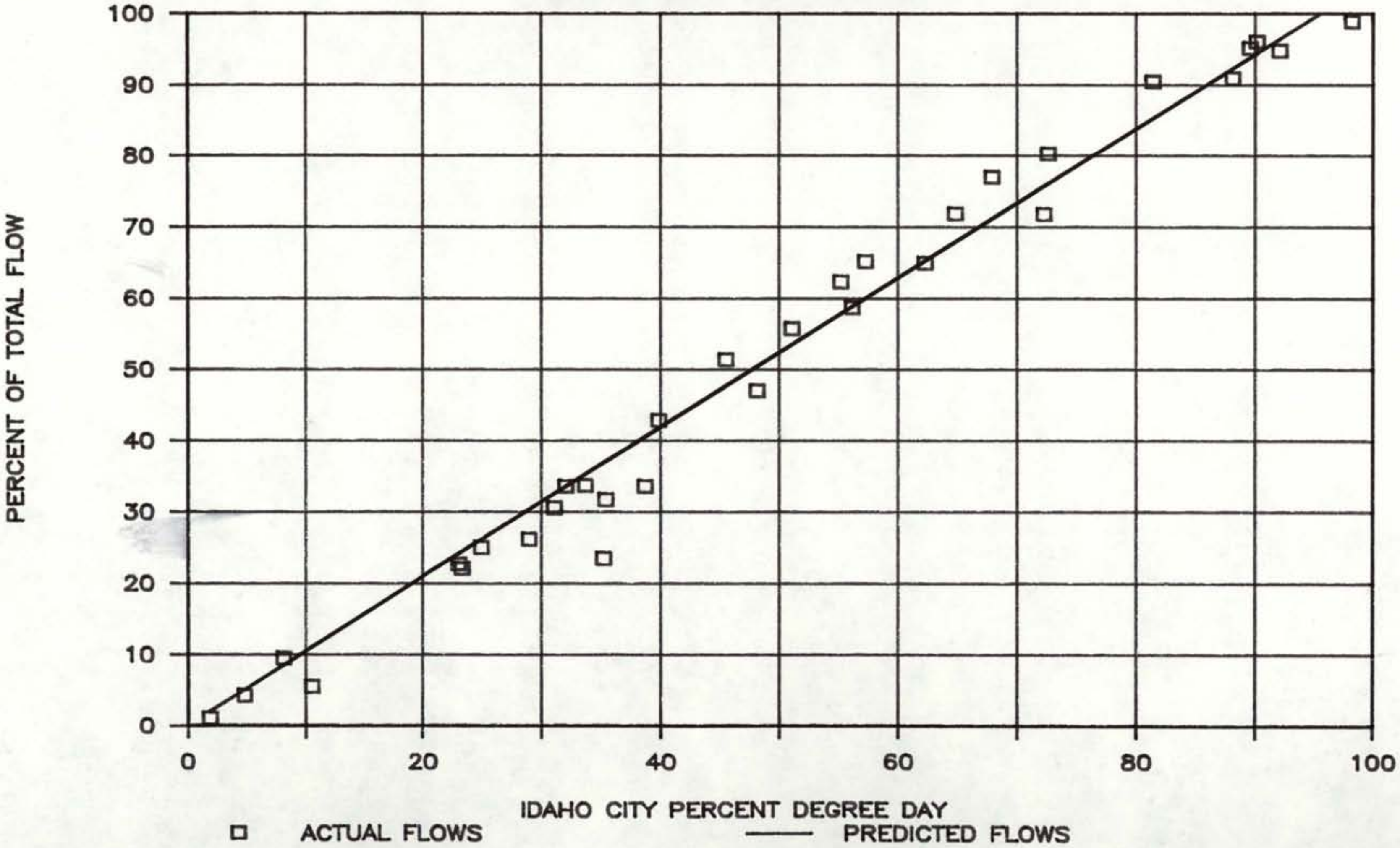
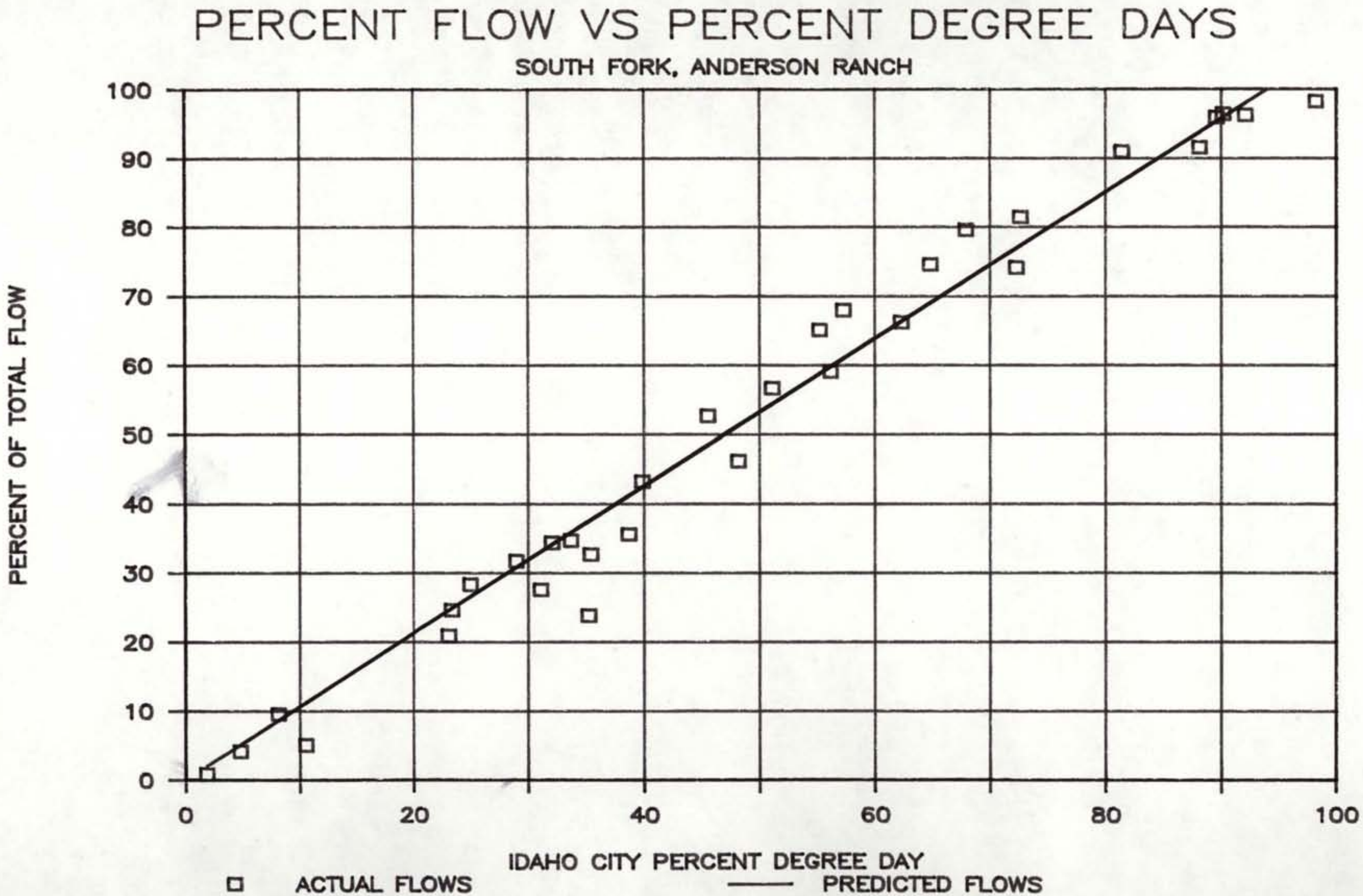


FIGURE 26



PERCENT FLOW VS PERCENT DEGREE DAYS
SOUTH FORK, ANDERSON RANCH
PERCENT OF TOTAL FLOW
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
IDAHO CITY PERCENT DEGREE DAY
ACTUAL FLOWS
PREDICTED FLOWS

The results of the previous analysis indicated that the percent degree factor might be useful in predicting basin inflows. Due to time constraints it was impossible to completely explore the possibilities of using the percent degree day factor as a predictive tool. Some work was accomplished in this area and the results follow. The reader should be aware that this work is only preliminary in nature and should be followed up with more exhaustive statistical analysis to confirm the applicability and reliability of this prediction process.

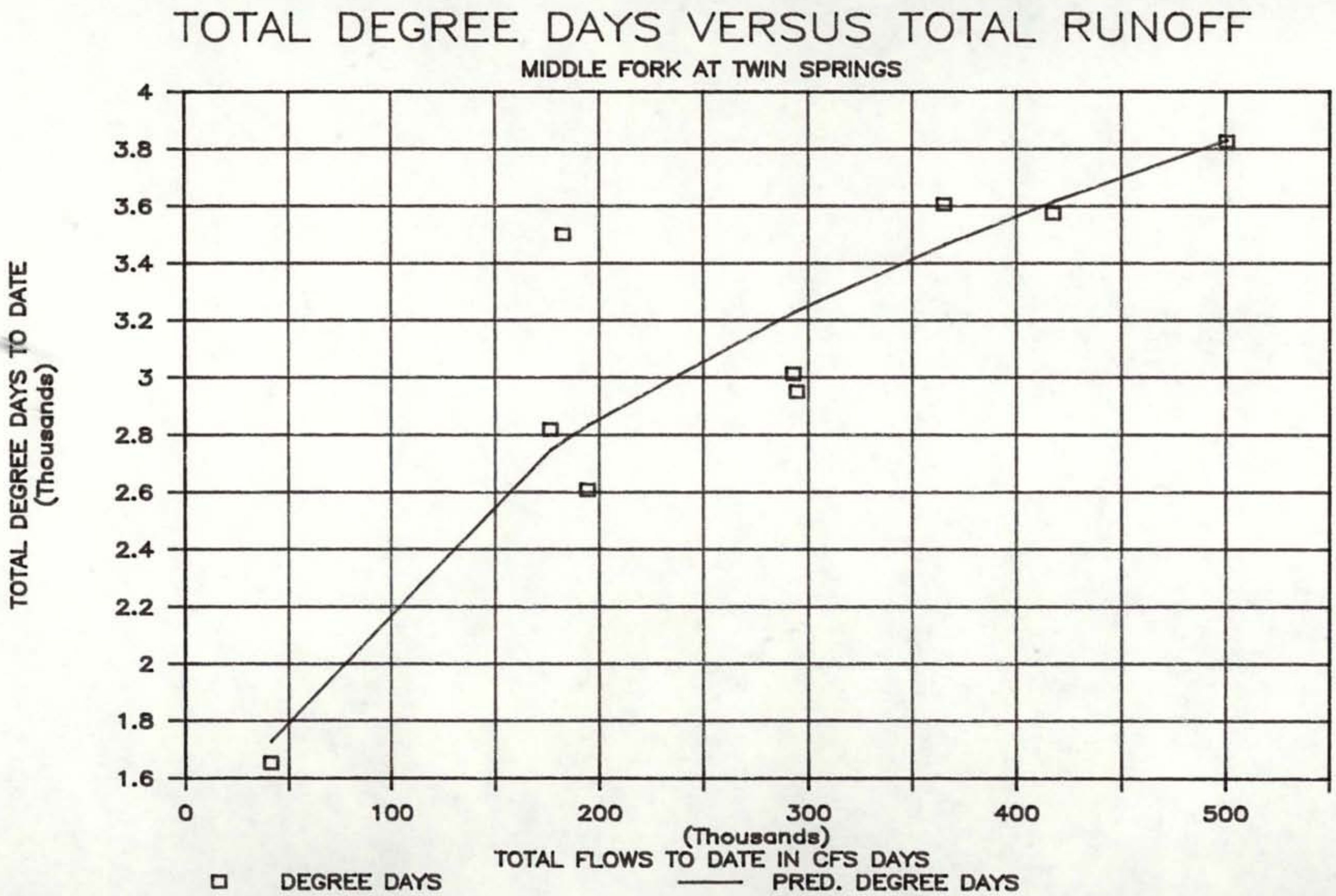
In order to use the percent degree day approach, one must first pick a temperature station to use in the analysis. After examining the percent degree days computed for the stations in the basin, it was determined that the percent degree values were so similar that it really would not make any difference which temperature station was chosen. The Idaho City Station was arbitrarily chosen to be used for the examples that follow.

In order to use the method in the predictive mode, the percentage of total degree days must be computed throughout the melt season. This requires knowing the past and predicted future temperatures at the chosen temperature station and knowing the total seasonal degree days since percent degree days is computed as shown below:

PERCENT DEGREE DAYS = (TOTAL DEGREE DAYS TO DATE) / (TOTAL SEASONAL DEGREE DAYS) X 100%

In order for the method to be successful, the total seasonal degree days must be predicted at the beginning of and during the melt season. Intuitively it seems reasonable that there should be a relationship between total seasonal flow volume and total seasonal degree days required to melt this volume. Figure 27 shows a plot of total degree days versus total runoff for nine years of data for flows on the Middle Fork at Twin Springs and temperatures at Idaho City. It appears that a nonlinear relationship would best describe this process. The line drawn thru the data points is merely an estimate of best fit and is not based

FIGURE 27



TOTAL DEGREE DAYS VERSUS TOTAL RUNOFF
MIDDLE FORK AT TWIN SPRINGS
TOTAL DEGREE DAYS TO DATE
(Thousands)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
0
100
200
300
400
500
(Thousands)
TOTAL FLOWS TO DATE IN CFS DAYS
DEGREE DAYS
PRED. DEGREE DAYS

on any statistical analysis. More work in this area is definitely needed in order to obtain a strong predictive tool for estimating the total degree days required to melt a given volume of runoff.

If the relationship between total runoff and total degree days can be established, one can predict the total seasonal degree days by using the available volume forecasts. Next percent of total degree days would be computed for each day during the melt season. At the beginning of the melt season average temperatures could be used throughout the season. Next the percent degree days would be transformed to percent of flow using relationships similar to those shown in Figures 25 and 26. Once percent of total runoff is predicted, it is a simple computation to predict total inflows per day throughout the melt season. The predictive process could be updated with time as more precise seasonal runoff forecasts are available and as more and more actual basin temperatures become available as the melt season progresses.

This method of flow prediction is certainly not suggested to replace that using the much more sophisticated SSARR model. It is suggested that this method could be used as a second check on the results of the more sophisticated model. If large discrepancies between the two methods exist, a warning flag could be raised and added precautions could be taken in the reservoir management procedures.

One big advantage of this simple predictive technique is that it is easily adapted to use on a personal computer. The technique lends itself to the spreadsheet approach to computations as used by "LOTUS" or some other spreadsheet programs. This means that the predictions would be very inexpensive and fast to run, and many alternative situation could be explored in a very short time period. This extensive "WHAT IF" capability could be a powerful tool to use to supplement the SSARR model.

Again it must be stressed that this percent degree day technique has not been explored thoroughly so no strong statistical support for the technique is provided. The technique does appear promising enough that additional work might be justified on this flow prediction technique.

SUMMARY AND CONCLUSIONS

This study involved an in depth investigation of the snow depletion process in the Boise Basin of South Central Idaho. Snow covered area maps that were developed in the first phase of this study were used in developing typical snow covered area maps and for investigating the areal distribution of snow during the snow melt season.

The first portion of the project involved development of what were termed simplistic snow covered area maps. These maps were developed from the simplistic viewpoint that snow cover started from the highest point in the basin and continued without interruption to lower elevations. The snow line elevation was considered to be constant throughout the basin for each value of snow covered area studied. The simplistic maps were developed for 10, 15, 20, 25, and 35 percent snow covered area. A separate map was developed for each of four subbasins and for the entire Boise River Basin.

Next typical snow covered area maps were developed for the specific percent snow covered areas shown above. These maps were drawn from the snow covered area maps developed during the phase I studies that were completed earlier. Visual interpolations and extrapolations were used to develop these maps that indicate what portions of the basin would be snow covered for each of the specific percent snow covered areas.

The simplistic and typical snow covered area maps were compared to see if any differences between the two representations could be identified. The simplistic method is quite similar to the representation used by the SSARR model which is now used by the Corps in its reservoir operation procedures. Any difference in the typical and simplistic maps would indicated areas where the simplistic viewpoint of the model might be in error.

Three areas of major difference between the simplistic and typical snow covered area maps were identified. The Big Smokey and Little Smokey Basins in the South Fork Basin and the Upper North Fork and Upper Queens River Basins in the Middle Fork Drainage all showed identifiable differences between the typical and simplistic maps. There were also smaller difference between the two map types in the Upper Grimes Creek

Basin near Placerville. These difference between the simplistic maps and the typical maps reveal areas where the SSARR model could be in error since it is using more or less a simplistic viewpoint of snow depletion to model the real world which is melting more in the fashion of that shown on the typical snow cover maps.

A geographic information system model was used to simulate the topographic features of the basin. Elevations were input to the model, and distribution of slope aspects were computed for the four subbasins studied. The distribution of slope aspect direction within and between subbasins was examined. The results of these studies showed that there is some variability of slope aspect within the various basins, with some basins having much higher percentages of certain aspect directions than others. Since the SSARR model does not directly account for slope aspect within the basin an uneven distribution of slope aspect could lead to problems in computing snowmelt within the SSARR model.

The South Fork Basin is characterized with a high percentage of south facing slopes, whereas the Lucky Peak Local Basin has large areas of low elevation and fairly flat areas. Because of these abnormalities the SSARR representations of these two basins should be monitored to be sure that adequate allowances are made for the uneven distribution of slope aspect.

A comparison was also made between actual measured average snow line elevations from the snow covered area maps and the average snow line elevations that would have been assumed by the SSARR model for the same snow covered area. There were difference between the two representations of snow line in almost all of the basins especially during the later stages of snowmelt. Several graphs are provided so that Corps personal can correlate snow lines as seen from the air during snow flights with actual snow covered areas that have been measured for similar conditions in the past. These should be helpful in keeping the snow covered area values in the SSARR model in step with actual on the ground values.

The last portion of the study involved investigating some simple relationships between heat input and runoff that occur in the basin. There appears to be some relatively strong correlations between percent of total melt season degree days and percent of total season runoff.

A simple runoff prediction procedure is outlined, but due to time constraints no rigorous statistical verifications were performed to substantiate the reliability of the procedure. If a procedure similar to the one outlined could be developed, it would provide another tool in runoff prediction process and would help to identify times when the more sophisticated SSARR model might be running into difficulties.

The various curves charts and graphs presented in this study should be helpful to those trying to operate the Boise River System to a higher degree of precision. The recommendations and warning should provide some clues as to where problem areas could occur in the SSARR model of the basin.

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