LONG-TERM TRENDS IN GLACIER AND SNOWMELT RUNOFF WIND RIVER RANGE, WYOMING

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CHAPTER 1

INTRODUCTION

The Wind River Range is an unbroken 100-mile long barrier in west central Wyoming that is host to 63 glaciers covering 17 square miles in area. Seven of the ten largest glaciers in the American Rocky Mountains are found in the Wind River Range, with areas from 393 to 1130 acres (Bonney, 1987) while the total area of glaciers in the Wind River Range is larger than that of all other glaciers, 134 covering 12 square miles, in the American Rockies (Field, 1975; Davis, 1988).

Glaciers contribute an undocumented amount to streamflow in Wyoming. Glaciers can be considered as natural reservoirs which store water in the winter and release it in the summer. Glacier runoff is likely to be most important during the late summer and early fall when low flows are critical for consumptive water users and instream flow needs. In addition, glaciers may release especially large quantities of water in years of low precipitation when water from other sources such as winter snowpack may be in short supply.

According to most authors (e.g., Meier, 1951; Dyson, 1952; and Mears, 1972), glaciers in the Wind River Range have generally been in a negative regime since 1850. While the most pronounced retreat occurred in the late 1930s, the glaciers continued to retreat, some at an alarming rate. Dyson (1952) reported that glaciers in the Wind River Range were retreating at a rate of 7 to 41 percent per year. Systematic studies of glacier mass balance have not been conducted on Wind River glaciers since the one- or two-year studies in the 1950s. Trends in glacier regime over the last four decades need to be documented and modeled relative to external and internal controls to better understand the implications of long-term trends for water supply in the Green and Missouri River drainages and obligations under interstate compacts.

Objectives

The objectives of this study were to:

1. analyze temporal trends in snowdepth and/or water equivalent for all climatic stations in the Wind River Range,

2. analyze temporal trends in runoff from existing streamflow gaging stations affected by glacier runoff and snowmelt from the Wind River Range,

3. use aerial photos and ground photos to document the trends in glacier regime as far back as photos are available, and

4. perform field reconnaissance for direct measurements of runoff from the Wind River Range glaciers.

Description of the Wind River Range

The Wind River Range is the largest discrete mountain mass in Wyoming and also contains the highest summit peaks, such as Gannett Peak 13,804 ft, Fremont Peak 13,745 ft, and Wind River Peak 13,192 ft (Fig. 1a and 1b). The average height of the peaks and ranges is about 11,000 ft. The range extends from South Pass City on the south to Fish Lake Mountain on the north, and is about 125 miles long by 25 miles wide.

Glaciated peaks mark the central region and permanent glaciers lie in the higher valley heads of the Wind River Range. Mountain glaciers formed in the Wind River Mountains during the later Pleistocene and moved from the peaks through the canyons and in the northern part of the range extended out into the margin of the Wind River Basin. Along all of the glaciated valleys are numerous small recessional moraines which show that the edges of the glaciers halted many times during retreat (Branson and Branson, 1941).

The glaciers occur in the highest parts of the Wind River Range throughout most of its length, with the greatest concentration located within the Fremont Peak quadrangle along the east slope of the Continental Divide from Gannett Peak to Knife Point Mountain. Most of the small glaciers, less than 0.19 square miles in area, lie close to an altitude of 11,900 ft.

The mean annual precipitation in the upper ranges of the Wind River Mountains is 40 to 60 inches, in contrast to the adjacent Wind River Basin average of 8 inches. According to Martner (1986), most of the Wind River Range precipitation occurs during the winter as snow. Total annual snowfall averages 200 inches with April being the month of the greatest amount.

Description of Gannett and Dinwoody Glaciers

Meier (1951) described in detail the glaciers of the Wind River Range. Although the overall sizes of Gannett and Dinwoody glaciers have diminished since Meier's measurements, his descriptions are still appropriate.

Gannett Glacier is the largest glacier in the American Rockies, with an area in 1950 of 1.77 square miles (Fig. 2). Meier describes Gannett Glacier as a system of contiguous valley glaciers, with four independent tongues separated by ice divides.

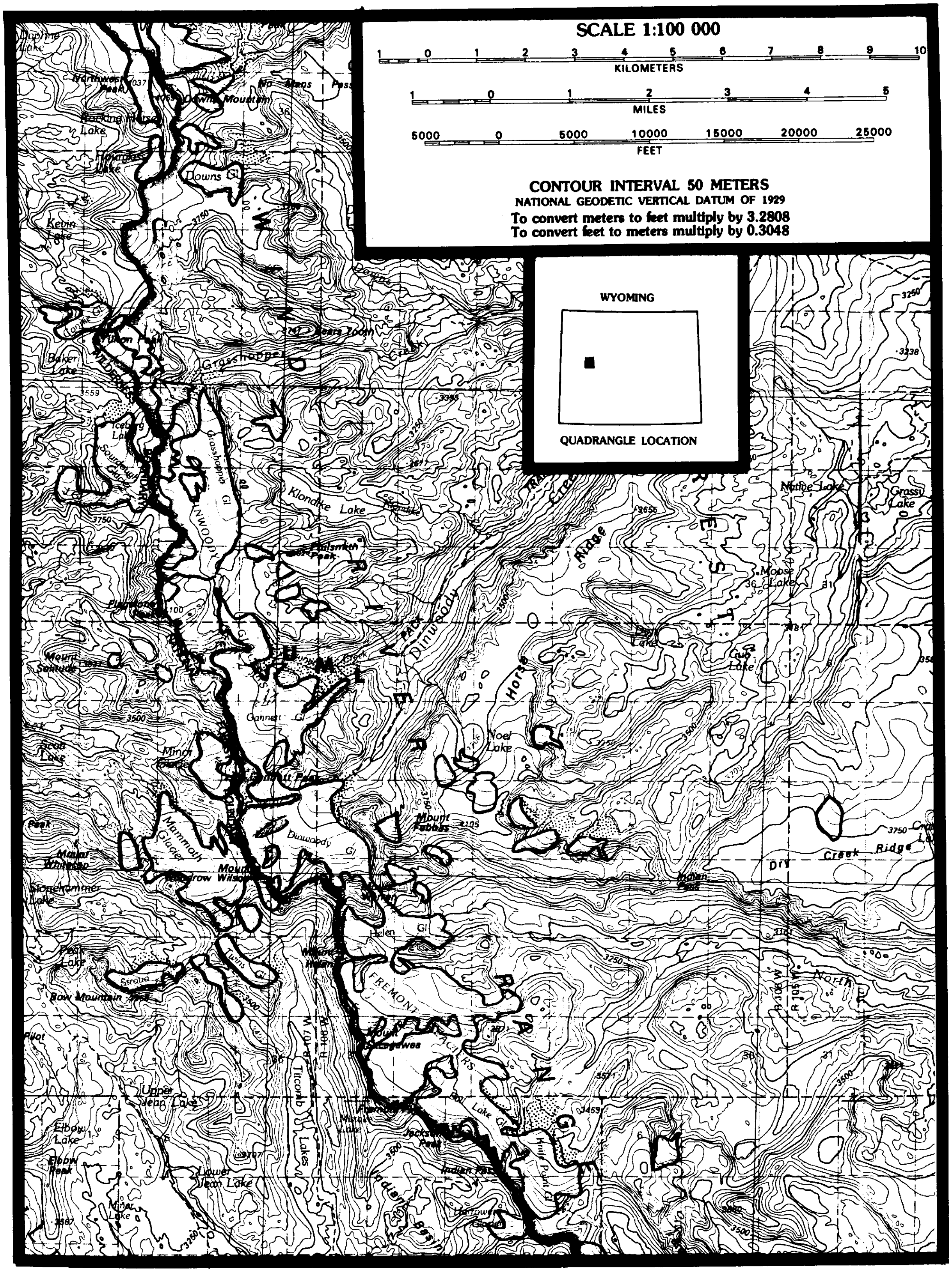

Figure 1a. Glaciers of the Wind River Range.

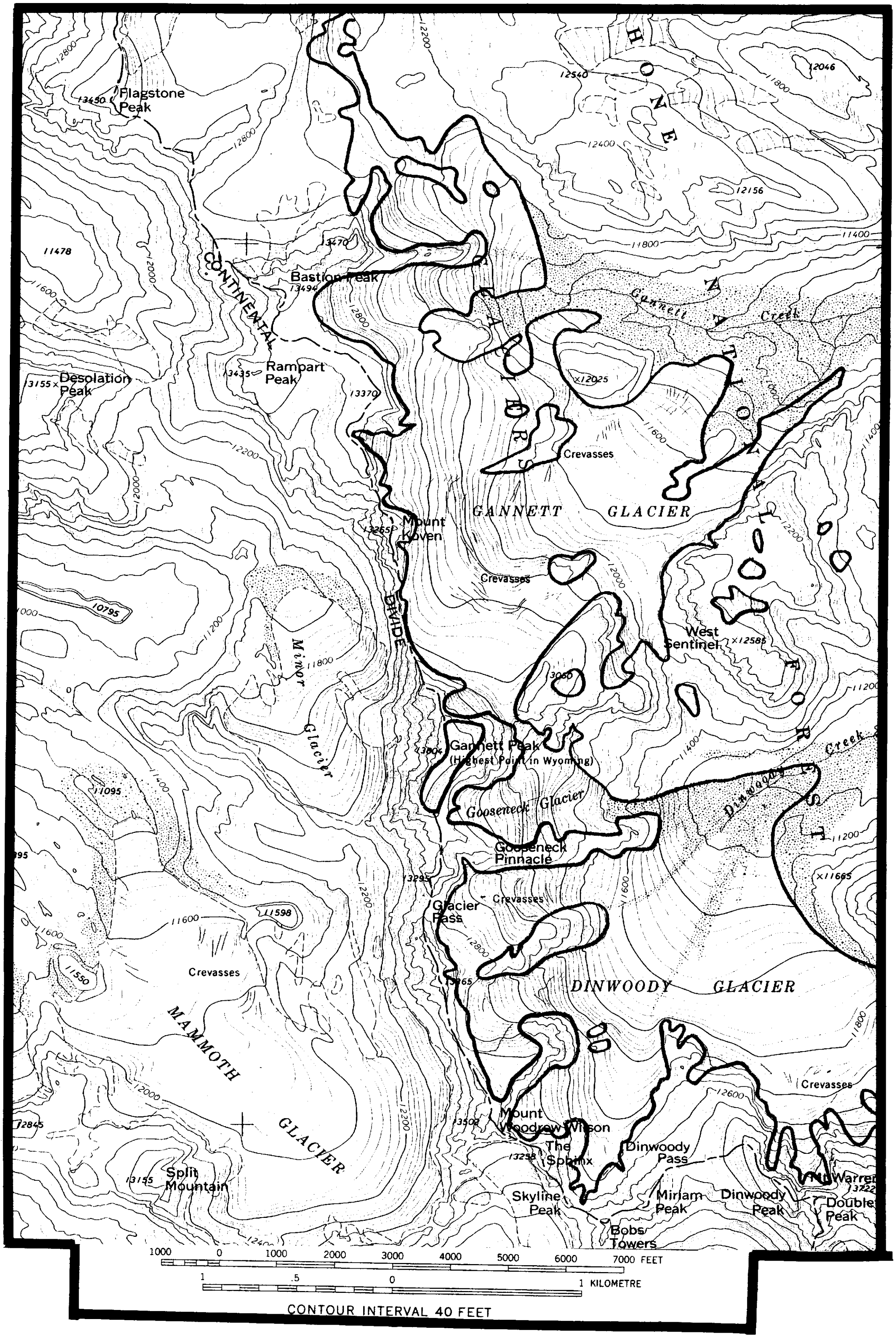

Figure 1b. Dinwoody and Gannett Glaciers in the Wind River Range, Wyoming.

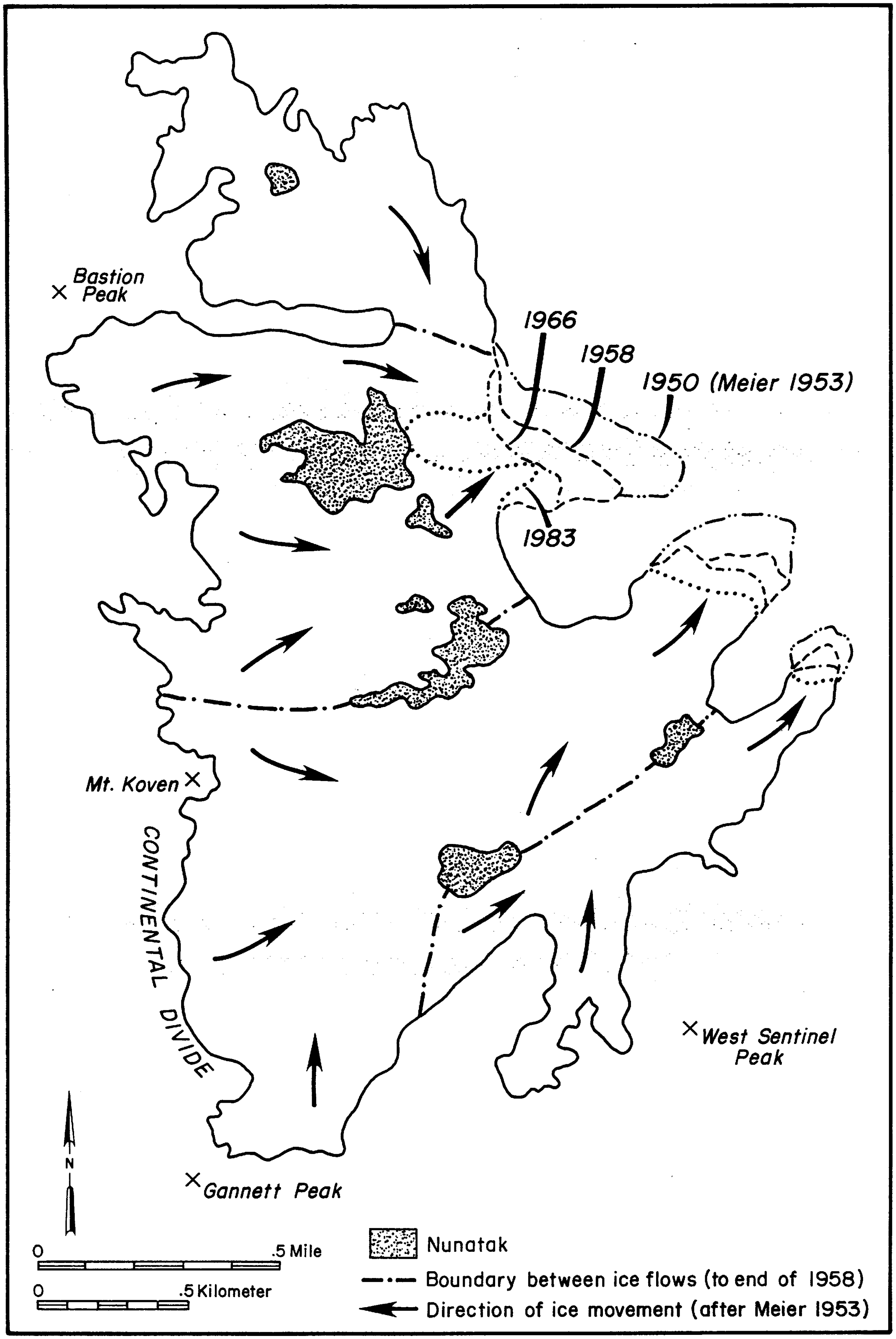

Figure 2. Planview Map of Gannett Glacier.

The upper margin of the glacier is steep and gradually transforms into an irregular, gently rolling plateau characterized by many large crevasses. Below this plateau, several rock nunataks channel the flow into independent lobes. The surface of Gannett Glacier is relatively clear of debris, except for its medial moraines.

Dinwoody Glacier is the fourth largest of the Wind River Range glaciers with an area in 1950 of 1.34 square miles (Fig. 3). It has a palmate shape with steep tributary fingers of ice feeding into a large, gently-sloping central basin from which a small tongue reaches only a small distance. The tributary glaciers are clean and crevassed in contrast to the central basin which is littered with much coarse debris and uncrevassed. Medial moraines on the ice surface extend along either side and below the snout of Dinwoody Glacier to form morainal ridges. An extensive moraine dating back to the maximum advance of the glacier during the Little Ice Age surrounds the terminus.

Gannett and Dinwoody glaciers contribute meltwater to the Wind River drainage via Dinwoody Creek. Actually, the flow from Gannett Glacier originates in Gannett Creek directly below the glacier. Gannett Creek joins Dinwoody Creek approximately 1 mile below Gannett Glacier. This confluence is approximately 1.5 miles below Dinwoody Glacier.

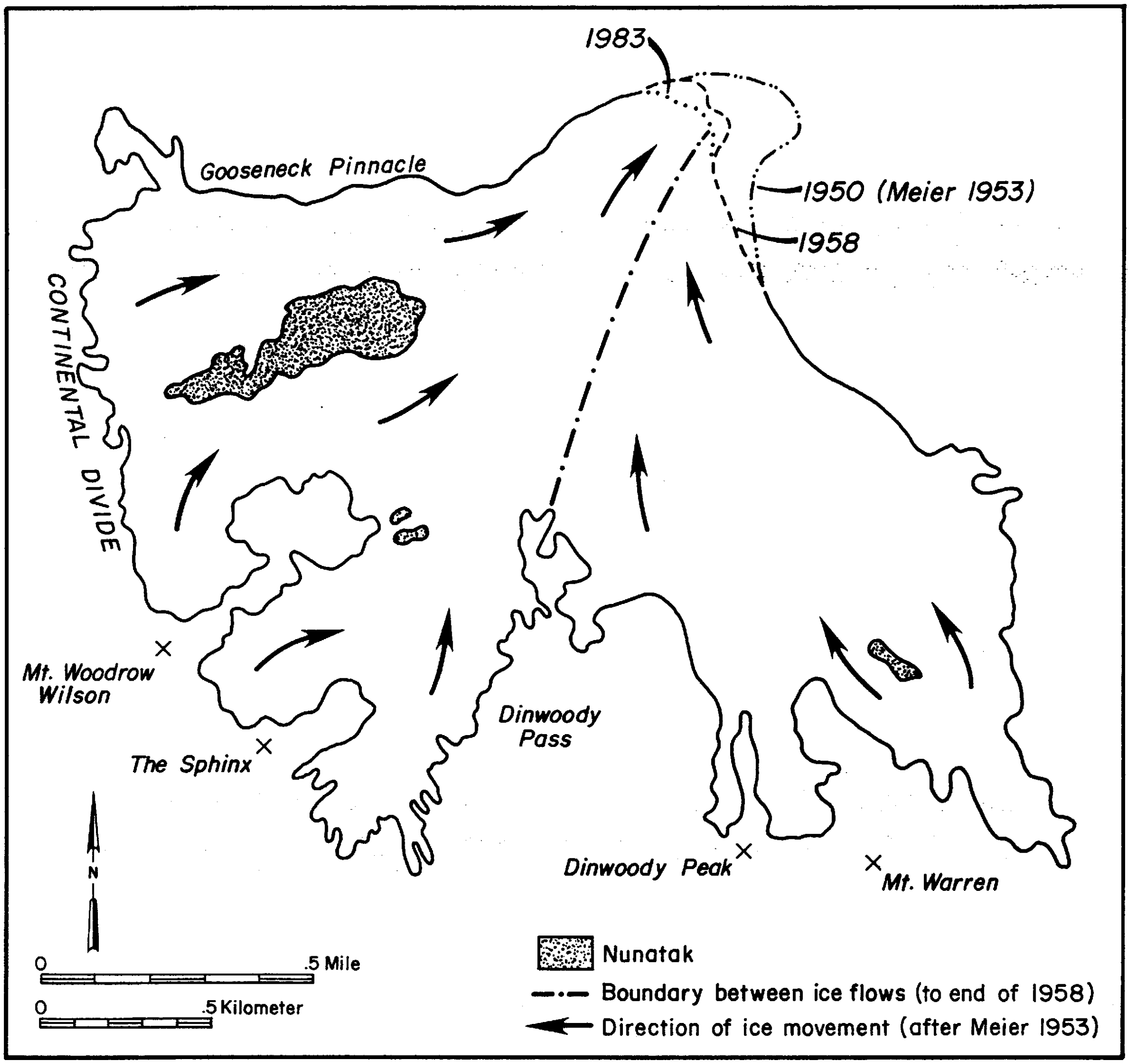

Figure 3. Planview Map of Dinwoody Glacier.

CHAPTER 2

SNOW DEPTHS AND WATER EQUIVALENTS

The first objective of this study was to analyze temporal trends in snow depth and/or water equivalents for stations in the Wind River Range. Accomplishment of this objective required identification of the stations to be considered and then analyses of available data. Since the glaciers being studied herein were on the east slope of the Wind River Range, only east slope stations were considered. The main temporal patterns identified were that both annual snow depths and water equivalents were cyclic in nature. Comparison to tree ring data indicates that these patterns were also occurring over the 1562 through 1965 period.

Snow Depth and Snow Water Equivalent Data

Snow depth and snow water equivalent data for all east slope stations (Fig. 4) of the Wind River Range were acquired from the Water Resources Data System at the Wyoming Water Research Center. The snow depth and snow water equivalent data consist of monthly measurements for each of the months February through May and are given in the Appendix. The dates of measurement vary somewhat between stations, months, and/or years. No adjustments for the variation of the measurement dates have been attempted for these analyses.

The length of records which were available for each station are listed in Table 1 along with the station ID codes, elevations, latitudes, and longitudes. Two groups of stations are listed, with the first group being the stations selected for use in the analyses. Generally, stations in this group have the longer records.

The snow recording stations nearest Dinwoody and Gannett glaciers are Dinwoody and Cold Springs. Unfortunately, Cold Springs has a very short period of record and, thus, was not used in the analyses. The Dinwoody station is also nearest to Dinwoody Creek and was selected for use in analyses of the relationship between Dinwoody Creek streamflow versus snow depth and water equivalent. Stations north of Dinwoody and Gannett glaciers include Big Warm Springs, Burroughs Creek, DuNoir, Geyser Creek, Little Warm, and Sheridan Ranger Station while stations south of Dinwoody and Gannett glaciers include Blue Ridge, Hobbs Park, Middle Fork, and St. Lawrence Ranger Station.

Regressions were performed for the Dinwoody station and all other stations considered for this analysis to compare snow depth and snow water equivalent records at these stations with those at the Dinwoody station (Table 2). Comparisons were made only for

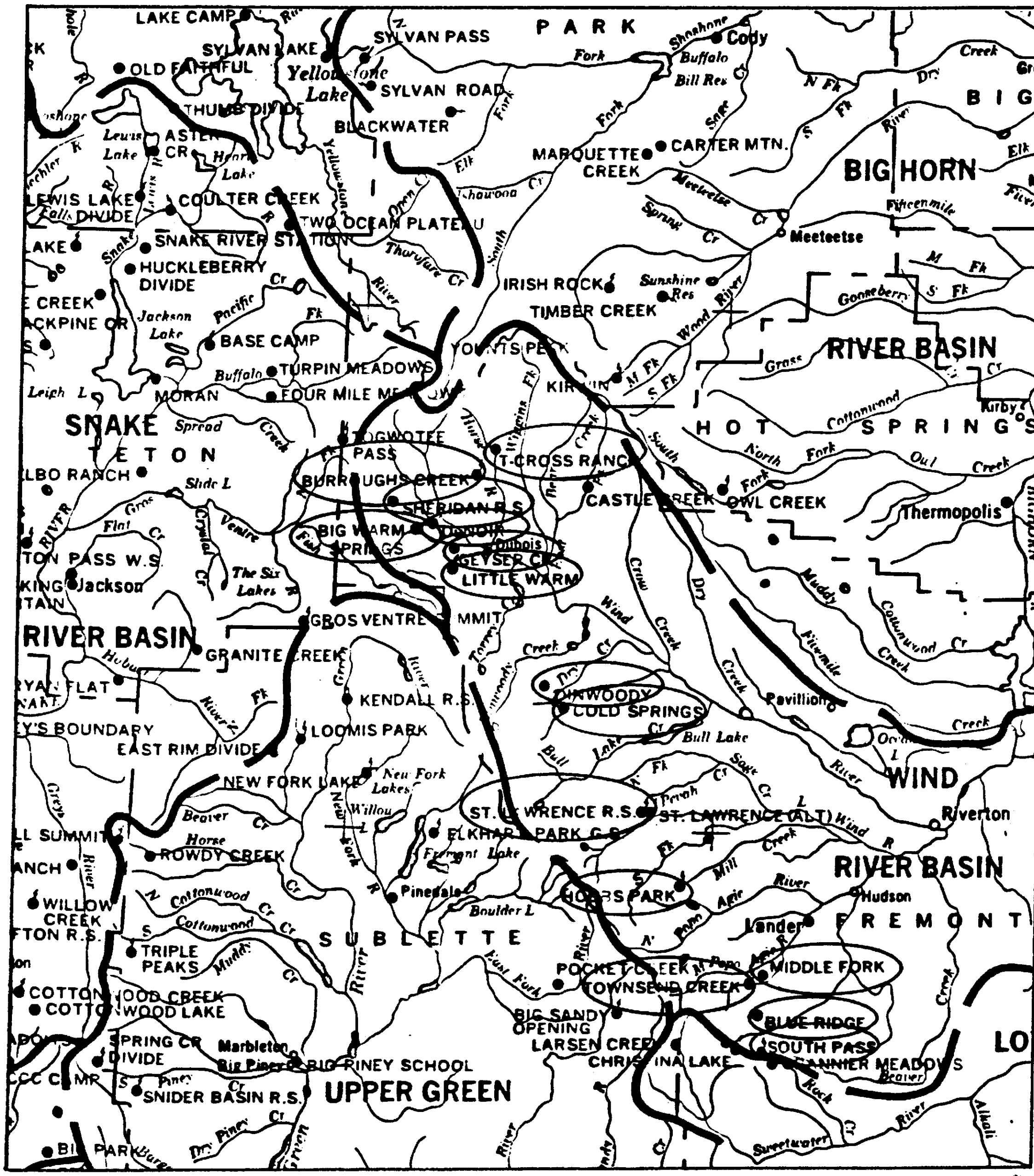

Figure 4. Snow Depth and Water Equivalent Stations.

TABLE 1. SNOW DEPTH AND WATER EQUIVALENT STATIONS (EAST SLOPE)*

Station	ID	Elev ft	Lat Deg	Lat Min	Long Deg	Long Min	Length of Record
Blue Ridge	08G02	9620	42	39	108	52	1940-87
Burroughs Creek	09F04S	8750	43	42	109	40	1949-87
Dinwoody	09F10	10140	43	17	109	26	1949-87
DuNoir	09F06	8760	43	34	109	48	1941-87
Geyser Creek	09F07	8500	43	32	109	45	1949-87
Hobbs Park	09G03S	10100	42	52	109	06	1949-87
Little Warm	09F08S	9370	43	30	109	45	1949-87
Sheridan R.S.	09F25	7790	43	38	109	55	1936-86
St Lawrence R.S.	09F27S	8620	43	02	109	10	1941-87
T-Cross Ranch	09F03	7900	43	43	109	38	1941-87
Big Warm Springs	09F12	8370	43	34	109	51	1955-87
Cold Springs	09F25S	9630	43	16	109	26	1956-77
Dinwoody Glaciers	09F17	10500	43	14	109	34	1959-77
Dry Creek	09F09	9620	43	12	109	26	1949-72
Middle Fork	08G06	7420	42	44	108	51	1968-87
South Pass	08G03S	9040	42	34	109	51	1940-87
Townsend Creek	08G07S	8700	42	42	108	54	1975-87

*Data consist of monthly measurements for February through May.

TABLE 2. DINWOODY VS OTHER STATIONS' SNOW DEPTH AND WATER EQUIV

STATION	COEFFICIENTS OF DETERMINATION							
	SNOW DEPTH				WATER EQUIVALENT			
	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
Blue Ridge	.470	.342	.110	.412	.440	.352	.234	.414
Burroughs Crk	.620	.795	.721	.670	.622	.748	.759	.762
Dinwoody	-	-	-	-	-	-	-	-
DuNoir	.778	.793	.699	.794	.789	.811	.822	.699
Geyser Crk	.722	.609	.637	.669	.736	.652	.804	.594
Hobbs Park	.672	.732	.538	.660	.692	.712	.678	.650
Little Warm	.782	.837	.682	.796	.786	.879	.831	.868
Sheridan R.S.	.543	.628	.391	.418	.585	.634	.609	.384
St Lawrence	.523	.505	.350	.576	.513	.481	.369	.447
T-Cross Ranch	.580	.655	.531	.466	.492	.610	.610	.527

Note: Regressions are for the years 1949 through 1986.

those stations with records extending from 1949 through 1986 (the year 1987 was not included since the Sheridan Ranger Station site was moved in 1987). Except for Hobbs Park, the stations comparing most closely with the Dinwoody records were all located north of the Dinwoody station. These include Burroughs Creek, DuNoir, Geyser Creek, Hobbs Park, and Little Warm, with the latter giving the best comparison of any of the stations. Thus, much of the analyses of temporal trends in snow depth and water equivalent were performed using data from the Dinwoody station and the other five listed stations.

Temporal Trends in Snow Depth and Snow Water Equivalent

Data from six stations--Burroughs Creek, Dinwoody, DuNoir, Geyser Creek, Hobbs Park, and Little Warm--were used for investigating temporal trends in snow depth and snow water equivalent. The Dinwoody station was selected since it was the station closest to Dinwoody and Gannett glaciers. The other five stations were included because the data from these stations were correlated fairly high with that from the Dinwoody station.

Averages over the six stations of the snow depth and snow water equivalent data were calculated for each month for the years 1949 through 1987 (Table 3). Inspection of the table indicates a cyclic pattern in years of high and low snow depths and water equivalents. This indicates some year to year resistance of snowfall patterns.

The cyclic nature of the snowfall data is better depicted when moving means are calculated to smooth the data and these means are given as deviations from the long-term averages (Table 4 and Fig. 5). Although snow depth and water equivalent data were available for 1949 through 1987 the long-term averages were calculated using the 1958 through 1986 data, which was the same period for which streamflow data were available. All deviations from the long-term averages are given as percentages.

Monthly temperature data were acquired for Dubois and Lander for the years 1949 through 1985 to determine if a cycle similar to that which existed in the snowfall data might occur in another climatic parameter. Summer temperatures are considered more important to glacier volume changes than are winter temperatures. Thus, the temperatures considered were for the months of May through October. Five-year moving means were calculated for the May through October averages and deviations (in degrees F) from the long-term, 1958-85, May through October averages were determined for both locations (Table 5 and Fig. 5). Summer temperatures were generally above average following winters having low snowfall and below average following winters having high snowfall.

TABLE 3. AVERAGES OF SNOW DEPTHS AND WATER EQUIVALENTS

YEAR	SNOW DEPTH (INCHES) FEB	MAR	APR	MAY	WATER EQUIVALENTS (INCHES) FEB	MAR	APR	MAY
1949	36.8	45.4	53.8	31.8	8.9	13.2	15.7	11.4
1950	51.5	49.0	56.7	50.3	13.8	15.6	18.6	17.7
1951	42.7	51.2	56.8	52.7	12.2	16.6	16.1	16.2
1952	34.8	41.3	45.3	32.3	8.9	11.0	13.1	11.0
1953	31.7	36.0	35.5	34.0	7.5	11.2	11.9	11.6
1954	37.7	37.7	54.2	40.5	8.2	10.8	15.0	15.1
1955	16.8	24.7	38.3	36.2	3.2	5.9	10.6	11.5
1956	47.2	50.5	53.8	58.3	13.5	14.9	17.9	20.4
1957	29.5	33.5	41.0	53.8	6.8	8.3	11.4	16.5
1958	25.2	28.0	34.3	39.8	5.1	6.5	8.3	10.2
1959	29.5	40.0	44.2	37.8	6.8	10.1	11.5	12.1
1960	24.3	30.3	30.8	25.2	5.1	7.0	8.2	7.5
1961	19.7	29.3	36.2	34.3	4.6	6.1	8.3	9.2
1962	39.8	49.5	52.2	39.5	10.4	13.2	15.0	12.5
1963	24.2	32.7	36.2	44.2	4.9	9.2	10.7	13.5
1964	26.8	31.5	42.2	42.3	5.7	7.3	9.9	11.8
1965	42.5	48.2	58.0	54.7	12.0	15.2	17.9	18.8
1966	23.8	26.0	27.8	27.3	5.6	6.2	7.3	7.6
1967	36.0	40.7	46.0	52.0	8.9	11.2	13.2	15.6
1968	29.3	32.7	34.5	34.2	6.7	8.1	9.6	10.2
1969	34.8	41.5	37.5	25.0	8.5	9.8	10.8	9.0
1970	34.5	29.3	42.8	51.3	7.2	8.5	11.1	15.4
1971	47.0	51.3	61.7	61.3	14.3	15.9	19.8	23.9
1972	52.2	61.8	53.3	56.7	13.8	18.1	18.7	21.3
1973	26.7	27.8	36.5	38.7	5.9	6.6	7.7	9.8
1974	34.7	39.0	53.2	49.3	8.7	10.6	15.2	17.0
1975	33.3	36.5	48.8	50.7	7.9	9.9	12.4	16.4
1976	33.8	45.2	53.5	43.5	9.9	12.0	16.1	15.0
1977	10.3	10.2	26.0	12.2	1.9	2.0	5.0	3.2
1978	37.7	43.2	40.3	38.7	11.2	13.0	13.7	12.4
1979	37.5	39.8	41.2	34.0	9.6	11.0	11.1	10.3
1980	32.8	33.2	49.2	30.3	7.7	9.4	12.2	10.8
1981	23.8	25.0	38.0	22.8	5.1	6.4	8.6	7.0
1982	41.2	41.7	48.0	44.2	10.0	10.7	13.8	14.9
1983	25.0	30.8	40.0	46.2	6.0	7.9	9.3	13.4
1984	31.2	35.0	39.8	48.7	7.5	8.4	9.9	12.5
1985	25.8	35.7	38.7	25.3	5.7	7.2	8.8	7.6
1986	34.2	64.7	54.0	52.3	9.1	16.7	17.3	18.1
1987	35.2	41.8	45.3	28.0	9.0	10.5	12.4	9.4

Note: The data used for the averages are for the stations of Burroughs Creek, Dinwoody, DuNoir, Geyser Creek, Hobbs Park, and Little Warm.

TABLE 4. DEVIATIONS OF SNOW DEPTH & WATER EQUIVS FROM 58-86 AVGS

	SNOW DEPTH (%)				WATER EQUIVALENTS (%)			
YEAR	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
1951	24.8	19.6	15.6	0.4	31.8	38.0	33.2	12.0
1952	25.4	15.5	15.8	4.8	30.0	33.1	32.0	17.9
1953	3.5	2.5	7.2	-2.3	2.7	13.3	18.4	8.1
1954	6.3	2.1	5.8	0.5	6.1	9.8	16.4	10.0
1955	3.0	-2.1	3.8	11.3	0.7	4.3	13.5	18.7
1956	-1.1	-6.4	3.2	14.2	-5.5	-5.3	7.4	16.5
1957	-6.3	-5.2	-1.4	12.8	-9.1	-6.7	1.4	11.7
1958	-1.6	-2.2	-4.9	7.3	-4.2	-4.5	-2.7	5.4
1959	-19.0	-13.5	-13.1	-4.7	-27.1	-22.4	-19.0	-12.3
1960	-12.5	-4.9	-7.9	-11.8	-17.8	-12.4	-12.8	-18.6
1961	-13.1	-2.4	-7.0	-9.6	-18.3	-6.9	-8.8	-13.4
1962	-14.8	-7.0	-7.9	-7.4	-21.1	-12.7	-11.5	-13.9
1963	-3.3	2.6	4.7	7.4	-3.4	4.1	5.0	4.0
1964	-0.7	0.9	0.8	3.9	-0.9	4.3	3.3	1.5
1965	-3.1	-3.9	-2.1	10.1	-4.7	0.2	0.2	6.4
1966	0.1	-3.9	-2.9	5.1	-0.1	-2.0	-1.6	1.1
1967	5.2	1.5	-5.0	-3.5	7.1	3.1	-0.1	-3.3
1968	0.1	-8.6	-12.1	-5.2	-5.2	-10.6	-11.7	-8.7
1969	14.8	4.9	3.7	11.3	17.1	9.2	9.6	17.1
1970	25.0	16.3	7.1	13.6	29.7	23.3	18.9	26.1
1971	23.4	13.6	8.0	15.9	27.7	20.2	15.7	25.5
1972	23.3	12.3	15.3	28.0	28.2	21.8	23.2	38.1
1973	22.6	16.2	18.1	27.7	30.0	24.7	25.4	39.7
1974	14.2	12.9	14.3	19.3	18.7	16.7	19.1	25.6
1975	-12.3	-14.8	1.6	-2.9	-11.9	-16.1	-4.2	-3.0
1976	-5.3	-6.6	3.3	-2.9	1.7	-3.1	6.0	1.1
1977	-3.5	-6.1	-2.3	-10.6	4.0	-2.2	-1.0	-9.4
1978	-3.9	-7.9	-2.1	-20.8	3.5	-3.3	-1.3	-18.3
1979	-10.2	-18.7	-9.3	-31.1	-8.8	-14.7	-14.0	-30.9
1980	9.4	-1.8	1.0	-15.1	12.0	3.1	0.9	-12.4
1981	1.3	-8.5	0.8	-11.4	-1.4	-7.3	-6.6	-10.9
1982	-2.7	-11.1	0.2	-4.0	-6.8	-12.7	-8.6	-7.4
1983	-7.1	-9.7	-4.7	-6.5	-11.9	-17.1	-14.4	-12.4
1984	-0.5	11.6	2.7	8.2	-1.6	3.9	0.4	5.1
1985	-4.3	11.6	1.5	0.1	-4.2	3.5	-2.0	-3.6
Avgs*	31.6	37.3	42.9	40.1	7.8	9.8	11.8	12.7

Notes: The yearly values are based on 5-year moving means.

The data used for the averages are for the stations of Burroughs Creek, Dinwoody, DuNoir, Geyser Creek, Hobbs Park, and Little Warm.

*Averages are for the period 1958-86 and are in inches.

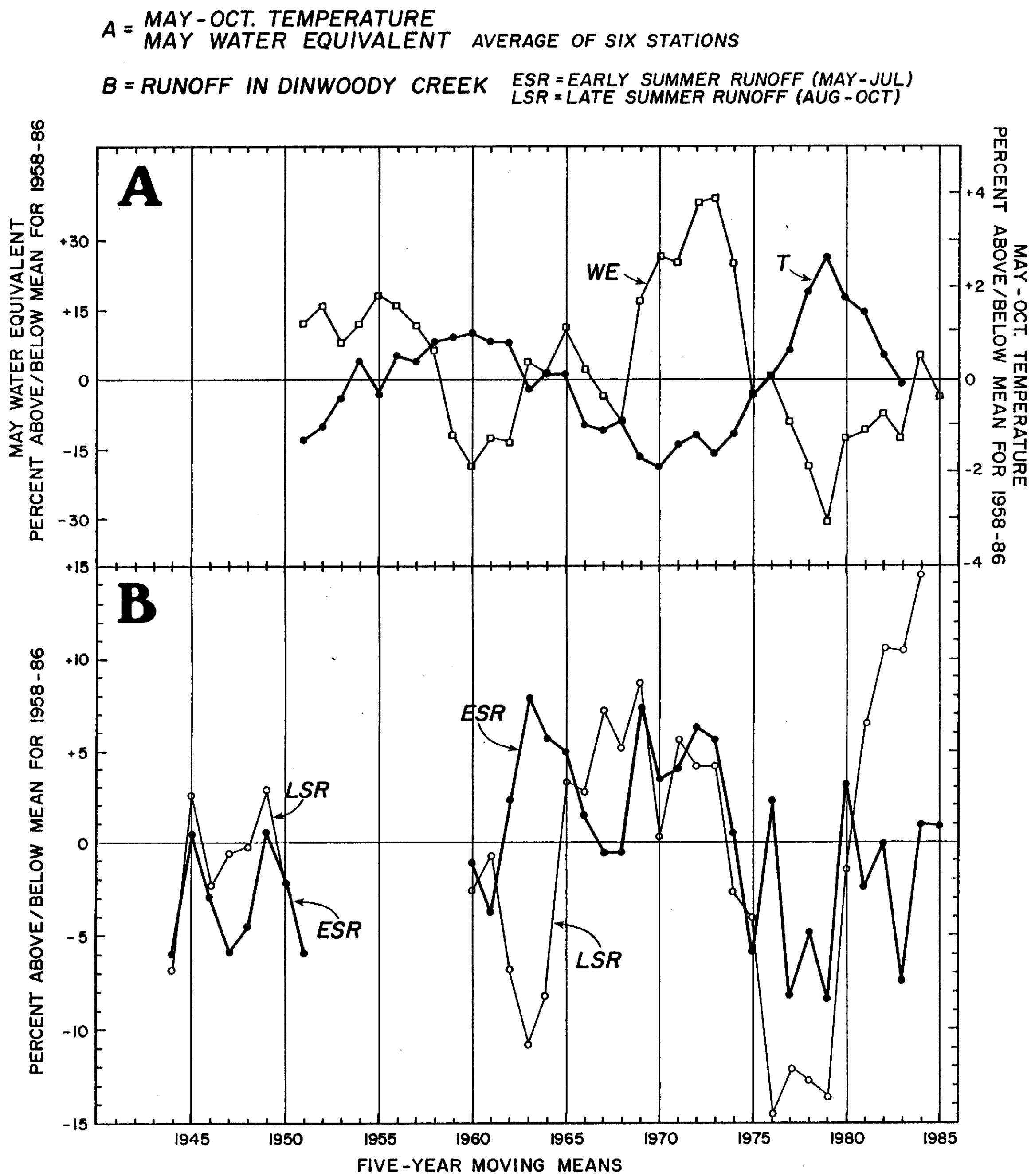

Figure 5. Trends in Temperature, Snow Water Equivalent, and Runoff.

TABLE 5. MEAN MAY-OCT TEMPERATURES AND DEVIATIONS FROM 58-85 AVGS

	DUBOIS		LANDER	
YEAR	MAY-OCT MOVING MEANS (F)	DEVIATION FROM 1958-85 AVG (F)	MAY-OCT MOVING MEANS (F)	DEVIATION FROM 1958-85 AVG (F)
1951	50.13	-0.69	56.90	-0.84
1952	53.19	-0.54	61.38	-0.43
1953	51.46	-0.22	60.76	0.40
1954	52.10	0.20	60.84	1.35
1955	51.66	-0.15	61.36	0.87
1956	52.24	0.27	61.67	0.90
1957	51.44	0.19	58.97	0.64
1958	53.55	0.41	60.90	0.64
1959	51.71	0.45	59.53	0.19
1960	52.78	0.50	61.39	0.46
1961	52.41	0.40	59.38	0.79
1962	51.71	0.41	60.36	0.87
1963	53.06	-0.09	62.54	0.15
1964	51.74	0.04	59.90	0.46
1965	50.26	0.04	57.81	0.20
1966	53.10	-0.50	60.93	-0.66
1967	51.69	-0.58	59.04	-0.65
1968	50.36	-0.44	58.24	-0.36
1969	51.34	-0.86	59.98	-0.88
1970	50.95	-0.99	59.25	-0.99
1971	50.99	-0.73	58.34	-0.77
1972	51.07	-0.63	58.47	-0.78
1973	51.65	-0.84	59.37	-1.00
1974	51.82	-0.64	59.90	-0.75
1975	49.91	-0.16	58.17	-0.28
1976	52.02	-0.02	59.60	-0.32
1977	53.44	0.32	60.82	-0.13
1978	52.38	0.98	59.17	0.30
1979	53.50	1.35	60.82	0.51
1980	53.21	0.90	60.32	0.22
1981	53.90	0.84	60.66	0.52
1982	51.44	0.26	59.38	0.39
1983	52.10	-0.05	60.64	0.45
Avgs*	51.93		59.85	

Notes: The yearly values are based on 5-year moving means.

The data used for the averages are for the stations of Burroughs Creek, Dinwoody, DuNoir, Geyser Creek, Hobbs Park, and Little Warm.

*Averages are for the period 1958-85.

Tree Ring Comparisons

Two studies of tree rings in the Wind River Range have been reported by Drew (1975). Both sites were located on Fremont Lake and the samples were collected by M. A. Stokes and T. P. Harlan. Samples from limber pine (Pinus flexilis) were acquired at Site A at an elevation of 7600 feet, with tree ring indices calculated from 1682 to 1965. Samples from Douglas fir (Psuedotsuga menziesii) were acquired at Site B at an elevation of 7500 feet, with tree ring indices calculated from 1562 to 1965 (Fig. 6). Fluctuations in the standardized tree ring index reveal times of favorable and unfavorable climates for growth. In this century, especially favorable times were evident from 1903-1918, 1925--1931, and 1942-1954. This latter period correlates with higher than average values in the May water equivalent of snow (Fig. 5). In addition, it has been noted that Dinwoody and Gannett Glaciers had readvanced by 1930 to their positions at the end of the Little Ice Age (Denton, 1975). Meier (1953) described the glaciers as slowing their retreat and entering a brief phase of positive mass balance between 1945-1950. Thus, an argument can be made for more extensive work linking glacier trends to tree ring indices at lower elevations.

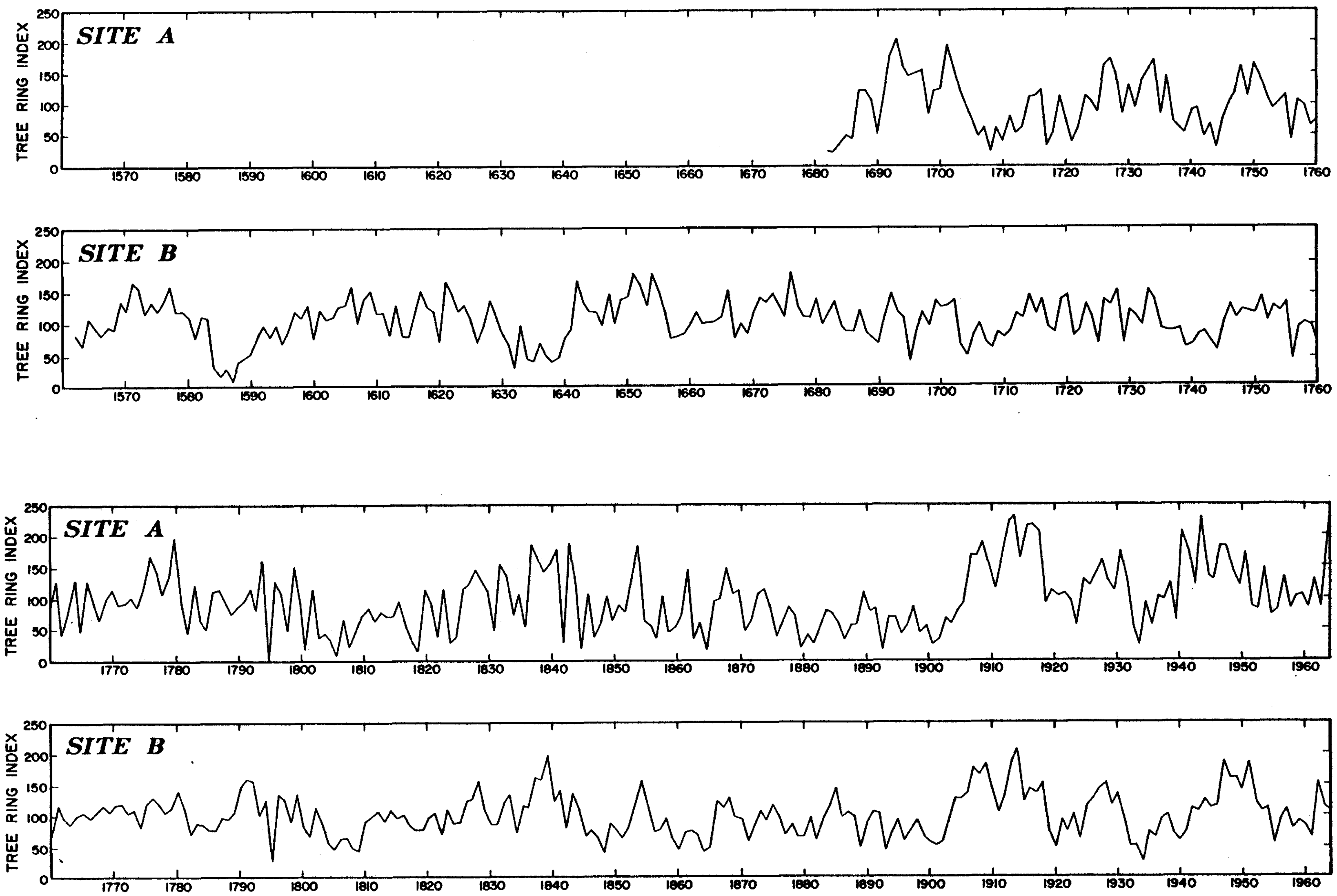

Figure 6. Tree Ring Indices for Two Sites in the Wind River Range.

CHAPTER 3

RUNOFF VS SNOW DEPTH AND SNOW WATER EQUIVALENT

The second objective of this study was to analyze temporal trends in runoff from existing streamflow gaging stations affected by glacier runoff and snowmelt from the Wind River Range. The intent of this objective was to determine the relationships between the amounts and seasonal distribution of summer runoff versus the amount of winter snowfall received in the Wind River Range, especially that portion of the Range in the immediate vicinity of Dinwoody and Gannett glaciers. A search of existing streamflow data revealed that the only gaging station affected by Dinwoody and Gannett glaciers was the one on Dinwoody Creek above the lakes near Burris, Wyoming.

Snow depth and snow water equivalent data for the Dinwoody station and runoff data for the Dinwoody Creek are given in the Appendix. Dinwoody Creek streamgage data are limited to the period 1958 through 1977. Monthly flow data are available for all twelve months of the year, but only the months May through October, which are the six highest flow months, were considered for this analysis. Monthly snow depth and water equivalent measurements are available for the four months February through May.

Linear regressions were performed with streamflow as the dependent variable and either snow depth or snow water equivalent as the independent variable (Tables 6 and 7). Regressions were performed for monthly streamflow, total early summer season runoff (May through July), total late summer season runoff (August through October), and total summer runoff (May through October) versus various combinations of snow depth and water equivalent including May data, April data, April through May averages, March through May averages, and February through May averages. It was assumed that late spring (May and/or April) snow depth and water equivalent measurements would best reflect the availability of water for the summer runoff period. Therefore, regressions were not performed for runoff versus the February and March snow data as done for the April and May snow data.

Regression results clearly indicate that the only correlation which exists between streamflow and winter snowfall is for the June runoff. Except for June runoff, the coefficients of determination for regressions of runoff versus snow depth or water equivalent are extremely low. Regressions using runoff periods longer than a month show a correlation between runoff and snow data only when the period includes the June runoff.

Correlations between June runoff and snow depths were slightly higher than those between June runoff and snow water equivalents. Thus, it appears that snow depth data are better predictors of runoff than are water equivalent data.

TABLE 6. DINWOODY CREEK FLOW VS DINWOODY STATION SNOW DEPTH

DEPENDENT VARIABLE (STREAMFLOW)	INDEPENDENT VARIABLE (SNOW DEPTH)	INTERCEPT	SLOPE	COEFFICIENT OF DETERMINATION
May	May	7704	412	.000
Jun	May	11108	338	.541
Jul	May	22725	156	.084
Aug	May	17169	60	.072
Sep	May	8841	-19	.000
Oct	May	1975	13	.011
May	Apr	9028	15	.000
Jun	Apr	4250	510	.573
Jul	Apr	17832	273	.142
Aug	Apr	18959	25	.000
Sep	Apr	11834	-85	.085
Oct	Apr	2381	5	.000
May-Jul	May	41537	536	.569
Aug-Oct	May	27986	54	.000
May-Oct	May	69523	589	.598
May-Jul	Apr	31110	798	.588
Aug-Oct	Apr	33173	-55	.000
May-Oct	Apr	64284	743	.426
May-Jul	Apr-May	35002	690	.626
Aug-Oct	Apr-May	29606	22	.000
May-Oct	Apr-May	64608	712	.569
May-Jul	Mar-May	38416	666	.565
Aug-Oct	Mar-May	29971	15	.000
May-Oct	Mar-May	68386	681	.504
May-Jul	Feb-May	40082	676	.525
Aug-Oct	Feb-May	29894	18	.000
May-Oct	Feb-May	69976	694	.472

Notes: Streamflow is the total, in acre-ft, for the period.

Snow depth is either the average, in inches, for the period or a single measurement for the individual months.

TABLE 7. DINWOODY CREEK FLOW VS DINWOODY STATION WATER EQUIVALENT

DEPENDENT VARIABLE (STREAMFLOW)	INDEPENDENT VARIABLE (WATER EQUIV)	INTERCEPT	SLOPE	COEFFICIENT OF DETERMINATION
MAY	MAY	8929	58	.000
JUN	MAY	14021	986	.490
JUL	MAY	23406	504	.100
AUG	MAY	18505	117	.000
SEP	MAY	9659	-126	.016
OCT	MAY	2240	25	.000
MAY-JUL	MAY	46355	1548	.506
AUG-OCT	MAY	30405	16	.000
MAY-OCT	MAY	76760	1564	.439
MAY-JUL	APR	46253	1819	.494
AUG-OCT	APR	31187	-47	.000
MAY-OCT	APR	77440	1772	.394

Notes: Streamflow is the total, in acre-ft, for the period.

Water equivalent is a single measurement, in inches, for the month.

CHAPTER 4

TRENDS IN GLACIER REGIMES

Aerial photos were used to study the trends in Dinwoody and Gannett glaciers over the last few decades. Aerial photographs were used to mark the position of the termini of Dinwoody and Gannett glaciers, to map and measure the surface area of each glacier, and to make snow/ice depth change calculations of selected areas of the glaciers.

Planview Mapping

Aerial photographs of the study area spanning four decades were obtained from the Shoshone National Forest Ranger Station in Dubois, Wyoming (1958, 1980); the EROS Data Center in Sioux Falls, South Dakota (1966); and the University of Wyoming Geology Library (1983). These photos help document Gannett and Dinwoody glaciers during recent time and may provide clues to the difference in response of the two glaciers.

Mapping of the termini and surface area were accomplished using a zoom transfer scope. Aerial photographs, both transparencies and prints, were enlarged to match the scale of a 1:24,000 topographic map of the study area. The boundaries of the two glaciers were then traced for each time period and overlaid to show the extent of glacier change over several decades.

The outlines of the glaciers were then digitized using a Tektronix computer and their area calculated with polygon and area programs. These programs allowed the entire glacier surface area minus any rock outcrops (nunataks) to be computed.

An area-elevation curve for each glacier was also constructed from the 1966 surface area data (Fig. 7). These data were chosen since the most current topographic map of the area was also published in 1966. By drawing contour lines on the outlines, the area between each 200-foot contour interval was calculated using the polygon and area programs. The cumulative surface area versus elevation was then plotted to construct the curve.

There are inherent errors in this process. Accuracy of the computed area depends on the skill of the operator/mapper to correctly interpret the boundaries of the glacier using the zoom transfer scope. Surface debris from high cirque walls and medial moraines often prohibit exact delineation of the glacier boundary. Another mistake could occur during the digitizing phase where precise movements are necessary for accurate input to the computer. Again, the accuracy of the final product depends on the expertise of the digitizer.

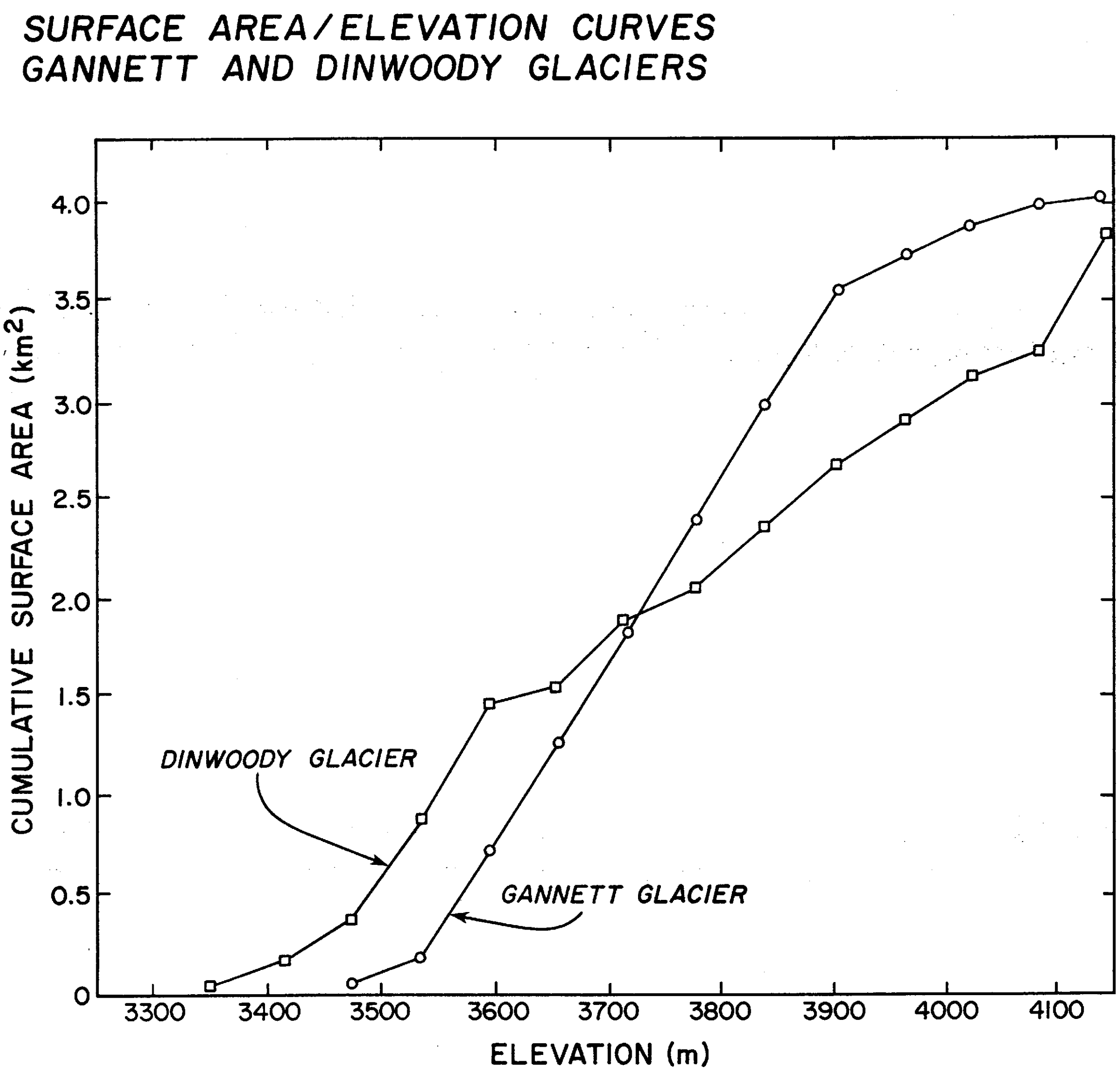

Figure 7. Area-Elevation Curves for Gannett and Dinwoody Glaciers.

In many instances, the limits of glacier ice were difficult to determine. The terminus of Dinwoody Glacier, in particular, was very difficult to map because of talus and debris on the margins and surface of the glacier. The terminus of Dinwoody Glacier was determined by comparing several different aerial photos of comparable dates and from field reconnaissance during the Summer of 1988.

The boundaries of Gannett and Dinwoody glaciers were drawn with reference to Meier (1951). He did not include Grasshopper Glacier when describing and mapping Dinwoody Glacier since the two separated in the 1930s. Likewise, Dinwoody Glacier was mapped herein minus Grasshopper Glacier so that surface area measurements could be meaningfully compared to those obtained by Meier.

The composite maps for Gannett and Dinwoody glaciers are shown in Figures 2 and 3. Quantitative data for the four-decade time span is presented in Table 8.

Surface area totals obtained from digitizing the planview maps of 1958, 1966, and 1983 (Figs. 8 and 9) are shown in Table 9. Meier's 1950 data are listed for comparison. The percent reduction for the 33-year period is 1.5 percent for Dinwoody Glacier and 13.6 percent for Gannett Glacier.

Volume Measurements

Snow/ice depth measurements were made for each glacier using a stereo zoom transfer scope fitted with a vertical measurement module (ZTS/VM) to analyze stereopairs of the aerial photographs. The ZTS/VM computes elevation or relative height of selected points on matched stereopairs. Preliminary information such as focal length, baseline distance, and units of measure, as well as calibration procedures (relative orienteering, leveling, scaling), must be input manually into the ZTS/VM computer. After initial setup, the scope will continually read out elevations of points selected on the aerial photo, provided the points are identifiable by the computer.

Unidentifiable points include bright white snow which often covers a large percentage of a glacier depending on the time of year. The high reflectance of "clean" glacier snow and ice prohibits accurate readings and restricts the sample size. The most accurate readings are taken near the end of the ablation season from areas with some debris or "dirty" snow and ice. Availability of suitable stereopairs can severely limit the sample size.

An additional limitation to this method is the quality of the aerial photographs. While the scale of the photo is irrelevant

TABLE 8. TERMINI RETREAT OF DINWOODY AND GANNETT GLACIERS

Glacier	Time Span 1950-58	1958-66	1958-83	1966-83	1950-83
Gannett					
upper lobe	81.6*	81.6		15.1	47.4
middle lobe	32.6	24.3		10.2	19.1
lower lobe	11.8	24.3		7.6	12.5
Dinwoody	56.3		5.3		17.8

*Table values are termini retreat in feet per year.

TABLE 9. TOTAL SURFACE AREA OF DINWOODY AND GANNETT GLACIERS

Glacier	Year 1950	1958	1966	1983
Gannett	1.77*	1.60	1.57	1.53
Dinwoody	1.34	1.33	N/A	1.32

*Surface areas are in square miles.

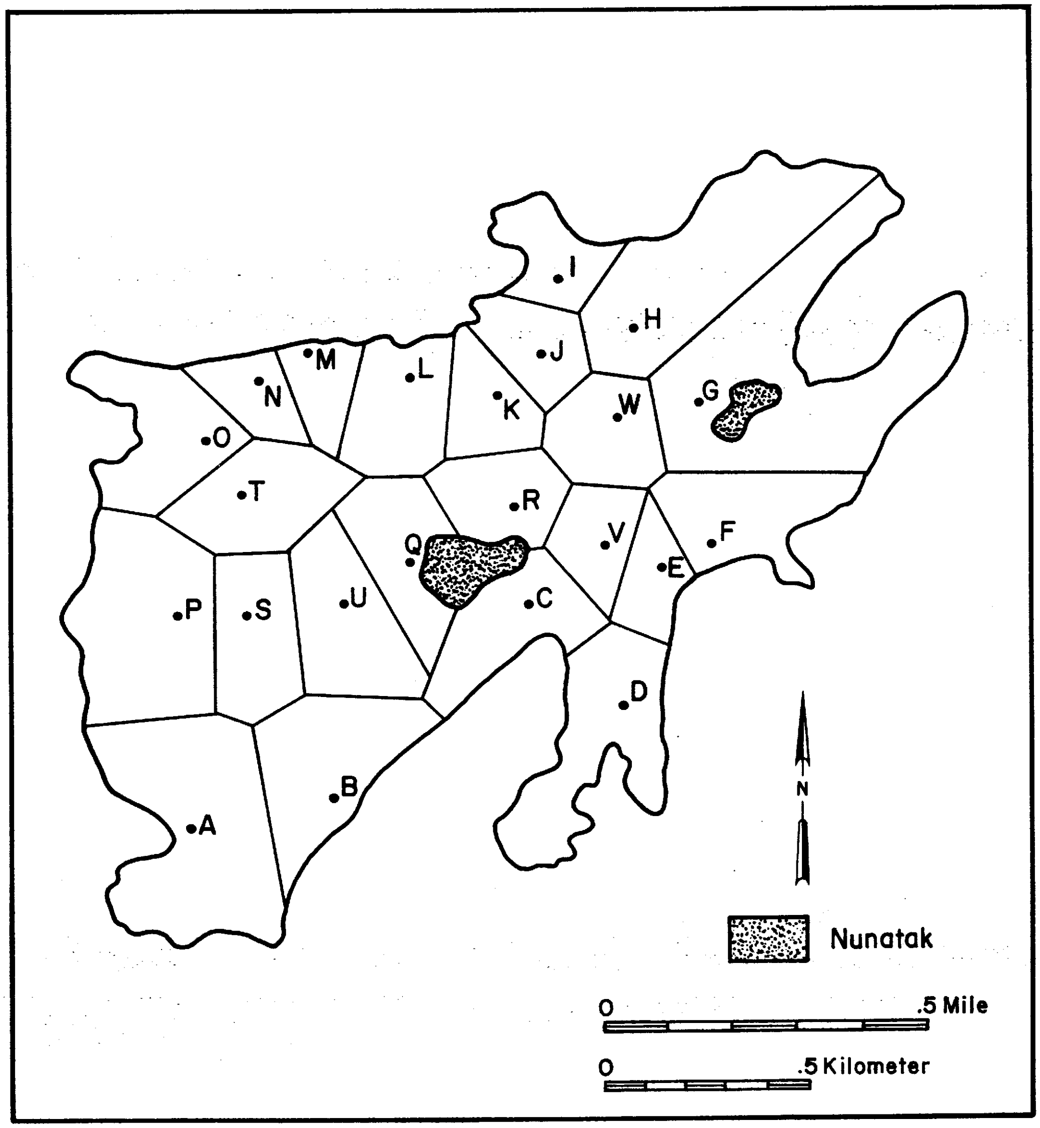

Figure 8. Gannett Glacier Sample Area, Thiessen Method.

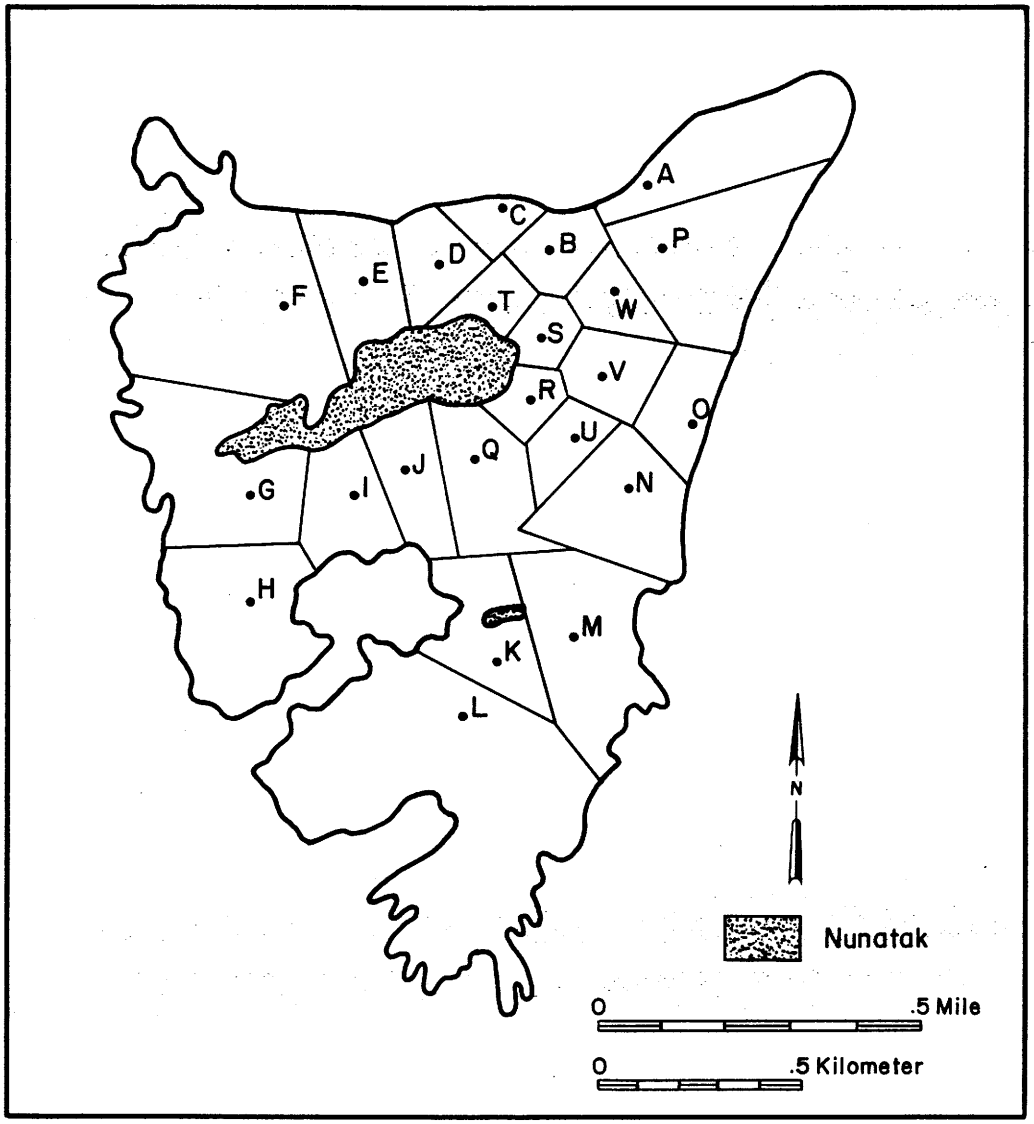

Figure 9. Dinwoody Glacier Sample Area, Thiessen Method.

the ZTS/VM, the vertical and horizontal distortion of some aerial photographs lead to inaccurate calibration data and consequently, to faulty elevation computations.

Two sets of aerial photographs were measured with the ZTS/VM spanning 25 years. The sample points in the 1958 and 1983 stereopairs were limited due to the availability of readable snow and ice. From the 1958 pair, 36 points from both Gannett and Dinwoody glacier were measured, covering one-half and one-third of their respective areas.

The second set of photographs analyzed were from 1983. Due to the time of year the photos were taken, snow coverage was extensive and many sample points could not be remeasured. For Gannett Glacier, 28 points were successfully remeasured; for Dinwoody Glacier, 23 points were remeasured.

The change in height (ΔH) for each of the twice-measured points was calculated by subtracting the 1983 data from the 1958 data. The ΔH data were then plotted on a contour map of the glaciers and identified by elevation.

The resulting information was used in two ways. First, the Thiessen-weighted average method was used to construct polygons around the sample points. Because of the concentration of points to particular areas of each glacier, major ice flows were identified and used as boundaries for the effective areas (Figs. 2 and 3). Using a Tektronix computer, the area of each polygon was digitized and measured, then expressed as a percentage of the total sample area (Tables 10 and 11). Weighted average ΔH for the total area was computed by multiplying the observed ΔH at each point by its assigned percentage of area and totaling.

These results are usually more accurate than those obtained by simple arithmetic averaging. By providing a weighted factor for each point, the Thiessen method allows for strong gradients and nonuniform distribution of points. A limitation of this method is that it does not allow for orographic influences. It simply assumes linear variation of precipitation between points and assigns each segment of area to the nearest point (Linsley et al. 1975, Dunne and Leopold 1978). Figures 8 and 9 illustrate the total sample area, sample points, and Thiessen polygons used to calculate the Thiessen-weighted average for the ΔH of each glacier. Additional calculations are presented in Tables 10 and 11.

Next, regression analysis was applied to determine the significance of the relationship between change in snow/ice height (the dependent variable) and elevation (the independent variable). Regression analysis of elevation and observed ΔH produced the following regression equations:

TABLE 10. THIESSEN-WEIGHTED AVG CALCULATIONS, GANNETT GLACIER

Polygon	Elev. (ft.)	Observed ΔH (ft.)	Area (sq. mi.)	Percent total area	Weighted ΔH (ft.)
A	12,920	136.2	.074	9.0	12.26
B	12,760	22.9	.045	5.5	1.26
C	12,160	7.1	.030	3.7	.26
D	11,960	-41.7	.047	5.8	-2.42
E	11,900	5.1	.015	1.8	9.18
F	11,860	17.9	.034	4.2	.75
G	11,700	30.0	.100	12.3	3.69
H	11,680	35.7	.063	7.7	2.75
I	11,760	20.6	.018	2.2	.45
J	11,760	35.9	.019	2.3	.83
K	11,870	55.0	.021	2.6	1.43
L	12,010	71.6	.030	3.7	2.65
M	12,240	48.4	.013	1.6	.77
N	12,400	40.2	.014	1.7	.68
O	12,500	74.0	.030	4.3	3.18
P	12,560	62.8	.057	7.0	4.40
Q	12,360	52.7	.028	3.4	1.79
R	11,880	65.0	.026	3.2	2.08
S	12,560	127.6	.032	3.9	4.98
T	12,360	111.6	.034	4.2	4.69
U	12,500	56.9	.036	4.4	2.50
V	11,940	35.4	.019	2.3	.81
W	11,760	65.4	.026	3.2	2.09
Totals			.816	100.0	61.06

Note: The total of the weighted elevation changes is equivalent to the overall weighted average elevation change.

TABLE 11. THIESSEN-WEIGHTED AVG CALCULATIONS, DINWOODY GLACIER

Polygon	Elev. (ft.)	Observed ΔH (ft.)	Area (sq. mi.)	Percent total area	Weighted ΔH (ft.)
A	11,300	15.9	.039	5.3	.84
B	11,600	58.8	.014	1.9	1.12
C	11,740	49.2	.009	1.2	.59
D	11,880	147.6	.017	2.3	3.40
E	12,160	148.0	.025	3.4	5.03
F	12,520	22.0	.091	12.3	2.71
G	12,520	111.9	.050	6.8	7.61
H	12,740	74.5	.046	6.2	2.18
I	12,200	77.8	.021	2.8	2.18
J	12,020	69.5	.020	2.7	1.88
K	12,180	123.7	.027	3.6	4.45
L	12,280	97.1	.137	18.5	17.96
M	12,000	120.5	.047	6.4	7.71
N	11,640	103.7	.035	4.7	4.87
O	11,500	12.1	.017	2.3	.28
P	11,320	22.7	.048	6.5	1.48
Q	11,740	114.6	.029	3.9	4.47
R	11,640	49.7	.009	1.2	.60
S	11,600	89.6	.009	1.2	1.08
T	11,660	78.4	.010	1.4	1.10
U	11,620	130.0	.012	1.6	2.08
V	11,540	121.7	.015	2.0	2.43
W	11,480	41.9	.013	1.8	.75
Totals			.740	100.0	76.80

Note: The total of the weighted elevation changes is equivalent to the overall weighted average elevation change.

Gannett Glacier:

$$\Delta H = -633 + (0.0561)(\text{elevation})$$
$$r = 0.518$$
elevation range = 11,680 to 12,920 feet

Dinwoody Glacier:

$$\Delta H = -285 + (0.0309)(\text{elevation})$$
$$r = 0.292$$
elevation range = 11,300 to 12,740 feet

Water equivalents for the amount of snow/ice lost from 1950 to 1983 from each glacier were calculated with the following equation:

$$WE = (\text{total glacier area} \times \text{average } \Delta H) \times (\text{density of firn ice})$$

The total area used in the equation for Gannett Glacier was 1.53 square miles (3.97 square kilometers); for Dinwoody Glacier the area used was 1.32 square miles (3.43 square kilometers). The density of firn ice = 0.80 gm/cm3. The results are listed in Table 12.

Repeat Photography

Repeat photography is an excellent means to evaluate landscape change and is especially useful for documenting glacier trends (Rogers, et al. 1984). Analysis of matched pairs of photographs can yield qualitative data as well as quantitative measurements of glacier movements and changes in glacier thickness.

Harrison (1960) stressed the need for a periodic and systematic program of glacier observations to determine the behavior of as many glaciers as possible in the western United States. The observations would not only provide a record of the variations of the glaciers in this country but would also allow comparison of their behavior patterns with glaciers in other parts of the world. Repeat photography of glaciers is one way to make these observations.

The first step in repeat photography is finding the site of the previous photograph, sometimes difficult when the older photo lacks information. As Rogers et al. (1984) state, reoccupying the original camera site amounts to placing the lens at the position of the original lens and aiming it at the same point. In

TABLE 12. ICE VOLUME AND WATER EQUIVALENT LOST FROM DINWOOODY AND GANNETT GLACIERS, 1958-1983

Glacier	Ice Lost (acre feet)	WE Lost (acre feet)
Gannett	59,829	47,863
Dinwoody	64,881	51,905

the absence of precise records, the correct position and aim of the camera lens can be found by applying the principle of parallax. This procedure identifies the aim point and fixes the camera at the proper distance from the subject. Note that the focal length of the new camera need not be proportional to that of the old (Currey 1967). Views of a landscape made with cameras of different focal lengths from the same lens position will match exactly, provided both are printed and cropped to the same size.

Repeat photography of glaciers presents special problems (Harrison 1960). Many older photographs were not taken to evaluate landscape change and may lack precise information about location and date. Reoccupying the original camera position may be impossible due to changes in the glacier over the years. If the original camera position was taken on the glacier itself, the site may no longer exist if the snow/ice depth has changed. The time of year the photo was taken should also be considered. Significant changes to the glacier occur during the summer ablation period so that photos taken in June may differ markedly from those taken in August.

Repeat ground photography was used during July 1988 field reconnaissance to document recent changes in glacier regime (Figs. 10-13). Four sets of photographs are included in Figures 10 through 13. Each pair contains a 30- to 50-year old photo of Gannett or Dinwoody Glacier together with the repeat photograph taken in July 1988 from the same viewpoint. Photographs of Gannett and Dinwoody glaciers dating back to 1935 were obtained from the American Heritage Center at the University of Wyoming. Six of the original camera sites were rephotographed. In some cases, the glacier thickness had declined to such an extent that reoccupying the original site was virtually impossible (Fig. 13). Other locations matched exactly and show dramatic changes over the years.

Discussion

Planview mapping from aerial photographs (Figs. 2 and 3) show that the rate of retreat in the termini of Gannett Glacier varied directly with the elevation of individual tongues of ice

Figure 10. Repeat Photographs of Gannett Glacier, 1958 vs 1988.

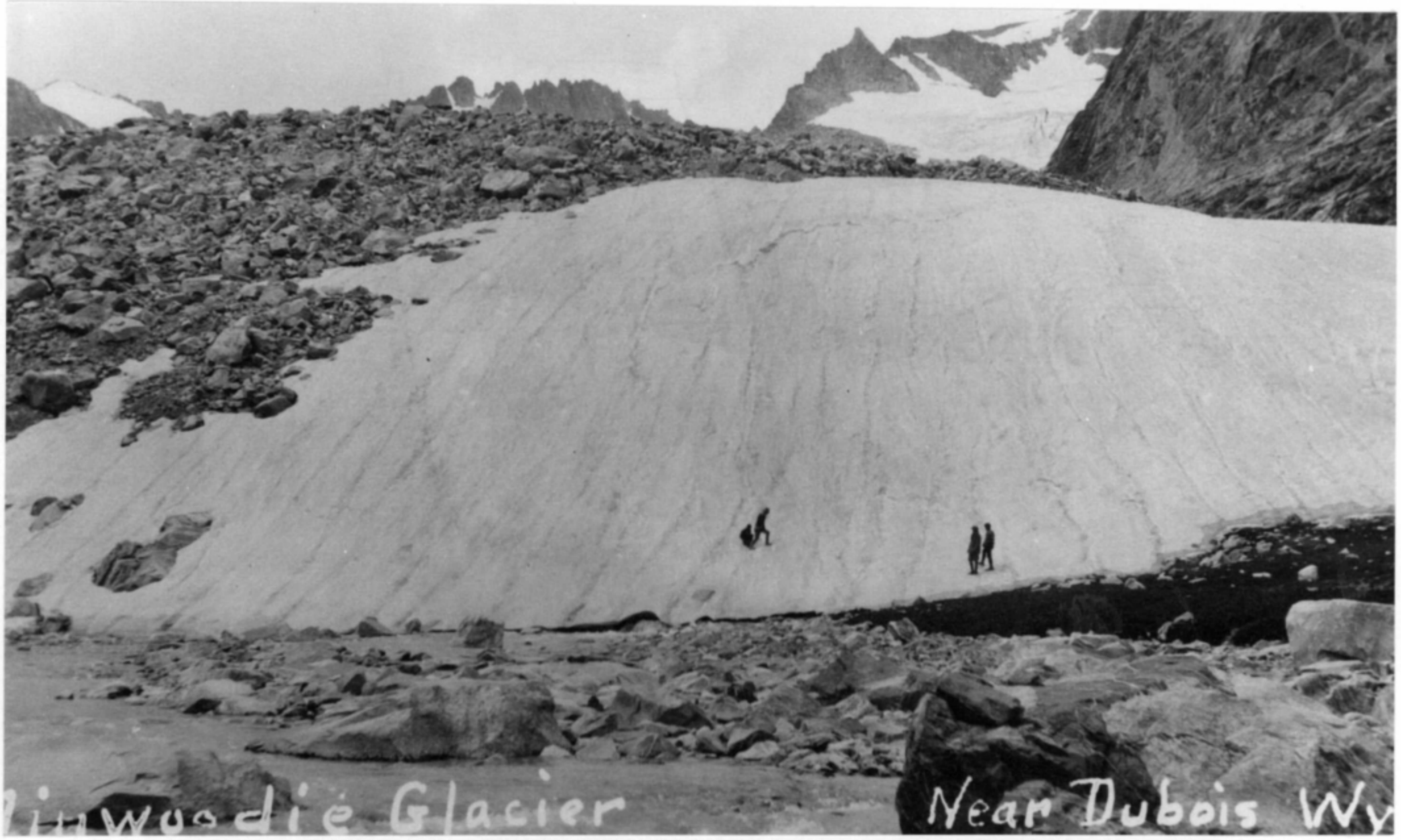

Figure 11. Repeat Photographs of Dinwoody Glacier, 1935 vs 1988.

Figure 12. Repeat Photographs of Gannett Glacier, 1935 vs 1988.

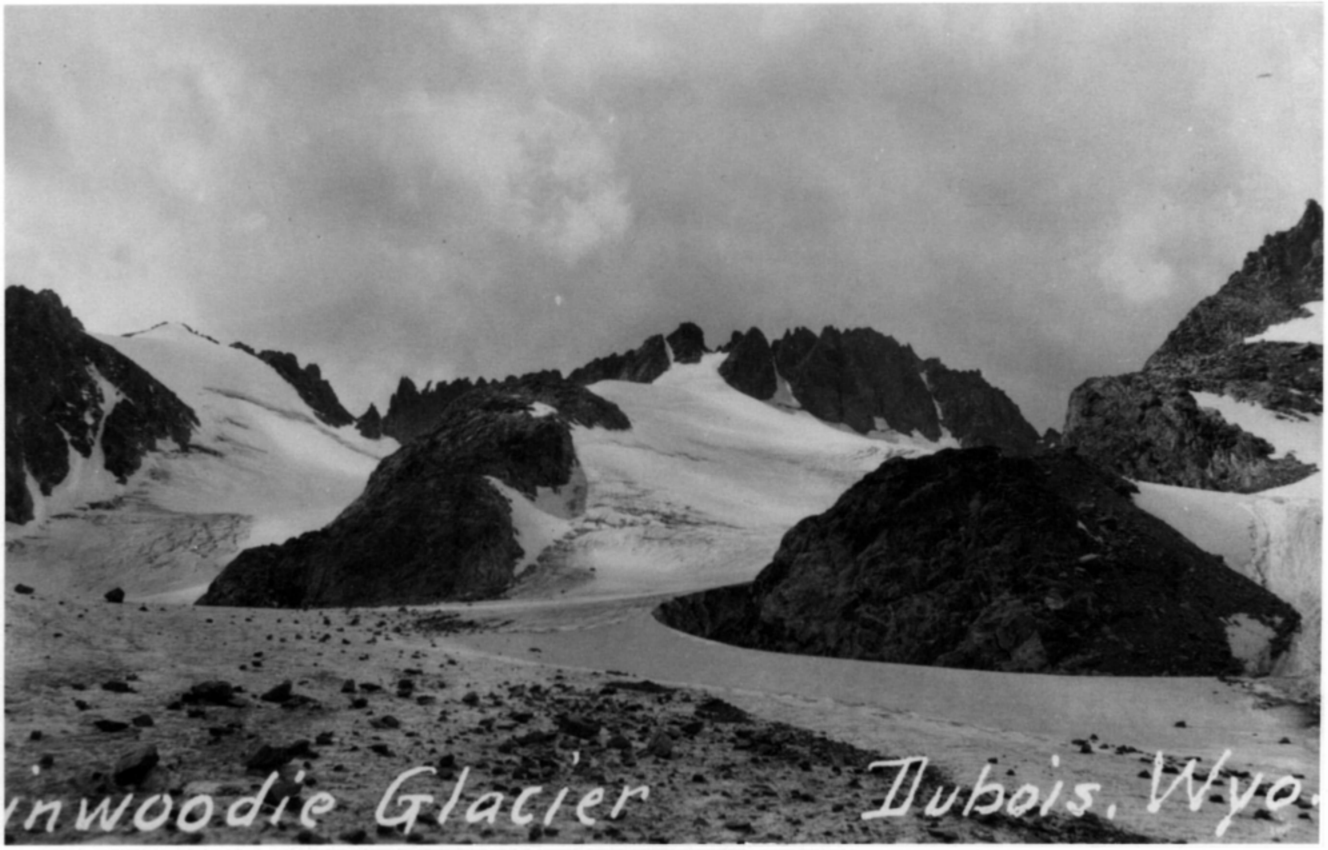

Figure 13. Repeat Photographs of Dinwoody Glacier, 1935 vs 1988.

Table 8). The upper tongue displayed the greatest retreat which can be attributed to its relatively small accumulation zone.

The single terminus of Dinwoody Glacier is difficult to map from aerial photographs due to masking by debris. Quantitative recession measurements are approximate although retreat is clearly indicated when comparing aerial photographs.

Repeat photography confirms termini retreat for both glaciers. As evidenced by the reduction in size of the ice-cored moraine and snowfield in Figure 11, the terminus of Dinwoody Glacier has responded dramatically to climate warming trends between 1935 and 1988. Likewise, the middle and lower tongues of Gannett Glacier show significant retreat between 1958 and 1988 (Fig. 10), although not as striking as Dinwoody Glacier even after accounting for the different time spans.

The termini of nearby glaciers have also been receding. According to Thompson and Love (1988), Knifepoint Glacier, to the south of Gannett and Dinwoody glaciers, has receded 750 feet (228 meters) since 1963. Its area, 1.16 square miles (3.0 square kilometers) as measured by Meier in 1950, and comparatively small accumulation zone account for the lengthy snout retreat in relation to Gannett and Dinwoody glaciers.

The reduction in surface area for Gannett Glacier is significantly greater than for Dinwoody Glacier. The difference can be explained by the number and position of termini which account for the majority of the area reductions (Figs. 2 and 3). Gannett Glacier has three independent tongues with separate source areas which have retreated in response to a decrease in glacier volume. Dinwoody Glacier has a single terminus covered with debris. Its source area is the entire glacier so that a decrease in glacier volume has a lesser effect on the terminus. The debris covering enhances the effect by insulating the ice from solar radiation and heat exchange with the air.

The reduction in volume for Gannett and Dinwoody glaciers is evident from repeat photography. In addition to reduction of snow and ice at lower elevations, Figures 12 and 13 show changes in glacier thickness at higher elevations as well. Over the 53-year time span, Dinwoody Glacier has responded more dramatically than Gannett Glacier, explained in part by their dissimilar area-elevation curves. The bulk of the surface area of Dinwoody Glacier lies at lower elevations where exposed glacier ice is subject to warmer air temperatures and exposure to solar radiation.

While repeat photography documents qualitative changes in Gannett and Dinwoody glaciers, the Thiessen-weighted average method provides quantitative support that the glaciers are in a negative regime. However, results of regression analysis did not show any specific trend in the amount of change in snow/ice depth with altitude.

The stereo ZTS/VM is a useful tool to measure heights and compute volumes but several criteria must be met to obtain the most accurate figures. First, the stereo pairs of aerial photographs must have minimal distortion vertically and horizontally. Second, photographs of glaciers should be taken near the end of the ablation season when the most ice is exposed. Third, the operator should be proficient with the scope. Because of the quality of the aerial photos used for this study, the H and volume data may seem intuitively high. The results obtained however are consistent with the overall trends of Gannett and Dinwoody glaciers.

CHAPTER 5

GLACIER RUNOFF

Access to Dinwoody and Gannett glaciers during the field reconnaissance phase of this study was via the Glacier Trail, the main northern route to Gannett Peak. It begins at Trail Lake Ranch near Torrey Lake, about 15 miles southeast of Dubois, Wyoming. The strenuous, picturesque trail reaches the canyon of Dinwoody Creek by crossing a high divide from Torrey Creek. The 23-mile long trail crosses Dinwoody Creek to Floyd Wilson Meadows, a suitable site for a base camp with access to both Dinwoody and Gannett glaciers. Above Wilson Meadows, Dinwoody Creek is joined by Gannett Creek. At this junction, either glacier can be reached by following its respective creek upstream.

Flow Measurements

Flow measurements were taken for Dinwoody and Gannett creeks on July 22, 1988. These are the first known documented flow measurements taken directly below the glaciers. Measurements were taken for both creeks near their confluence, which is about 1.5 miles below Dinwoody Glacier and about 1 mile below Gannett Glacier. Gannett Creek at this point had a fairly straight, well-defined channel with a cobble substrate. The cross section chosen at this point was 23.5 feet wide. On the other hand, the channel for Dinwoody Creek contained several large rocks, was fairly wide, and was not real straight. The cross section chosen for this site was 38.1 feet wide. Flow measurements were also taken for Gannett Creek immediately below Gannett Glacier. At this point, Gannett Creek was divided into two channels--a relatively large main channel and a rather small secondary channel. Both channels were straight and well-defined with small cobble substrate in the main channel and pebble substrate in the small channel. Cross section widths were 23.5 feet and 5.5 feet, respectively. The main channel, however, was difficult to wade and measure because of its greater depth and higher velocity.

The stream segments between the confluence of Dinwoody and Gannett creeks and Dinwoody and Gannett glaciers, respectively, were inspected carefully for other possible flow measuring sites as well as side streams that might contribute to their flows. Dinwoody Creek was highly accessible and appeared to have few contributions to its flow other than Dinwoody Glacier. However, the creek did not contain any additional sites suitable for flow measurements. Gannett Creek was not as accessible and it was not possible to inspect all areas that might have contributions from secondary streams. The stream channel immediately below Gannett Glacier was found to be the only other location besides that near the confluence of Dinwoody and Gannett creeks suitable for flow measurements.

The weather conditions on July 22 were warm and sunny. These had been the general conditions for some time prior to July 22. The summer had been dry and warm with most snow melt having already occurred.

The flow measurements taken for Dinwoody and Gannett creeks are given in Tables 13 through 16. Measurements were taken from mid-morning to mid-to-late afternoon. Streamflow was observed to have a diurnal cycle, with low flows in the early morning and high flows in mid-to-late afternoon. From visual observations, the flows rates at 10:00 am to 12:00 noon, the time at which the lower Gannett Creek flows were taken, would best be defined as average or slightly above average flows. The diurnal variation is depicted somewhat from the two Gannett Creek measurements, with the mid-afternoon flow at 30.75 cfs and the mid-to-late morning flow measured as 28.52 cfs.

Flow Estimates

The July 22, 1988 flow measurements have been used in combination with flow measurements made in the Cascades in the northwest U.S. to extrapolate flow estimates over the season. The seasonal flow estimates must be recognized as being very approximate since they are based on an extremely limited number of measurements. The estimates do provide a measure of the potential impact of glacier meltwater on the annual runoff from the Wind River Range. Many more measurements will be required to either confirm or adjust these estimates.

The annual runoff distributions, for calendar years and not water years, for Dinwoody Creek above the lakes near Burris, Wyoming and for South Cascade Glacier in the North Cascade Range of Washington (Meier, 1969) are given in Table 17. The amount of runoff which occurs as ice melt for South Cascade Glacier is also given. The annual runoff distributions from South Cascade Glacier and for Dinwoody Creek are similar with the South Cascade Glacier runoff lagging that of Dinwoody Creek somewhat (Figs. 14 and 15).

The total measured Dinwoody and Gannett creek runoff, expressed on a daily basis, was 131.7 acre ft per day. Assuming this value represents the July average runoff, then July runoff for Dinwoody and Gannett creeks near their confluence would be approximately 4080 acre ft. If one assumes the same annual distribution of ice melt for Dinwoody and Gannett glaciers as for South Cascade Glacier, the ice melt for Dinwoody and Gannett glaciers can be estimated as shown in Table 18.

Comparison of the estimated ice melt with Dinwoody Creek streamflow measurements permits a rough estimate of the contribution of Dinwoody and Gannett glaciers to the overall Dinwoody Creek streamflow (Table 19). The Dinwoody Creek flow measurements used are the averages for 1958 through 1978. Even though

TABLE 13. FLOW MEASUREMENTS FOR DINWOODY CREEK (NEAR GANNETT CREEK)

DISTANCE FROM LEFT EDGE OF WATER (FT)	WATER DEPTH (FT)	CROSS-SECTIONAL AREA (SQ FT)	VELOCITY (FT/SEC)	FLOW (CFS)
0.0	--		--	--
1.0	0.25	0.38	2.20	1.10
3.0	1.00	2.00	2.10	4.20
5.0	1.00	1.50	2.50	3.75
6.0	1.00	1.00	2.25	2.25
7.0	1.18	1.18	1.67	1.97
8.0	1.30	1.30	1.52	1.98
9.0	1.32	1.98	1.40	2.77
11.0	1.00	2.00	1.85	3.70
13.0	0.30	0.60	1.10	0.66
15.0	0.60	1.20	0.40	0.48
17.0	0.85	1.28	1.60	2.04
18.0	1.90	1.90	0.32	0.61
19.0	1.51	1.51	0.65	0.98
20.0	1.10	1.10	0.15	0.17
21.0	1.05	1.58	0.70	1.10
23.0	0.95	1.90	0.50	0.95
25.0	0.90	1.80	0.10	0.18
27.0	1.00	2.00	1.00	2.00
29.0	0.80	1.20	0.00	0.00
30.0	0.84	0.84	1.65	1.39
31.0	0.90	1.35	0.88	1.19
33.0	0.68	1.36	0.90	1.22
35.0	0.47	0.94	0.40	0.38
37.0	0.04	0.06	0.41	0.03
38.1	--		--	--

			TOTAL FLOW	35.10

NOTES: Date was 7-22-88 and time was 12:30pm to 1:00pm.

Measurements taken about 150 m above confluence with Gannett Creek. Immediately before small island where stream separates slightly.

Meter was a Marsh McBirney.

Temperature was 75°F with sunny skies and a few heavy cumulus (weather had been like this for a few days).

Observers: Meter---Greg Kerr
Notes---Larry Pochop

TABLE 14. FLOW MEASUREMENTS FOR GANNETT CREEK (NEAR DINWOODY CREEK)

DISTANCE FROM LEFT EDGE OF WATER (FT)	WATER DEPTH (FT)	CROSS-SECTIONAL AREA (SQ FT)	VELOCITY (FT/SEC)	FLOW (CFS)
0.0	1.05	0.26	1.25	0.33
0.5	1.05	0.79	1.25	0.98
1.5	0.80	0.80	0.50	0.40
2.5	0.82	0.82	0.95	0.78
3.5	1.00	1.00	1.80	1.80
4.5	0.55	0.55	1.80	0.99
5.5	1.25	1.25	1.50	1.88
6.5	1.38	1.38	0.92	1.27
7.5	1.40	1.40	1.65	2.31
8.5	1.35	1.35	2.65	3.58
9.5	1.10	1.10	2.25	2.48
10.5	1.20	1.20	0.85	1.02
11.5	0.90	0.90	1.20	1.08
12.5	1.18	1.18	0.45	0.53
13.5	1.35	1.35	0.55	0.74
14.5	1.12	1.12	0.15	0.17
15.5	0.85	0.85	1.55	1.32
16.5	1.00	1.00	1.12	1.12
17.5	1.05	1.05	1.62	1.70
18.5	0.60	0.60	1.83	1.10
19.5	0.48	0.48	1.82	0.87
20.5	0.55	0.55	1.78	0.98
21.5	0.87	0.87	0.65	0.57
22.5	0.45	0.36	1.30	0.47
23.5	0.50	0.15	0.35	0.05
			TOTAL FLOW	28.52

NOTES: Date was 7-22-88 and time was 10:45am to 11:25am.

Measurements taken 100 ft above the log crossing above the confluence to Dinwoody Creek.

Meter was a Marsh McBirney.

Temperature was 70°F with clear and sunny skies (weather had been like this for a few days).

Substrate was cobble and rock.

Observers: Meter---Greg Kerr
Notes---Larry Pochop

TABLE 15. FLOW MEASUREMENTS FOR GANNETT CREEK, MAIN CHANNEL

DISTANCE FROM LEFT EDGE OF WATER (FT)	WATER DEPTH (FT)	CROSS-SECTIONAL AREA (SQ FT)	VELOCITY (FT/SEC)	FLOW (CFS)
0.0	--	--	--	--
0.5	1.10	1.10	0.62	0.68
1.5	1.00	1.00	0.40	0.40
2.5	1.25	1.25	0.52	0.65
3.5	1.00	1.00	0.96	0.96
4.5	0.90	0.90	0.63	0.57
5.5	0.65	0.65	1.12	0.73
6.5	0.90	0.90	0.60	0.54
7.5	1.07	1.07	0.68	0.73
8.5	1.35	1.35	0.68	0.92
9.5	1.70	1.70	1.28	2.18
10.5	1.70	1.70	1.00	1.70
11.5	1.70	1.70	0.68	1.16
12.5	1.80	1.80	0.80	1.44
13.5	1.50	1.50	0.50	0.75
14.5	1.40	1.40	0.95	1.33
15.5	1.40	1.40	1.00	1.40
16.5	1.50	1.50	0.42	0.63
17.5	1.50	1.50	1.45	2.18
18.5	1.50	1.50	1.30	1.95
19.5	1.40	1.40	1.10	1.54
20.5	1.30	1.30	1.35	1.80
21.5	1.20	1.38	1.15	1.38
22.5	0.80	0.80	1.02	0.82
23.5	--	--	--	--

			TOTAL FLOW	26.44

NOTES: Date was 7-22-88 and time was 3:10pm to 3:35pm.

Measurements taken about 200 yards below foot of mountain containing Gannett Glacier.

Meter was a Marsh McBirney.

Temperature was 80°F with sunny skies and a few heavy cumulus (weather had been like this for a few days).

Observers: Meter---Greg Kerr
Notes---Larry Pochop

TABLE 16. FLOW MEASUREMENTS FOR GANNETT CREEK, SECONDARY CHANNEL

DISTANCE FROM LEFT EDGE OF WATER (FT)	WATER DEPTH (FT)	CROSS-SECTIONAL AREA (SQ FT)	VELOCITY (FT/SEC)	FLOW (CFS)
0.0	4.00	0.06	0.60	0.04
0.3	0.68	0.20	1.22	0.25
0.6	0.66	0.20	1.33	0.26
0.9	0.88	0.26	1.68	0.44
1.2	0.72	0.22	1.02	0.22
1.5	0.70	0.21	0.69	0.14
1.8	0.78	0.23	2.10	0.49
2.1	0.78	0.23	1.50	0.35
2.4	0.65	0.20	1.30	0.25
2.7	0.70	0.21	1.83	0.38
3.0	0.70	0.21	1.75	0.37
3.3	0.70	0.21	1.20	0.25
3.6	0.62	0.19	1.25	0.23
3.9	0.53	0.16	0.80	0.13
4.2	0.55	0.17	1.12	0.18
4.5	0.55	0.17	1.00	0.17
4.8	0.49	0.15	0.70	0.10
5.1	0.35	0.11	0.58	0.06
5.4	0.10	0.02	0.00	0.00
5.5	--	--	--	--

			TOTAL FLOW	4.31

NOTES: Date was 7-22-88 and time was 3:45pm to 4:15pm.

Measurements taken about 200 yards below foot of mountain containing Gannett Glacier. Taken directly across from those in the main channel.

Meter was a Marsh McBirney.

Temperature was 80°F with sunny skies and a few heavy cumulus (weather had been like this for a few days).

Observers: Meter---Greg Kerr
Notes---Larry Pochop

TABLE 17. ANNUAL DISTRIBUTION OF RUNOFF (ON A PERCENTAGE BASIS)

MONTH	SOUTH CASCADE GLACIER ICE MELT	SOUTH CASCADE GLACIER TOTAL	DINWOODY CREEK
JAN	--	1.5	0.5
FEB	--	1.3	0.4
MAR	--	0.8	0.5
APR	--	1.0	1.0
MAY	--	4.5	9.4
JUN	1.7	14.5	27.0
JUL	10.0	24.8	29.7
AUG	8.0	22.0	19.4
SEP	5.2	14.2	7.7
OCT	2.0	9.2	2.5
NOV	--	4.2	1.2
DEC	--	2.0	0.7
TOTALS	26.9	100.0	100.0

TABLE 18. ESTIMATED DINWOODY AND GANNETT CREEK ICE MELT RUNOFF

MONTH	ESTIMATED ICE MELT (ACRE-FEET)
JUN	691
JUL	4080
AUG	3268
SEP	2117
OCT	812

TABLE 19. ESTIMATED CONTRIBUTION OF DINWOODY AND GANNETT GLACIERS TO DINWOODY CREEK FLOW

MONTH	ESTIMATED ICE MELT (ACRE-FT)	DINWOODY CREEK FLOW (ACRE-FT)	% FLOW FROM ICE MELT
JUN	691	27790	3
JUL	4080	30642	13
AUG	3268	19990	16
SEP	2117	7929	27
OCT	812	2527	32

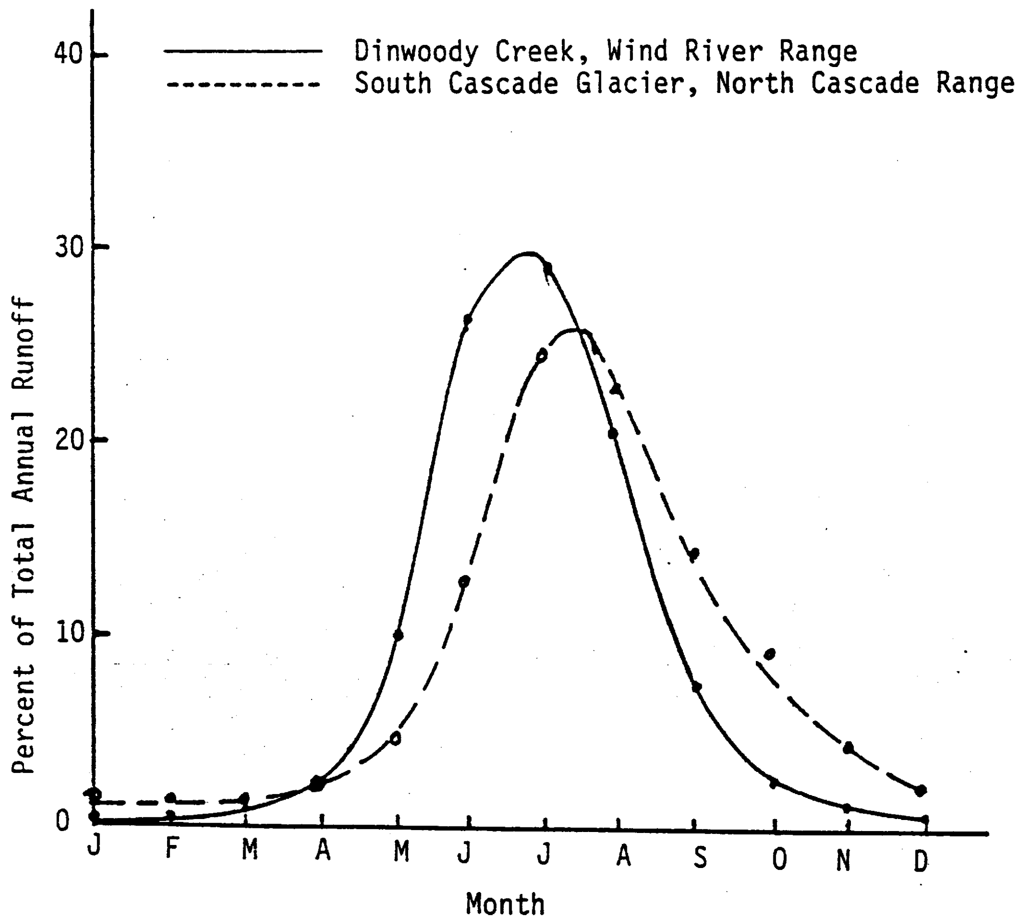

Figure 14. Annual Runoff Hydrographs.

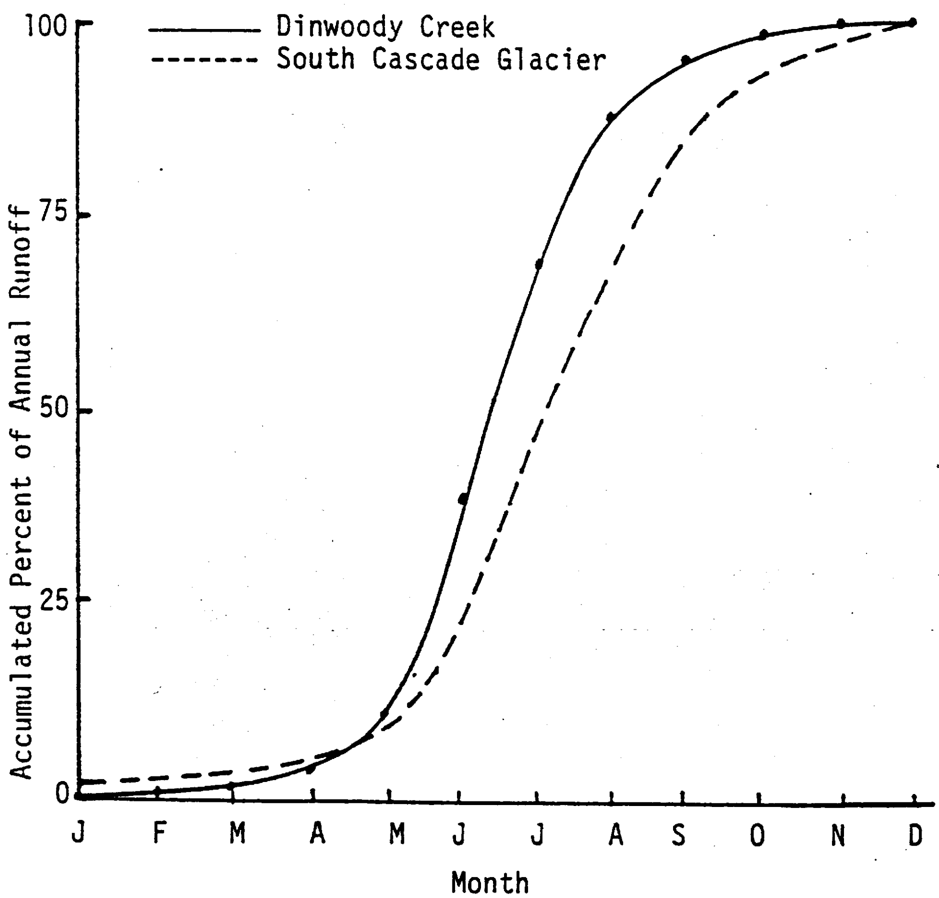

Figure 15. Accumulative Runoff Hydrographs.

the estimates are rough, they do show the potential for the glaciers to contribute a fairly large percentage to Dinwoody Creek late summer and early fall flow.

The total area of glaciers in the Wind River Range has been given (Denton, 1975) as 17.2 sq. mi. while the areas of Dinwoody and Gannett glaciers have been given as 1.3 sq. mi. and 1.7 sq. mi., respectively. Thus, the combined area of Dinwoody and Gannett glaciers is approximately 18 percent of the total area of glaciers in the Wind River Range.

CHAPTER 6

SUMMARY

The intent of this project was to perform a preliminary investigation of the trends in glacier and snowmelt runoff for the Wind River Range, Wyoming. The duration of the one-year project was from July 1, 1988 through June 30, 1989. The study focused on documenting trends in glacier regime and runoff to better understand the implications of long-term trends for Wyoming water supply and obligations of interstate compacts.

Time and budget constraints required development of very specific and limited objectives. The objectives were to analyze temporal trends in snowdepth, water equivalent, and runoff, to use aerial and ground photos to document the trends in glacier regime, and to perform field reconnaissance for direct measurements of runoff from the Wind River Range glaciers. All studies were limited to Dinwoody and Gannett glaciers and the climatic and streamflow data associated with these two glaciers. Again, because of time and budget constraints, and because this was an initial investigation of the Wind River glaciers, the intent was to analyze the temporal trends without defining the predictive relations between glacier regimes, runoff, and/or climate.

Study results clearly show that the recent trends of Dinwoody and Gannett glaciers are that they are receding. The glaciers have decreased in thickness as well as in overall size. Repeat photography of older photos dating back over 50 years shows dramatic differences in the amount of snow and ice and in the position of the termini. Volume reduction is also supported by changes in depth of snow and ice data spanning four decades. The retreat of the termini of the glaciers for the same time period can be traced from planview maps drawn from aerial photographs.

The reduction in volume of Gannett and Dinwoody glaciers, two of the largest glaciers of the range, represent a negative trend throughout the Wind River Mountains. The contributions of glaciers to streamflow in Wyoming are most important in the late summer, particularly when water from other sources is critically low. As the glaciers recede, the source area for meltwater is reduced and, consequently, so is their input to streamflow.

The amount of snow and ice lost from Gannett and Dinwoody glaciers from 1958-1983 is significant when compared to current runoff and volume data. Estimates and extrapolations from very limited flow measurements indicate that Gannett and Dinwoody glaciers contribute 12.3 percent of the June-October runoff to Dinwoody Creek. Based on the aerial photo work, the water equivalent of snow and ice lost annually from the two glaciers from 1958-1983 is 4.5 percent of the average June-October runoff to Dinwoody Creek. The snow and ice lost from just Dinwoody Glacier during the same 25-year period is equal to its remaining volume of 64,881 acre feet as measured by Driedger and Kennard (1986) using a backpack radio echo-sounder.

Again, based on an extremely limited number of flow measurements and extrapolating over the summer season, Dinwoody and Gannett glaciers were estimated to contribute approximately 27 percent of the September and 32 percent of the October flows to Dinwoody Creek. The July-October runoff from all glaciers in the Wind River Range, extrapolated from the Dinwoody and Gannett contribution on the basis of estimated area, was estimated to be approximately eight percent of the runoff in the entire Wind River and Green River basins for that four-month period.

If the glaciers continue to shrink, the effects of reduced water supply will be far-reaching. From local irrigation to interstate water compacts, users will have to accept and plan for a reduction in summer water supply. In years of low precipitation when water from sources such as snowpack is low, the glaciers may not have the reserve quantity of water they normally release to augment the usual runoff.

Much work remains to be done to provide predictive relations for the Wind River glaciers. The glaciers do appear to play an important role in existing water supplies. Correlations of the changes in glacier volume with temporal changes in snowfall, temperature, and runoff are needed. The water equivalent data for the snow/ice lost from Gannett and Dinwoody glaciers can be used with temporal snow and runoff data to predict the reduction in yearly water supply if the glaciers continue to diminish. Field work to accurately determine the volume of ice in the glaciers is essential. With this information, future glacier meltwater production can be predicted with appropriate downstream adjustments in water planning. Many more flow measurements are required in order to check the accuracy of the seasonal extrapolations made herein. Finally, tree ring studies may provide information about glacier trends much beyond the period of existing climatic records.

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APPENDIX

Project Personnel

Project Papers and Presentations

Field Reconnaissance Schedule

Dinwoody Creek Streamgage Data

Snow Depth and Water Equivalent Data*

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*Minus values in these tables indicate missing data.

PROJECT PERSONNEL

NAME	STATUS
Larry Pochop	Principal Investigator
Richard Marston	Principal Investigator
Greg Kerr	Principal Investigator
Marjorie Varuska*	Graduate Student
Dave Clarendon	Assisted in Field Reconnaissance

*Received a Masters Degree in Geography and Recreation based partially on work completed as part of this project.

PROJECT PAPERS AND PRESENTATIONS

Poster presentation. Wyoming Section AWRA, Cheyenne, WY., Nov. 1-2, 1988.

Hydrologic investigations of Wind River Glaciers. Water Talk presentation, Nov. 16, 1988.

Trends in Dinwoody and Gannett glaciers, Wind River Range. North West Glaciologists 1988 Meeting, Boulder, CO., Dec 2-3, 1988.

Presentation to the Wyoming Water Forum. Cheyenne, WY., Feb. 28, 1989.

Wind River Glaciers--Impact on current and future water supplies. Colorado-Wyoming Section Meeting of ASAE, Laramie, WY., March 31, 1989.

Glacial hydrology, Wind River Range, Wyoming. American Association for the Advancement of Science, Annual meeting, Las Cruces, New Mexico, April 6-8, 1989.

Recent trends in glaciers and glacial runoff, Wind River Range, Wyoming. 1989 Headwaters Hydrology Symposium, American Water Resources Assoc., Missoula, Montana, June 27, 1989.

Water supplies from the Wind River Glaciers. Governor's Economic Development field tours of Fremont County, WY., June 28-30,1989.

FIELD RECONNAISSANCE SCHEDULE

DATE*	ACTIVITY
July 19	Traveled to Dubois from Laramie
July 20	Hiked to outfitter base camp at Downs Fork (16 miles)
July 21	Hiked to Wilson meadows (7 miles) and set up camp
July 22	Flow measurements and repeat photos of Gannett Glacier
July 23	Repeat photos of Dinwoody Glacier
July 24	Hiked to Downs Fork
July 25	Hiked to trail head at Trail Lake and returned to Dubois
July 26	Returned to Laramie

*All dates are for 1988.

Note: Required 3 pack horses and 1 wrangler. Costs were $60 per day per pack horse plus $60 per day for the wrangler for 4 days.

DINWOODY CREEK STREAMGAGE DATA

YEAR	MAY	JUN	JUL	AUG	SEP	OCT
	MONTHLY FLOW DATA IN ACRE-FEET					
1958	18355	23096	21503	23619	9800	2106
1959	4372	30851	25825	20979	7075	2481
1960	6472	20081	22671	15652	9866	3475
1961	11538	30930	23514	18629	7400	2339
1962	13698	36688	32154	19008	5070	2301
1963	9953	27277	60190	20636	8860	3600
1964	10762	28058	36371	18022	3525	1591
1965	5157	30619	39983	22536	5121	2577
1966	10534	18764	28844	20065	9578	2465
1967	12238	33420	36881	23714	10520	4459
1968	5179	27370	29058	23429	9051	2916
1969	14245	20596	24946	21144	6807	1906
1970	9913	27804	29349	19410	6748	1563
1971	11699	43946	34590	24992	8553	3608
1972	8997	36089	25533	20596	6998	2648
1973	9427	19559	27723	20803	14880	3495
1974	10826	33999	30869	15995	6690	2017
1975	4403	21624	48831	16441	6040	2212
1976	12399	21997	32884	17990	8001	1993
1977	4381	21332	26329	18833	7664	2104

BLUE RIDGE STATION SNOW DEPTH AND WATER EQUIVALENT DATA

YEAR	SNOW DEPTHS (INCHES) FEB	MAR	APR	MAY	WATER EQUIVALENTS (INCHES) FEB	MAR	APR	MAY
1940	-9	17	17	14	-9.9	2.6	5.4	4.8
1941	14	18	31	46	2.8	3.8	6.8	14.0
1942	17	28	31	14	2.8	5.6	7.2	4.0
1943	51	43	43	25	12.8	14.6	14.2	9.2
1944	27	30	40	61	3.8	7.2	10.2	18.0
1945	17	25	22	59	2.4	5.8	6.6	17.0
1946	26	26	34	3	5.8	7.2	9.2	0.8
1947	27	30	34	28	6.6	7.0	10.8	10.2
1948	-9	29	46	32	-9.9	9.8	11.0	12.9
1949	40	53	51	22	9.4	16.0	15.6	9.2
1950	45	40	50	44	12.6	12.8	17.6	16.2
1951	29	34	36	37	6.6	9.0	9.4	12.3
1952	38	49	63	48	10.4	13.8	22.4	19.0
1953	24	34	31	30	6.0	9.8	9.2	7.2
1954	33	52	57	42	8.0	11.8	15.6	9.6
1955	14	-9	36	24	4.0	-9.9	10.9	9.3
1956	47	48	45	33	15.4	15.0	15.5	13.5
1957	25	27	32	44	5.6	6.4	8.0	13.1
1958	26	24	28	40	5.5	5.5	7.4	12.1
1959	20	25	39	19	4.0	5.7	8.9	6.1
1960	20	31	22	1	4.3	4.8	6.6	0.3
1961	15	22	32	29	3.9	4.4	8.0	6.7
1962	47	46	56	33	7.6	11.3	12.7	11.9
1963	14	31	38	43	2.7	9.2	12.2	12.4
1964	21	40	43	45	4.7	9.9	11.6	14.2
1965	54	62	57	51	16.1	19.7	20.0	17.8
1966	29	43	33	13	5.8	7.5	7.2	5.0
1967	43	42	52	55	11.5	12.8	15.9	18.1
1968	38	37	37	46	8.7	9.3	11.1	14.6
1969	44	48	53	41	11.3	13.5	16.6	15.9
1970	28	25	61	58	6.9	6.8	13.6	17.0
1971	47	58	55	71	16.1	16.9	18.1	25.4
1972	42	45	39	51	11.0	13.0	12.2	18.2
1973	38	36	77	64	9.0	11.4	14.2	18.4
1974	25	32	42	52	6.0	9.4	12.7	18.7
1975	22	25	39	46	6.2	7.8	10.2	16.3
1976	21	35	39	37	6.3	10.5	12.7	13.6
1977	18	12	38	6	4.4	4.0	8.6	2.0
1978	23	34	23	21	7.6	9.8	8.0	7.4
1979	38	34	40	30	9.6	8.9	11.3	9.4
1980	44	51	57	46	12.2	16.4	17.6	19.0
1981	28	-9	31	0	7.2	8.5	7.0	0.0
1982	33	30	39	34	9.2	8.0	10.2	11.2
1983	21	31	57	60	5.0	7.3	13.6	18.4
1984	35	40	57	62	9.5	10.8	15.2	19.5
1985	24	46	40	-9	6.2	9.6	9.4	7.7
1986	34	72	64	63	10.9	21.3	23.4	25.3
1987	25	35	38	8	5.3	9.3	10.2	3.2

BURROUGHS CREEK STATION SNOW DEPTH AND WATER EQUIVALENT DATA

	SNOW DEPTHS (INCHES)				WATER EQUIVALENTS (INCHES)			
YEAR	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
1949	39	45	51	28	9.4	13.2	12.6	10.6
1950	59	51	57	50	15.0	15.6	19.4	17.4
1951	52	68	70	58	17.6	23.0	26.0	24.0
1952	34	40	41	28	8.2	9.4	11.6	9.4
1953	48	46	41	40	10.6	15.4	15.0	16.4
1954	53	43	59	44	11.0	13.4	17.2	17.6
1955	21	25	39	30	4.9	7.4	10.0	9.6
1956	56	62	61	65	17.6	18.9	20.8	23.0
1957	33	39	44	47	7.8	9.5	12.8	16.4
1958	30	36	40	42	6.4	9.0	11.1	10.9
1959	42	54	47	42	11.0	14.1	15.1	14.2
1960	21	29	29	21	4.0	6.2	7.7	6.3
1961	22	35	35	36	5.1	7.2	9.0	10.3
1962	40	51	53	34	11.5	14.3	16.0	12.6
1963	29	41	38	48	6.0	12.5	12.6	15.5
1964	37	36	49	38	7.9	9.2	11.0	11.6
1965	58	60	74	69	16.7	21.2	23.8	24.4
1966	30	32	31	25	7.5	8.2	8.8	8.4
1967	40	43	44	42	9.7	12.1	12.9	14.3
1968	32	38	34	26	7.0	9.6	10.4	8.7
1969	38	42	38	17	9.4	12.0	11.8	8.3
1970	54	41	47	54	12.1	13.3	15.5	18.0
1971	52	59	66	60	15.3	17.7	21.3	24.0
1972	64	73	61	56	16.3	21.9	23.6	25.9
1973	25	27	36	32	5.7	6.4	7.6	8.3
1974	47	51	60	49	12.1	14.8	19.2	18.5
1975	32	44	55	52	8.3	12.6	15.4	19.6
1976	45	67	67	50	13.5	18.9	22.4	21.6
1977	12	11	21	5	2.0	2.2	3.8	1.2
1978	49	56	48	39	17.4	19.5	19.5	18.3
1979	42	47	47	35	12.0	14.2	14.5	13.8
1980	40	38	49	31	9.9	11.3	14.5	11.4
1981	22	30	35	21	5.8	7.4	8.1	7.0
1982	56	56	57	52	15.3	16.2	20.6	20.8
1983	30	35	39	37	7.2	9.6	10.2	10.8
1984	31	35	40	39	7.8	8.9	10.1	11.7
1985	27	34	40	24	5.8	7.2	9.8	8.1
1986	38	86	65	57	9.6	21.0	21.4	21.4
1987	34	44	47	28	7.8	9.8	11.6	10.4

DINWOODY STATION SNOW DEPTH AND WATER EQUIVALENT DATA

	SNOW DEPTHS (INCHES)				WATER EQUIVALENTS (INCHES)			
YEAR	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
1949	38	40	-9	33	9.4	11.6	-9.9	11.2
1950	49	50	60	54	13.8	15.4	19.6	18.0
1951	42	51	54	57	12.0	17.2	18.0	19.6
1952	36	44	47	41	9.6	12.0	13.4	12.8
1953	32	36	36	39	7.0	11.0	11.6	12.6
1954	28	35	50	47	6.2	8.4	13.0	16.4
1955	15	22	40	41	2.8	5.6	11.9	13.2
1956	40	48	51	63	11.2	13.8	16.3	21.0
1957	30	36	40	63	7.1	8.2	11.3	17.3
1958	32	30	37	48	6.6	7.1	8.7	11.6
1959	29	40	49	47	6.6	10.6	12.0	13.9
1960	30	35	38	39	7.6	8.4	9.3	11.3
1961	22	31	45	42	5.1	6.6	9.2	10.1
1962	42	51	54	52	11.2	13.5	14.2	13.5
1963	19	27	39	48	3.5	7.2	10.3	13.3
1964	24	31	42	45	4.8	7.2	8.8	12.0
1965	43	46	58	59	11.1	14.3	17.0	18.1
1966	22	23	28	33	5.4	5.2	6.5	8.2
1967	35	42	50	54	8.6	11.3	13.3	15.6
1968	30	33	41	40	7.1	8.2	10.2	10.5
1969	33	41	39	35	7.2	8.3	10.2	11.5
1970	34	31	49	60	7.1	8.4	11.3	15.9
1971	47	58	64	93	14.5	17.0	19.9	25.4
1972	56	72	60	69	16.3	19.9	20.4	23.7
1973	27	27	38	45	5.2	6.5	7.0	9.2
1974	35	41	58	54	8.4	10.5	15.5	17.6
1975	36	39	51	55	8.6	10.4	13.0	16.7
1976	31	-9	54	48	8.4	-9.9	15.5	15.6
1977	7	8	26	16	1.0	1.6	5.0	3.9
1978	34	37	39	51	8.7	11.0	11.2	11.9
1979	38	39	46	47	9.1	10.0	11.5	10.7
1980	30	30	55	38	6.9	7.3	10.7	13.1
1981	30	28	42	30	5.2	6.0	9.2	8.2
1982	38	39	46	42	9.0	9.2	12.0	13.4
1983	24	-9	41	48	6.5	7.7	9.2	13.4
1984	30	-9	38	51	7.6	8.6	8.6	12.6
1985	21	32	34	26	4.1	6.0	5.8	8.2
1986	36	69	58	64	9.9	17.1	17.5	23.0
1987	39	44	52	42	9.9	13.3	14.7	11.9

DUNOIR STATION SNOW DEPTH AND WATER EQUIVALENT DATA

YEAR	SNOW DEPTHS (INCHES) FEB	MAR	APR	MAY	WATER EQUIVALENTS (INCHES) FEB	MAR	APR	MAY
1941	20	26	29	22	4.4	5.0	6.0	6.6
1942	24	26	30	6	4.8	5.8	6.8	1.7
1943	54	56	57	27	14.4	16.3	20.5	12.7
1944	14	17	25	0	2.5	4.0	6.4	0.0
1945	22	27	27	24	4.2	6.4	8.0	6.4
1946	36	26	33	2	6.0	7.0	7.6	0.8
1947	34	41	36	33	7.8	5.6	9.4	9.2
1948	-9	27	31	23	-9.9	5.8	8.2	5.8
1949	30	35	41	3	6.0	9.4	11.0	1.0
1950	41	41	45	31	11.2	12.4	12.8	11.2
1951	33	38	43	31	8.4	11.0	13.2	11.0
1952	26	31	32	6	6.4	7.2	8.2	2.0
1953	24	27	26	18	5.4	7.6	8.2	5.8
1954	30	28	40	23	5.8	7.6	10.2	7.8
1955	11	18	28	19	1.2	3.6	8.0	6.0
1956	38	39	45	42	9.2	10.2	13.8	14.0
1957	22	23	30	37	4.5	5.3	7.4	11.2
1958	18	19	24	21	2.9	4.0	5.6	5.0
1959	23	31	31	21	4.7	6.6	7.6	6.4
1960	14	22	21	7	2.3	4.3	5.3	1.4
1961	13	17	20	11	2.7	3.2	4.1	3.2
1962	34	43	45	23	7.9	10.5	12.0	6.9
1963	20	30	29	27	4.1	8.4	8.8	9.4
1964	21	23	32	30	4.3	4.6	8.7	9.8
1965	31	37	47	35	8.4	10.6	12.7	12.5
1966	19	22	22	13	4.1	4.6	5.6	4.4
1967	28	33	34	33	6.4	8.7	9.4	10.5
1968	23	27	25	21	5.0	6.1	6.7	6.8
1969	26	33	30	4	5.7	6.3	7.4	1.2
1970	25	22	30	36	4.7	5.9	7.5	11.1
1971	40	40	50	60	11.0	11.3	14.8	18.1
1972	41	45	39	34	10.2	13.0	13.5	12.8
1973	22	23	29	22	4.5	5.3	5.9	6.0
1974	27	30	40	30	6.2	7.5	11.0	9.1
1975	27	29	39	40	6.3	6.8	8.9	12.0
1976	25	35	43	30	6.1	7.3	11.9	8.0
1977	9	7	16	0	1.8	1.2	2.8	0.0
1978	30	37	33	19	8.8	10.5	10.7	7.9
1979	36	37	33	17	8.8	9.9	9.0	5.2
1980	25	25	32	11	5.7	6.6	6.5	3.5
1981	16	19	27	5	3.6	4.2	5.4	1.4
1982	32	34	37	30	5.8	6.8	10.0	9.6
1983	18	23	25	29	3.2	3.6	5.0	7.2
1984	27	-9	28	28	5.6	6.2	6.9	7.3
1985	20	27	32	7	3.6	4.8	6.4	2.2
1986	25	48	38	30	5.7	11.0	11.8	9.8
1987	29	36	34	4	7.0	8.0	9.4	1.6

GEYSER CREEK STATION SNOW DEPTH AND WATER EQUIVALENT DATA

	SNOW DEPTHS (INCHES)				WATER EQUIVALENTS (INCHES)			
YEAR	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
1950	34	34	39	27	7.6	10.0	11.4	8.6
1951	33	37	43	31	8.0	11.2	13.4	11.4
1952	25	30	30	6	5.6	6.8	8.8	2.0
1953	22	26	25	16	5.0	7.4	7.6	5.6
1954	28	25	40	21	5.6	7.2	10.2	7.6
1955	12	17	29	23	1.7	3.4	7.2	6.8
1956	39	36	40	35	9.6	9.2	11.8	12.0
1957	21	25	31	34	4.2	5.6	7.4	10.9
1958	13	16	23	15	2.4	3.8	5.4	4.0
1959	19	27	31	18	4.5	6.5	6.7	6.0
1960	14	20	17	6	2.5	4.2	4.2	1.4
1961	12	19	22	15	2.2	3.3	4.6	4.8
1962	29	36	36	12	6.6	8.7	9.5	4.0
1963	16	27	26	27	3.6	7.4	7.8	8.2
1964	16	18	30	24	3.5	4.4	6.7	6.5
1965	27	33	43	31	7.0	9.3	12.1	9.3
1966	16	18	18	12	3.7	3.8	4.6	3.2
1967	23	27	29	30	5.1	7.1	8.2	8.1
1968	19	21	21	17	4.3	4.8	5.6	4.4
1969	22	29	24	1	5.9	6.4	6.1	0.5
1970	20	17	27	30	3.9	4.6	5.8	8.9
1971	35	34	46	53	10.0	10.2	13.9	17.1
1972	36	45	35	32	8.7	12.7	11.7	11.9
1973	19	20	26	21	4.0	4.5	5.0	5.4
1974	22	24	35	27	4.9	6.1	9.3	8.3
1975	24	25	34	32	5.7	6.1	7.8	10.0
1976	23	30	38	0	6.2	7.5	10.4	0.0
1977	1	0	16	1	0.1	0.0	2.4	0.3
1978	29	34	31	17	7.6	9.1	9.7	6.5
1979	31	32	27	15	7.8	9.2	7.3	4.2
1980	20	19	27	3	4.3	6.4	8.3	1.0
1981	10	5	22	0	1.8	3.3	5.2	0.0
1982	28	28	33	24	5.2	7.4	9.8	8.4
1983	13	18	20	31	2.4	3.4	4.0	9.6
1984	22	-9	24	29	4.4	5.1	5.7	6.0
1985	17	21	23	6	3.4	4.0	5.2	1.8
1986	19	38	29	20	4.7	9.0	8.8	7.0
1987	19	23	22	5	5.0	5.4	6.2	2.0

HOBBS PARK STATION SNOW DEPTH AND WATER EQUIVALENT DATA

	SNOW DEPTHS (INCHES)				WATER EQUIVALENTS (INCHES)			
YEAR	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
1949	40	51	58	43	10.6	15.8	20.2	17.0
1950	61	56	67	69	16.4	19.0	22.2	24.6
1951	34	44	51	58	8.8	12.6	16.4	21.2
1952	44	52	63	63	12.2	16.0	18.8	22.6
1953	28	37	35	42	7.6	12.0	11.0	10.4
1954	39	46	67	46	9.6	13.8	19.4	18.4
1955	17	34	41	45	3.5	8.6	12.3	15.4
1956	52	56	55	63	16.4	18.2	20.4	24.2
1957	34	33	45	71	8.3	10.0	13.5	20.8
1958	25	28	37	57	5.6	5.7	7.6	13.7
1959	27	35	51	44	4.9	9.1	11.9	13.5
1960	31	35	35	31	6.4	9.1	9.8	9.7
1961	21	33	46	48	5.9	7.6	11.9	13.7
1962	40	52	57	50	11.1	14.7	18.0	16.6
1963	32	28	39	55	6.1	7.4	10.5	16.7
1964	27	41	46	61	6.2	8.8	11.7	15.3
1965	48	55	60	63	15.1	17.9	20.3	23.2
1966	26	28	30	32	6.1	7.3	8.0	9.8
1967	44	47	62	82	12.8	13.9	18.0	23.5
1968	33	36	41	53	8.4	9.5	11.9	15.4
1969	44	50	44	47	11.3	10.8	14.2	17.0
1970	33	30	55	67	7.6	8.2	13.1	18.9
1971	49	58	65	96	16.1	18.5	22.5	28.8
1972	52	57	53	72	14.3	17.5	18.5	24.7
1973	36	36	45	62	8.5	8.8	10.7	16.9
1974	33	42	59	73	8.7	11.9	17.2	26.5
1975	34	37	54	60	8.0	10.4	13.2	18.0
1976	31	38	50	62	8.9	10.6	14.7	19.0
1977	15	15	42	26	3.0	3.3	8.3	7.2
1978	32	34	32	46	8.8	9.3	8.8	7.4
1979	35	37	45	43	8.5	9.3	11.6	11.6
1980	41	44	79	56	10.4	13.2	17.4	19.8
1981	34	31	51	40	7.0	8.0	11.4	12.4
1982	38	37	47	50	9.6	9.2	13.0	15.4
1983	28	-9	60	68	7.8	10.2	13.2	20.0
1984	36	-9	58	71	9.2	10.1	14.2	20.6
1985	29	45	46	39	7.2	9.8	11.4	12.3
1986	43	71	66	68	13.3	21.0	22.0	22.1
1987	41	54	64	46	11.9	13.5	17.3	15.4

LITTLE WARM STATION SNOW DEPTH AND WATER EQUIVALENT DATA

	SNOW DEPTHS (INCHES)				WATER EQUIVALENTS (INCHES)			
YEAR	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
1949	-9	56	65	52	-9.9	15.8	18.8	17.4
1950	65	62	72	71	18.6	21.4	26.2	26.2
1951	62	69	80	81	18.6	24.4	27.4	27.8
1952	44	51	59	50	11.6	14.6	18.0	17.4
1953	36	44	50	49	9.6	14.0	18.2	18.8
1954	48	49	69	62	10.8	14.4	19.8	22.6
1955	25	32	53	59	5.0	7.0	14.4	18.2
1956	58	62	71	82	16.8	19.1	24.2	28.2
1957	37	45	56	71	8.8	11.1	16.0	22.4
1958	33	39	45	56	6.9	9.4	11.1	16.0
1959	37	53	56	55	9.0	13.4	15.7	18.3
1960	36	41	45	47	7.5	10.1	12.6	14.7
1961	28	41	49	54	6.5	8.9	11.1	13.2
1962	54	64	68	66	14.3	17.4	20.6	21.2
1963	29	43	46	60	6.0	12.3	14.1	18.0
1964	36	40	54	56	7.6	9.8	12.3	15.6
1965	48	58	66	71	13.8	17.9	21.4	25.1
1966	30	33	38	49	6.8	7.9	10.1	11.8
1967	46	52	57	71	10.9	14.0	17.2	21.7
1968	39	41	45	48	8.5	10.6	12.7	15.1
1969	46	54	50	46	11.6	15.1	15.2	15.2
1970	41	35	49	61	8.0	10.5	13.3	19.5
1971	59	59	79	0	19.1	20.4	26.3	30.0
1972	64	79	72	77	17.1	23.6	24.3	28.6
1973	31	34	45	50	7.6	8.3	9.9	12.9
1974	44	46	67	63	11.6	12.9	19.2	22.1
1975	47	45	60	65	10.4	13.1	16.2	22.2
1976	48	56	69	71	16.1	15.7	21.8	25.5
1977	18	20	35	25	3.3	3.8	7.6	6.6
1978	52	61	59	60	15.8	18.9	22.3	22.6
1979	43	47	49	47	11.6	13.3	12.9	16.2
1980	41	43	53	43	9.3	11.8	15.6	15.7
1981	31	37	51	41	7.2	9.6	12.1	13.3
1982	55	56	68	67	14.8	15.6	17.4	21.6
1983	37	47	55	64	9.2	12.6	14.0	19.6
1984	41	-9	51	74	10.6	11.3	13.8	17.0
1985	41	55	57	50	10.0	11.6	14.2	13.0
1986	44	76	68	75	11.4	20.8	22.0	25.2
1987	49	50	53	43	12.2	13.0	15.2	15.0

SHERIDAN RANGER STATION SNOW DEPTH AND WATER EQUIVALENT DATA

	SNOW DEPTHS (INCHES)				WATER EQUIVALENTS (INCHES)			
YEAR	FEB	MAR	APR	MAY	FEB	MAR	APR	MAY
1936	-9	-9	34	2	-9.9	-9.9	8.6	1.0
1937	-9	18	17	7	-9.9	3.0	2.7	3.0
1938	-9	13	22	0	-9.9	2.9	5.2	0.0
1939	-9	24	16	1	-9.9	3.1	4.1	0.5
1940	-9	16	8	0	-9.9	4.0	2.7	0.0
1941	18	21	19	0	3.7	4.6	5.7	0.0
1942	16	17	20	0	2.3	3.0	4.1	0.0
1943	44	44	45	4	11.8	13.6	13.6	1.5
1944	10	12	15	0	1.5	2.7	3.9	0.0
1945	15	22	21	0	3.3	5.4	5.8	0.0
1946	21	23	21	0	3.0	5.1	4.2	0.0
1947	24	27	26	9	5.4	4.4	7.6	3.0
1948	-9	28	27	10	-9.9	5.7	5.8	2.0
1949	26	31	32	0	6.0	8.2	8.2	0.0
1950	26	23	28	8	5.9	7.0	7.3	3.0
1951	29	34	36	14	7.3	10.1	10.6	4.0
1952	24	29	28	0	5.7	6.9	7.5	0.0
1953	27	27	25	13	6.2	7.8	8.3	5.5
1954	26	26	38	10	4.8	7.2	10.8	4.0
1955	18	21	31	13	2.8	3.8	7.4	3.0
1956	38	38	40	34	9.2	10.3	11.9	10.7
1957	27	27	31	31	4.8	6.3	7.8	8.8
1958	22	23	28	19	3.4	7.1	6.2	3.2
1959	21	30	30	14	3.8	6.5	7.1	2.9
1960	18	24	22	12	2.4	4.2	5.6	0.5
1961	20	22	20	10	3.2	2.6	4.5	1.4
1962	32	36	37	9	7.1	9.1	9.3	1.2
1963	22	28	27	22	3.9	7.4	8.3	7.4
1964	25	25	36	22	4.8	4.4	8.2	4.9
1965	32	37	41	22	8.7	9.6	10.4	6.5
1966	22	24	23	10	4.2	4.6	5.5	1.6
1967	28	31	29	25	5.8	8.1	8.6	8.2
1968	24	26	22	10	3.7	5.8	5.5	2.5
1969	28	31	28	0	6.0	7.8	7.4	0.0
1970	29	23	26	25	4.8	6.2	6.7	8.0
1971	28	28	37	33	6.5	7.0	9.4	11.3
1972	36	38	33	25	8.7	11.1	11.5	9.3
1973	18	19	24	14	3.8	4.1	4.0	3.9
1974	24	31	34	22	5.8	6.9	8.8	6.6
1975	24	26	39	31	4.6	6.0	9.1	9.2
1976	27	41	41	24	6.2	9.7	11.1	3.0
1977	9	9	13	0	1.1	1.6	2.4	0.0
1978	29	34	28	0	7.0	9.2	8.9	0.0
1979	33	34	30	16	8.3	9.0	7.6	4.5
1980	25	22	25	0	5.8	5.8	7.2	0.0
1981	12	15	16	0	2.4	3.4	4.4	0.0
1982	34	30	36	25	7.6	8.6	9.6	8.4
1983	17	20	21	12	3.6	3.6	4.8	3.0
1984	20	-9	22	14	4.6	5.4	6.1	3.9
1985	16	22	23	0	2.9	4.7	4.8	0.0
1986	21	41	27	3	4.7	11.2	9.0	0.6

ST LAWRENCE RANGER STATION SNOW DEPTH AND WATER EQUIVALENT DATA

YEAR	SNOW DEPTHS (INCHES) FEB	MAR	APR	MAY	WATER EQUIVALENTS (INCHES) FEB	MAR	APR	MAY
1941	10	12	31	29	1.8	1.9	6.8	9.0
1942	16	19	21	7	3.5	4.5	4.8	1.6
1943	48	46	43	29	12.4	14.5	13.9	11.3
1944	14	20	25	53	1.8	3.2	6.1	12.4
1945	-9	-9	-9	-9	1.7	2.8	4.4	9.5
1946	-9	-9	-9	-9	5.0	5.9	7.2	1.4
1947	20	24	19	22	3.9	4.6	4.5	5.3
1948	-9	-9	-9	-9	-9.9	4.4	5.0	7.1
1949	23	31	35	14	5.6	8.8	10.0	4.6
1950	32	29	39	30	8.4	8.2	10.2	10.0
1951	18	20	28	24	3.4	4.2	7.0	7.1
1952	25	31	37	28	5.6	8.4	10.4	9.2
1953	17	23	21	17	4.2	6.4	6.0	5.0
1954	20	25	35	16	4.0	6.0	9.2	5.8
1955	7	18	23	20	1.3	3.6	6.4	7.2
1956	30	32	28	34	8.6	9.5	9.9	9.0
1957	18	19	23	39	3.6	4.0	5.5	11.6
1958	12	13	14	27	1.9	2.0	3.2	5.9
1959	11	19	30	21	1.9	4.2	5.7	5.7
1960	17	18	11	4	2.4	4.6	3.1	1.0
1961	9	15	21	13	2.3	3.2	5.0	3.9
1962	25	34	36	22	6.1	9.1	9.3	7.2
1963	12	13	22	30	1.8	3.4	6.3	8.3
1964	17	23	30	36	3.7	4.8	7.2	8.7
1965	35	35	40	35	10.1	10.4	12.2	11.2
1966	15	16	15	11	3.4	3.9	3.3	3.1
1967	27	30	38	45	6.6	8.2	9.9	12.5
1968	22	24	28	33	4.3	5.6	7.3	9.8
1969	25	21	27	19	5.1	5.6	7.8	7.2
1970	17	13	26	40	3.3	3.0	5.7	9.2
1971	25	36	37	65	7.0	8.5	10.1	16.3
1972	31	28	25	28	7.8	8.1	8.3	9.1
1973	25	24	32	38	4.7	5.9	7.2	9.7
1974	16	23	31	35	3.6	5.0	8.2	11.0
1975	16	17	30	31	3.4	4.7	6.1	9.7
1976	15	22	30	37	4.2	5.2	8.4	9.4
1977	8	8	23	7	1.8	1.5	4.9	2.3
1978	17	20	16	15	3.0	3.4	3.8	3.0
1979	26	26	32	24	5.2	5.4	7.2	6.8
1980	24	23	54	22	4.9	6.1	10.3	7.4
1981	18	14	29	14	3.0	3.6	6.8	4.2
1982	13	12	16	10	2.2	2.8	3.8	3.0
1983	11	-9	28	30	3.0	4.9	6.4	9.0
1984	26	-9	37	44	6.9	7.4	8.8	12.0
1985	15	30	28	0	2.9	4.4	5.9	0.0
1986	26	46	42	42	6.9	12.0	10.8	12.0
1987	21	32	36	17	5.2	7.9	9.3	6.3

T-CROSS RANCH SNOW DEPTH AND WATER EQUIVALENT DATA

YEAR	SNOW DEPTHS (INCHES) FEB	MAR	APR	MAY	WATER EQUIVALENTS (INCHES) FEB	MAR	APR	MAY
1941	14	17	20	10	2.5	3.3	4.9	2.8
1942	13	17	18	0	1.9	3.3	3.6	0.0
1943	56	46	58	18	15.4	16.0	21.1	9.8
1944	12	12	15	0	2.3	2.5	3.4	0.0
1945	12	20	14	9	2.3	4.0	3.8	2.3
1946	21	22	21	0	3.6	5.1	4.2	0.0
1947	25	30	26	22	5.2	6.6	6.8	4.8
1948	21	25	25	12	4.5	5.2	6.0	3.1
1949	27	30	31	0	5.7	7.8	7.8	0.0
1950	31	25	30	21	5.4	6.7	7.9	7.0
1951	33	39	40	25	8.4	11.8	14.0	9.2
1952	19	22	25	15	3.6	5.2	7.8	6.0
1953	28	26	23	17	6.2	7.8	7.2	6.4
1954	31	31	38	19	6.2	7.0	9.4	6.4
1955	11	15	25	10	1.8	3.2	6.0	3.4
1956	34	33	34	31	8.6	9.0	10.8	9.8
1957	18	22	24	26	3.3	5.2	6.1	7.6
1958	13	13	18	11	3.6	2.3	3.5	2.1
1959	22	30	26	13	4.7	6.2	6.9	4.7
1960	11	17	12	4	2.4	3.1	3.1	0.5
1961	12	19	19	4	2.6	3.7	4.4	1.2
1962	26	29	30	1	5.7	7.6	7.5	0.2
1963	21	25	21	19	4.1	7.0	6.4	6.5
1964	19	18	29	14	4.0	4.2	5.9	4.2
1965	37	39	48	32	11.2	12.3	13.5	10.6
1966	21	22	20	6	5.1	5.2	5.6	1.9
1967	20	24	22	14	4.6	5.7	6.0	4.6
1968	18	19	16	1	3.3	3.7	3.0	0.2
1969	23	29	24	0	5.6	6.9	6.5	0.0
1970	27	19	24	31	5.2	5.0	6.1	9.8
1971	31	35	37	29	8.4	8.7	10.6	10.7
1972	38	42	28	15	8.6	11.6	10.3	5.7
1973	18	20	29	15	4.1	4.4	4.7	4.3
1974	26	30	35	13	6.0	6.9	8.7	3.9
1975	24	25	35	33	5.2	6.0	8.5	10.0
1976	28	45	41	20	5.4	10.1	11.4	7.8
1977	0	1	6	0	0.0	0.1	1.2	0.0
1978	31	38	29	5	9.0	11.5	10.2	1.7
1979	33	34	27	14	8.3	9.2	8.2	3.3
1980	29	25	33	0	6.6	7.4	9.2	0.0
1981	12	15	18	0	2.4	3.6	4.8	0.0
1982	33	34	31	21	6.9	9.0	9.2	6.6
1983	17	21	22	14	3.8	4.4	4.6	3.4
1984	21	24	23	9	3.8	4.5	5.3	2.6
1985	20	25	26	1	3.6	5.0	5.8	0.4
1986	21	54	35	17	4.5	12.0	11.8	5.8
1987	22	30	29	0	5.0	6.0	7.2	0.0