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RECENT GLACIER CHANGES IN THE WIND RIVER RANGE, WYOMING

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Abstract: Parallax measurements on matching aerial photograph stereopairs from 1958 and 1983 were used to calculate the ice lost from Dinwoody Glacier in the Wind River Range of Wyoming. The ice remaining in Dinwoody Glacier was measured using a portable radio echo-sounder. Isopach maps of lost ice thickness and remaining ice thickness in the glacier were constructed from these point measurements. Calculations of lost and remaining ice volumes, converted to water-equivalent values, were derived from planimetric measurements from these isopach maps. The water equivalent remaining in Dinwoody Glacier is approximately equal to that lost between 1958 and 1983. Should this rate of downwasting and retreat continue, Dinwoody Glacier will disappear in 27 years, with significant adverse impacts on late summer and early fall water supplies for downstream irrigators and instream flow needs. [Key words: glaciers, glacier runoff, radio echo-sounding, Wind River Range, Wyoming.]

INTRODUCTION

Runoff from the Wind River Range contributes to three major continental-scale drainage basins: the Missouri-Mississippi, Green-Colorado, and Snake-Columbia (Fig. 1). Glacier melt supplements water supplies in the late summer and early fall when irrigation demand remains high and other sources of runoff have diminished (Marston et al., 1989; Pochop et al., 1990). Progressive recession and downwasting of glaciers reduces their value as a source of runoff. Mass balance trends for

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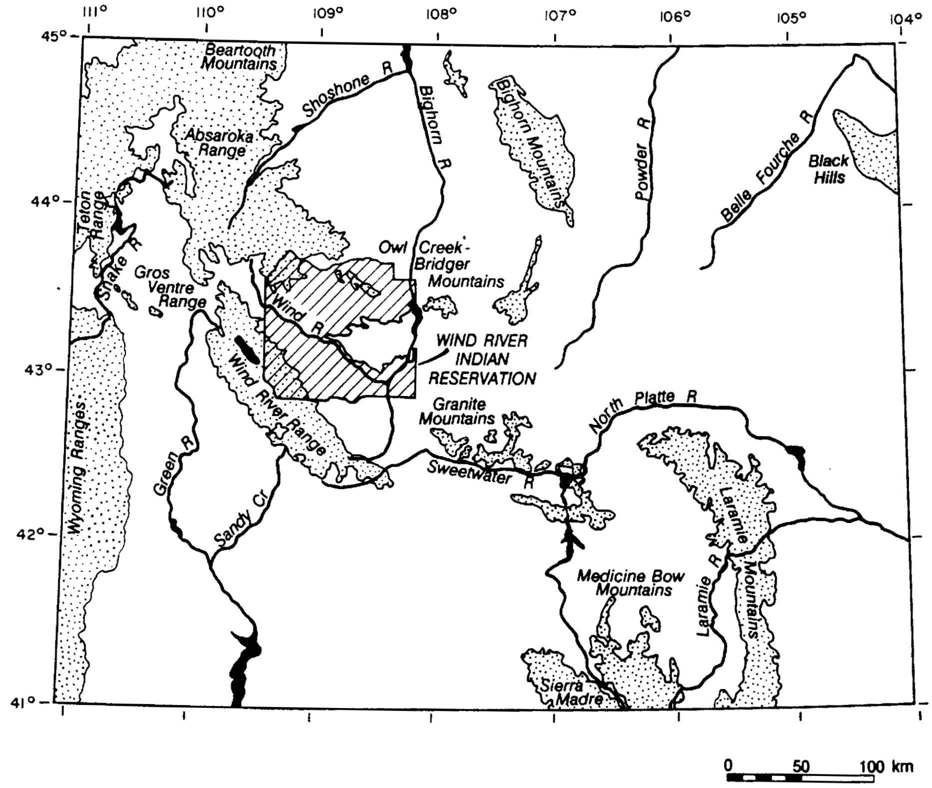

Fig. 1. Glaciers of the Wind River Range, Wyoming (solid tone area within the range), in relation to the Wind and Green river drainages and the Wind River Indian Reservation.

glaciers in the Wind River Range over the last three decades have not been quantified. The purpose of this study is to determine the water equivalent lost and the water equivalent remaining in storage for Dinwoody Glacier in the Wind River Range.

ENVIRONMENTAL SETTING

The Wind River Range, a large discrete mountain mass in west-central Wyoming, extends approximately 200 km from northwest to southeast forming a major orographic barrier to air masses moving southward and eastward (Fig. 1). Annual precipitation ranges from 200 mm at the base of the range to 1000 mm at the crest. Most precipitation occurs as winter snow, with a mean annual snowfall (1951–1980) of 1.5 to 5.1 m (Martner, 1986).

The total area of glaciers in the Wind River Range, 37.8 km^2 in 1983, is larger than that of all other glaciers in the American Rocky Mountains (Davis, 1988; Field, 1975; Meier, 1951). Seven of the 10 largest glaciers in the American Rocky Mountains are located in the Wind River Range. Dinwoody Glacier, the fourth largest with an area of 2.91 km^2, and Gannett Glacier, the largest with an area of 3.33 km^2 (Pochop et al., 1990), represent 16.5% of the total glacier area in the Wind River Range. Glaciers in the central section of the range are restricted to elevations over 3400 m. Present ice in these glaciers is considered to have accumulated during the Little Ice Age (Dyson, 1952), but Love and Thompson (1987) and Thompson and Love (1988) cited evidence that the ice may date back to the Audubon advance, 3000 y B.P. Of the total area of glaciers in the Wind River Range, 77% is situated in the Wind River drainage. The remainder is in the Green River drainage.

Dinwoody Glacier, the subject of this study, has been described by Meier (1951) as having a palmate shape with steep tributary fingers of ice feeding into a large, gently sloping central basin from which a small tongue reaches farther downslope. The tributary glaciers are clean and crevassed, in contrast to the central basin, which is littered with abundant coarse debris and is uncrevassed. The terminus is located at an elevation of 3414 m. The glacier contributes meltwater to Dinwoody Creek which joins the Wind River near the west (upstream) edge of the Wind River Indian Reservation (Fig. 1). The Wind River is a subdrainage of the Bighorn-Yellowstone-Missouri-Mississippi system. Annual runoff in the Wind River drainage is critical for irrigation and instream flow requirements of fisheries (Ostresh et al., 1990).

LOST GLACIER STORAGE

According to most authors (e.g., Dyson, 1952; Mears, 1972; Meier, 1951), glaciers in the Wind River Range have generally been in a negative regime since 1850, the approximate end of the Little Ice Age. Wentworth and Delo (1931), however, reported that Dinwoody Glacier had readvanced by 1930 to its position of greatest advance during the late Neoglacial. The area of Dinwoody Glacier as of 1930 was estimated to be 3.85 km^2 by Dyson (1952). Pronounced retreat occurred at substantial rates during the 1930s, slowing after 1940, with terminal retreat becoming negligible between 1945 and 1950 (Meier, 1951). In 1950 the area was estimated to be 3.47 km^2. Meier and Post (1962) documented renewed retreat in 90% of the Wind River glaciers in the 1950s. By 1958 the area of Dinwoody Glacier had been reduced to 3.44 km^2. No quantitative studies have been forthcoming of glacier retreat or glacier downwasting in the Wind River Range since 1960.

Substantial downwasting in the Wind River Range glaciers over the past five decades was qualitatively revealed by repeat ground photography of Dinwoody Glacier. Following procedures of Harrison (1960) and Rogers et al. (1984), photographs from mountaineering expeditions in 1935 were compared to photographs taken in summer 1988 from the 1935 photo positions (Fig. 2a and 2b).

Quantitative measures of change in Dinwoody Glacier volume were obtained from analyses of aerial photograph stereopairs taken late in the ablation seasons of 1958 and 1983. A vertical measurement module, fitted to a stereo zoom transferscope, computed the elevation of 23 points on the glacier. Points were chosen with the aid of a random numbers table. Points in areas of clean ice were eliminated because the vertical measurement module could not produce an accurate parallax measurement. Lost ice thickness values computed for the points were field-

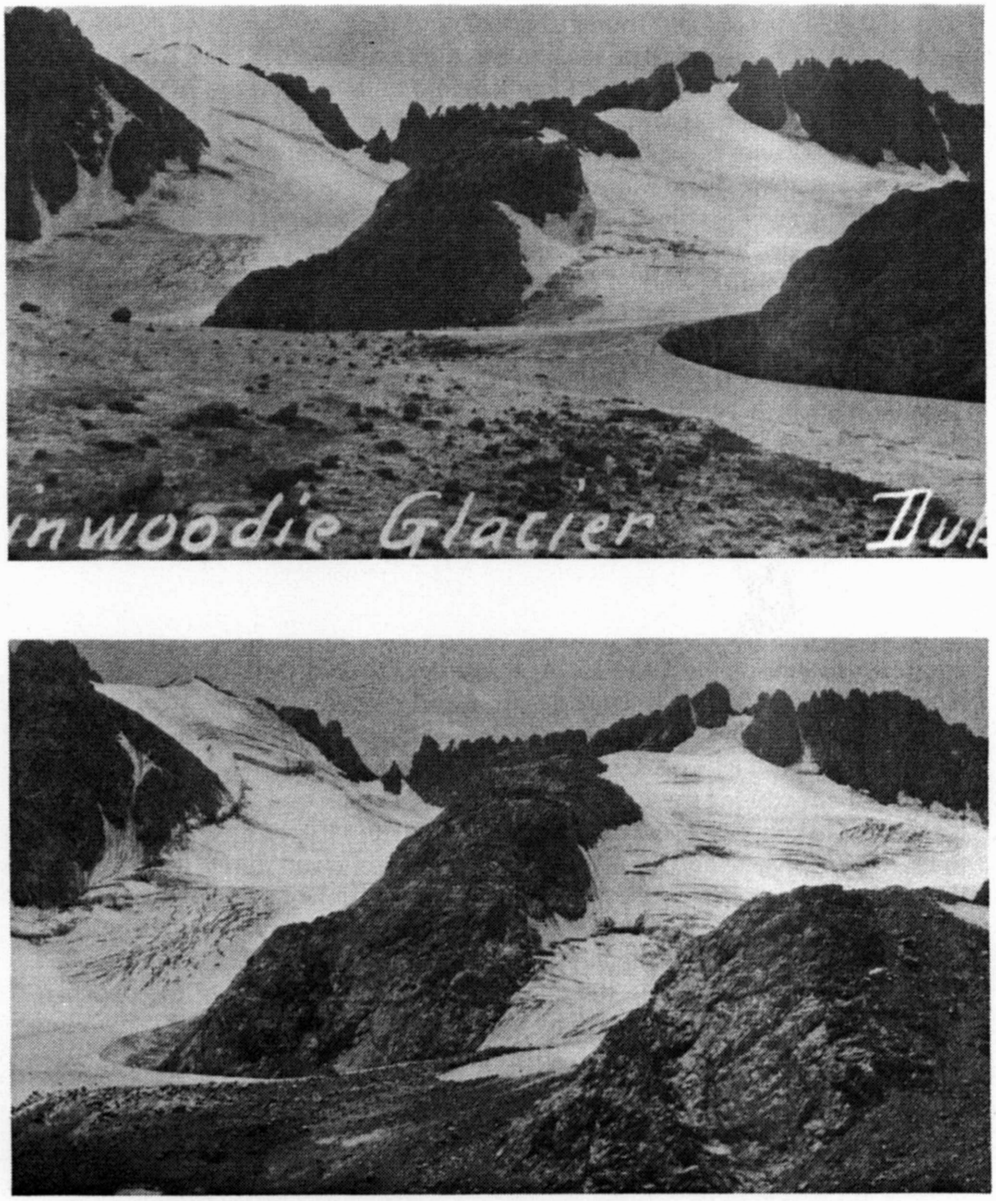

Fig. 2. Repeat photographs of Dinwoody Glacier, 1935 (2a) and 1988 (2b). Photograph from 1935 from the C.W. Brandon Collection (#366), courtesy of the American Heritage Center at the University of Wyoming. Photo for 1988 by the authors. The striking change in ice thickness is most evident upon comparing the elevation of the glacier surface adjacent to bedrock berms on the two photos.

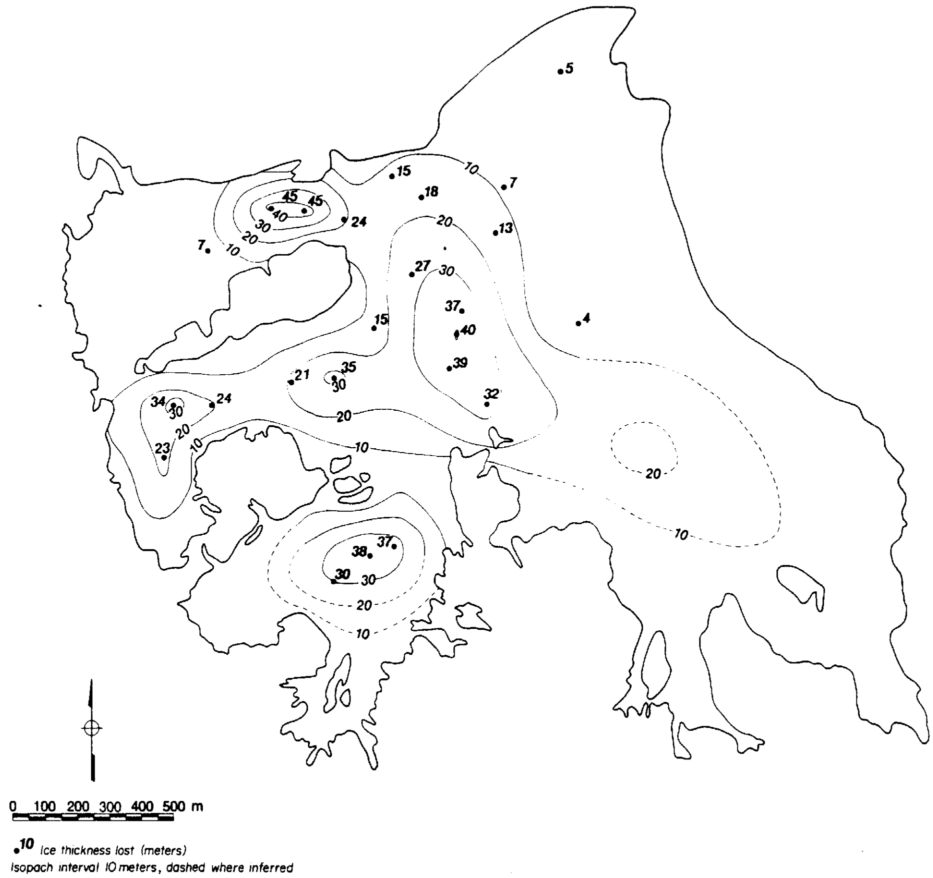

Fig. 3. Isopach map of ice thickness lost. Points of known value were derived by parallax measurements with the stereo zoom transferscope and field checked. Isopachs were drawn with the PLOT88 software package using a combination of spline and Laplacian interpolation algorithms.

checked in summer 1989 by comparing altimeter readings on the glacier surface with elevations on 1958 topographic maps. The maximum error found was 1.5 m (6.6%).

The volume of ice lost between 1958 and 1983 was calculated by planimetry from an isopach map of lost ice thickness (Fig. 3). Isopachs were dashed where measurement points were lacking. The greatest losses of ice thickness occurred in high elevation cirques on the south and west, and in the central portion of the glacier fed by those tributary glaciers. Normally, downwasting is inversely related to elevation. The reverse trend in this case may be explained by ice stagnation, by surging of the ice out of steep cirque basins, or by higher incoming longwave radiation affected by surrounding terrain. Areal reduction of 0.53 km^2 was limited to the terminus. The combination of an areal reduction of 15.4% and an average reduction in firn-ice thickness of 23 m yielded a volume lost of 80 x 10^6 m^3. To convert this volume to a water-equivalent value, a density of 800 kg/m^3 was used.

This value is justified as an average of the lower density old snow and firn and the higher density glacier ice which would have been lost. Moreover, this value is reliable for Dinwoody Glacier where the downwasting and retreat occurred at a faster rate than the residence time of ice in the glacier as documented by Meier (1951). The water equivalent lost from Dinwoody Glacier between 1958 and 1983 was 64 x 10^6 m^3. This compares with an estimated loss of 59 x 10^6 m^3 in water equivalent from Gannett Glacier. A simple area-weighted extrapolation results in a water-equivalent of 745 x 10^6 m^3 lost from the entire Wind River glacier field, or an average of 29.8 x 10^6 m^3/yr.

REMAINING GLACIER STORAGE

A portable radio echo-sounder was utilized to determine the remaining water stored in Dinwoody Glacier based upon the approach described by Driedger and Kennard (1986), Jacobel et al. (1988), Watts and England (1976), and Watts and Wright (1981). Ice thickness was calculated for 62 radio echo-sounding sample points during summer 1989, with values ranging up to 111 m. An isopach map of remaining ice thickness was prepared (Fig. 4). In the inaccessible portions of the glacier, isopachs were inferred by first estimating glacier volume with an equation for small glaciers (Driedger and Kennard, 1986):

$$V = 3.93A^{1.124}, \qquad (1)$$

where A is area (m^2) and V is estimated volume (m^3).

The greatest ice thickness remains in the central basin and southern and eastern cirques. Planimetry of the isopach map revealed a remaining ice volume of 78 x 10^6 m^3. Assuming a density of 880 kg/m^3, the water-equivalent remaining in the glacier as of 1989 was 69 x 10^6 m^3.

Driedger and Kennard (1986) used a radio echo-sounder to derive a remaining ice volume in Dinwoody Glacier of 80 x 10^6 m^3. This volume was calculated from nine sample points along a single transect on the glacier. Using a basal shear-stress relation, they estimated the total volume at 100 x 10^6 m^3. However, after testing the basal shear-stress relation against measured ice volumes in the portions of the glacier with good control on depth provided by the radio echo-sounding, the present study found the basal shear-stress approach overestimated glacier volume. The basal shear-stress relation assumes the glacier has attained plastic deformation at its base, a condition which would eventually lead to an equilibrium profile. However, internal deformation is not likely to be found on Dinwoody Glacier and an equilibrium profile cannot be expected on a palmate-shaped glacier. Post et al. (1971) and Muller (1976) used methods where glaciers were assigned volumes according to various size classes. These size-class relations derived estimated volumes of 95 x 10^6 m^3 and 34.8 x 10^6 m^3 respectively. Macheret and Zhuravlev (1982) developed an area relation from radio echo-sounding of polar glaciers on Svalbard. The exponent is nearly identical to that in equation (1) but the coefficient is approximately three times greater. The estimated volume for Dinwoody Glacier using this equation is only 9.12 x 10^6 m^3.

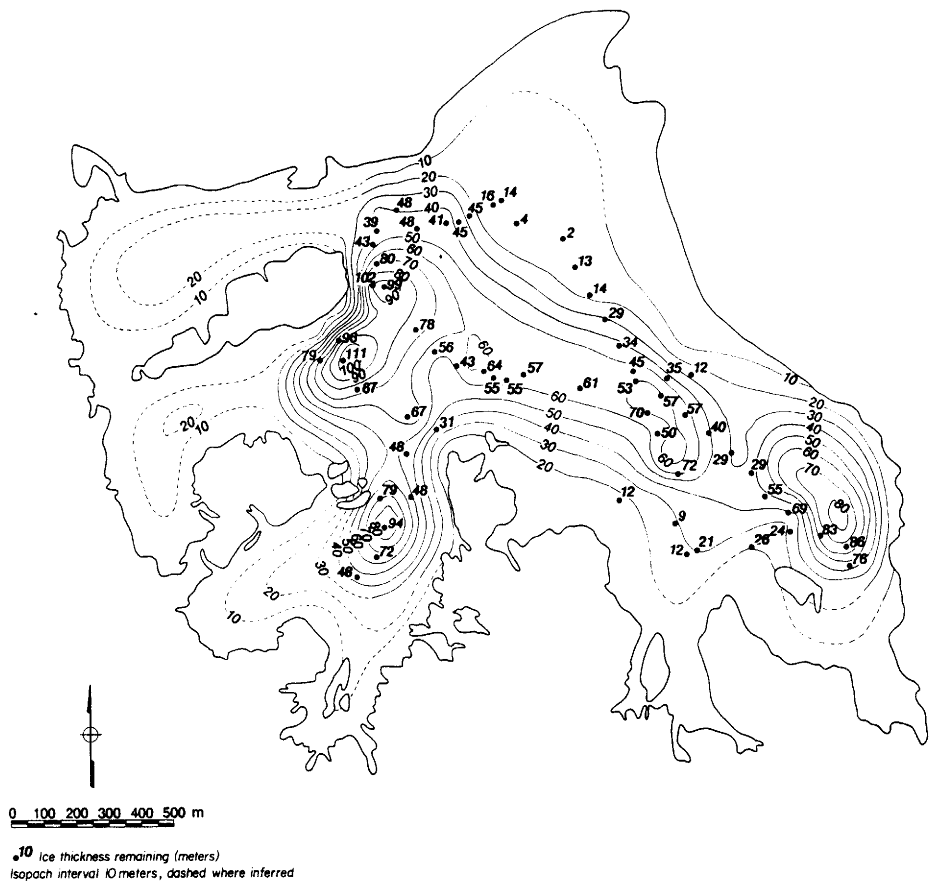

Fig. 4. Isopach map of ice thickness remaining. Points of known value were derived by radio echo-sounding. Isopachs were drawn with the PLOT88 software package using a combination of spline and Laplacian interpolation algorithms.

Assuming the rates of retreat and downwasting for the 1958–1983 period continue, Dinwoody Glacier will disappear in 27 years. Although quantitative data on downwasting are lacking, other glaciers in the Wind River Range show generally greater rates of retreat (Thompson and Love, 1988). The loss of runoff will restrict downstream water consumption in Wyoming, particularly on the Wind River Indian Reservation. In June 1989, after 12 years of litigation, the U.S. Supreme Court awarded the Indians reserve water rights of 617×10^6 m^3/yr. This is 30 times the amount of water lost annually from glacier storage between 1958 and 1983. Irrigation headgates have been closed to non-Indian irrigators as late summer water shortages occur. At the same time, the Indians intend to dedicate 21–29% of their reserve water for protection and maintenance of fisheries, a move that is causing bitter regional conflicts.

CONCLUSION

The volume of firn-ice/water lost from Dinwoody Glacier between 1958 and 1983 approximated the volume of ice/water remaining in 1989. Meltwater from glaciers on the northeast slope of the Wind River Range contributes significantly to overall runoff to the Wind River Reservation. If present trends of glacier retreat and downwasting continue, Wind River Range glaciers will disappear within the next three decades, exacerbating regional conflicts over the degraded water supply.

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