HYDRO-CLIMATOLOGICAL TRENDS AND VARIABILITY IN MOUNTAINS OF THE WESTERN UNITED STATES[1]

Growing demands for optimum use of available water resources, with increased attention on environmental considerations, have focused attention on the need for more accurate advance knowledge of the flow of rivers fed by the melting snowpack of our western mountains. This in turn has caused streamflow forecasters to examine the basic data networks on which they must rely in preparing their forecasts.

As might be expected, the watershed areas with the least satisfactory data networks are those which are too remote and inaccessible for winter travel to headwater areas to obtain needed data. Most of these areas are included in the land designated as a part of the National Wilderness Preservation System and parts of National Forests classified as "primitive". The Wilderness Act (P. L. 88-577) passed in 1964, and subsequent regulation implementing the act, placed restrictions which prohibit the use of helicopters, oversnow vehicles, and modern telemetering equipment within the designated areas.

Wilderness and primitive areas are generally rough, inaccessible, undeveloped, high mountainous areas. Many of these areas are situated along the basin divides where precipitation, snow accumulation, and water yield are a maximum for the watersheds concerned. The Forest Service reports that as of July 1, 1968, 14.5 million acres of land in National Forests of the United States were designated as wilderness and primitive areas. Of this, 13.7 million acres are in the eleven western states.

Until recently, because of remoteness and inaccessibility with attendant hazard to human life, efforts to obtain hydrometeorological data from these areas have been very limited. Recent development of remote sensing and telemetry equipment, improved helicopter capabilities and more versatile motorized oversnow equipment have made data gathering from these remote areas more feasible. In addition, intensified water resource development to serve an expanding population has accentuated the need for more accurate knowledge of the water supply potential of these areas.

The Wilderness Act made no provision for using new techniques in collecting data. Manual collection is permitted providing nothing is disturbed. Constructing shelter cabins is not permitted. The technological and physical limitations which have given us our greatest problems in the past could be overcome if the legal restraints of the Wilderness Act were removed.

While these restraints continue, attempts to improve forecasting relationships have continued thru studies of the interrelationships of the mountain snowpack, precipitation, and streamflow records collected on the periphery of the wilderness and primitive areas. Present analysis has shown that in some areas for which studies have been completed, shifting climatic trends and yearly variability

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Figure 1. Snowpack Variability across High Uintas Primitive Area, Utah– North to South

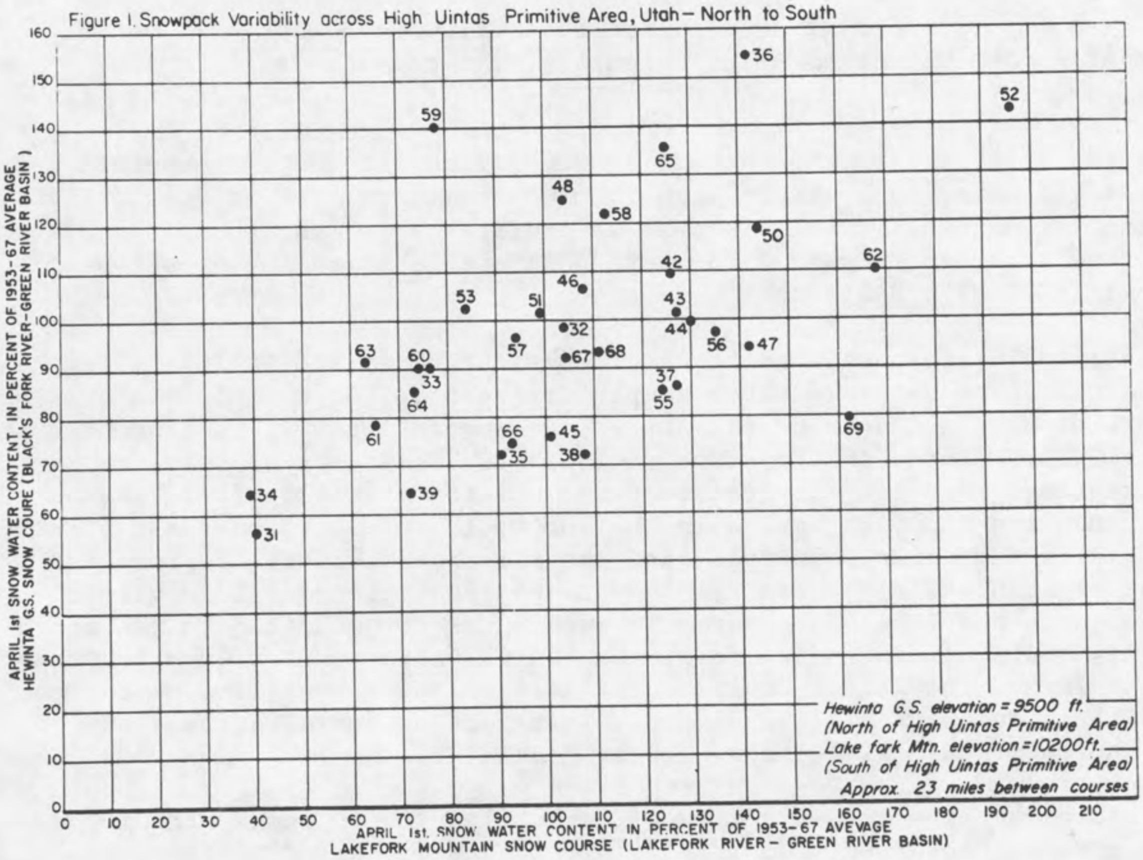
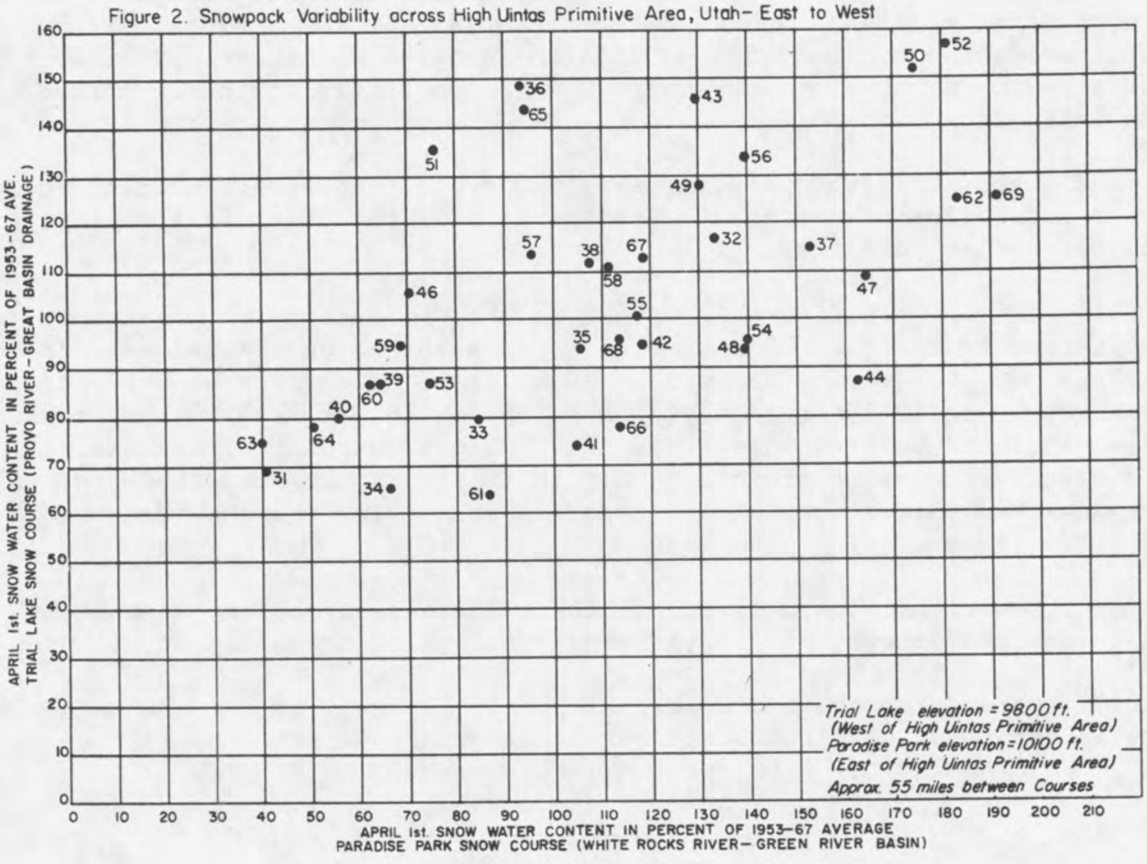


Figure 2. Snowpack Variability across High Uintas Primitive Area, Utah– East to West



are so marked that it seems that adequate streamflow forecasts will not be provided until data networks, using telemetry, can be extended into the restricted areas.

Figures 1 and 2 illustrate the extreme yearly variability of the mountain snowpack across the watersheds of the High Uintas Primitive Area in Utah. Figure 1 illustrates the variability within a 23-mile distance from north to south across the primitive area, and Figure 2 shows an equal variability in an east-west direction in a 55-mile distance.

The variability in snowpack conditions creates extremely difficult problems in trying to prepare reliable water supply forecasts. For example, in 1959 on the north side of the mountains the April 1st snowpack was 140 percent of average at Hewinta G.S., whereas on the south side it was 79 percent at Lakefork Mountain and 69 percent at Paradise Park (east of the primitive area). There was no way of knowing how the snowpack varied in the short distance between these points across the primitive area. In this case the snowpack variation represented the difference between a flood potential and drought conditions. It is also of interest to note that the above normal snowpack was not confined to the north side of the mountains, as indicated by the King's Cabin courses 20 miles east of Paradise Park. The King's Cabin courses are on the south slope of the mountains and had a snowpack of 113 percent. This further confused the issue of just how the snowpack varied through these mountains.

The 1969 snowpack shows the same type of variability north and south of the primitive area but reversed from 1959. In this case it was 79 percent at Hewinta G.S., with 162 percent at Lakefork Mountain, 192 percent at Paradise Park. Here again, did the heavy southern snowpack continue far enough to the north to constitute a dangerous high water potential for south slope streams? Did it continue far enough onto the north slope to promise an average or better water supply on the north slope streams? How far south did the below normal conditions at Hewinta extend?

Figures 3 and 4 show that snowpack variability across the Bridger-Glacier and Bridger-Popo Agie Wilderness areas in Wyoming is also too great for preparing acceptable streamflow forecasts.

The year 1944, as shown in Figure 3, serves to show the economic impact that could result from an inaccurate streamflow forecast based on a false assumption of the way the snowpack varies across the 20 miles of wilderness area separating the snow courses. In 1944 the snow at the Dutch Joe snow course in the Green River drainage of the Colorado River basin was only 52 percent of average, indicating severe drought conditions. Only 20 miles away at Mosquito Park, on the Popo Agie - Wind River drainage of the Missouri basin, the snowpack was 117 percent of average.

In such a year additional readings across the wilderness areas are absolutely essential before the drought and above normal streamflow areas can be defined.

The historical record for the two courses shown in Figure 4 is shorter than for Figure 3, but these also show unacceptable snowpack variability in the

Figure 3. Snowpack Variability Across Bridger-Popo Agie Wilderness Areas – East to West

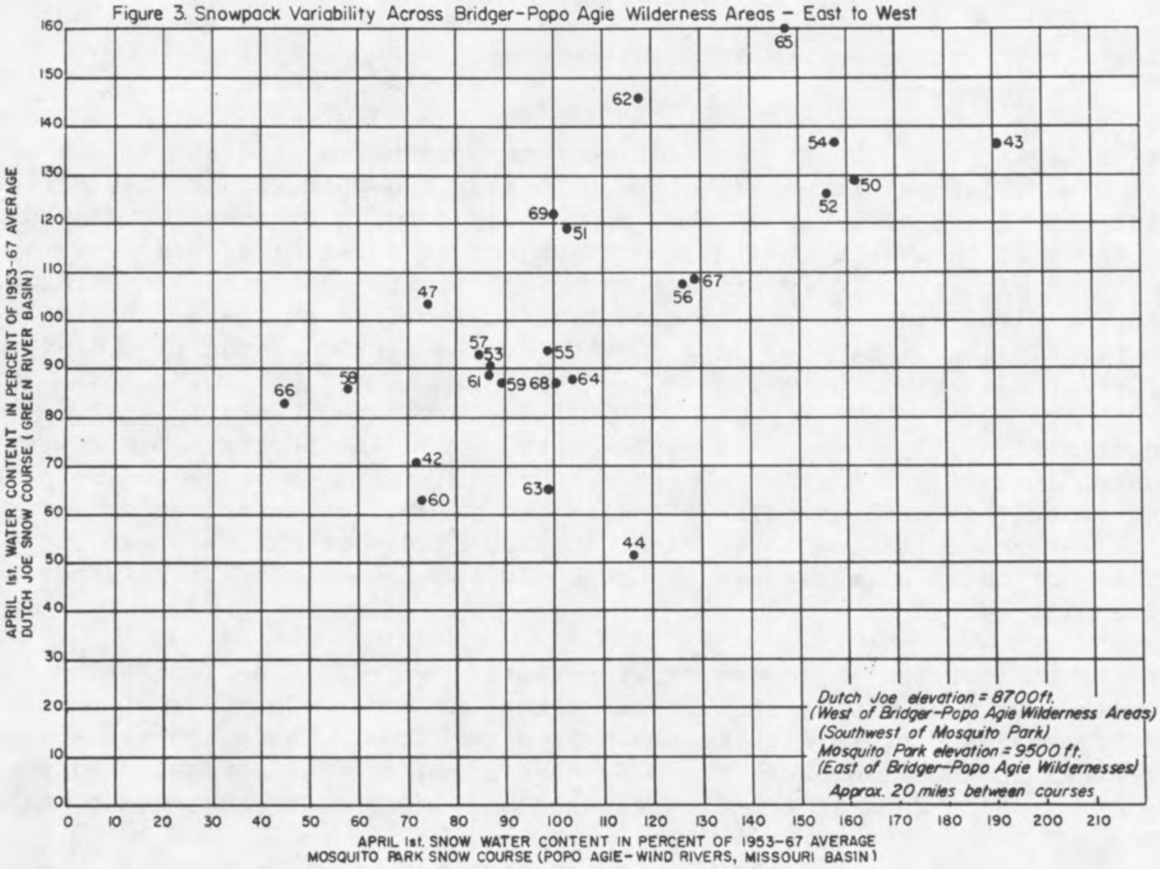
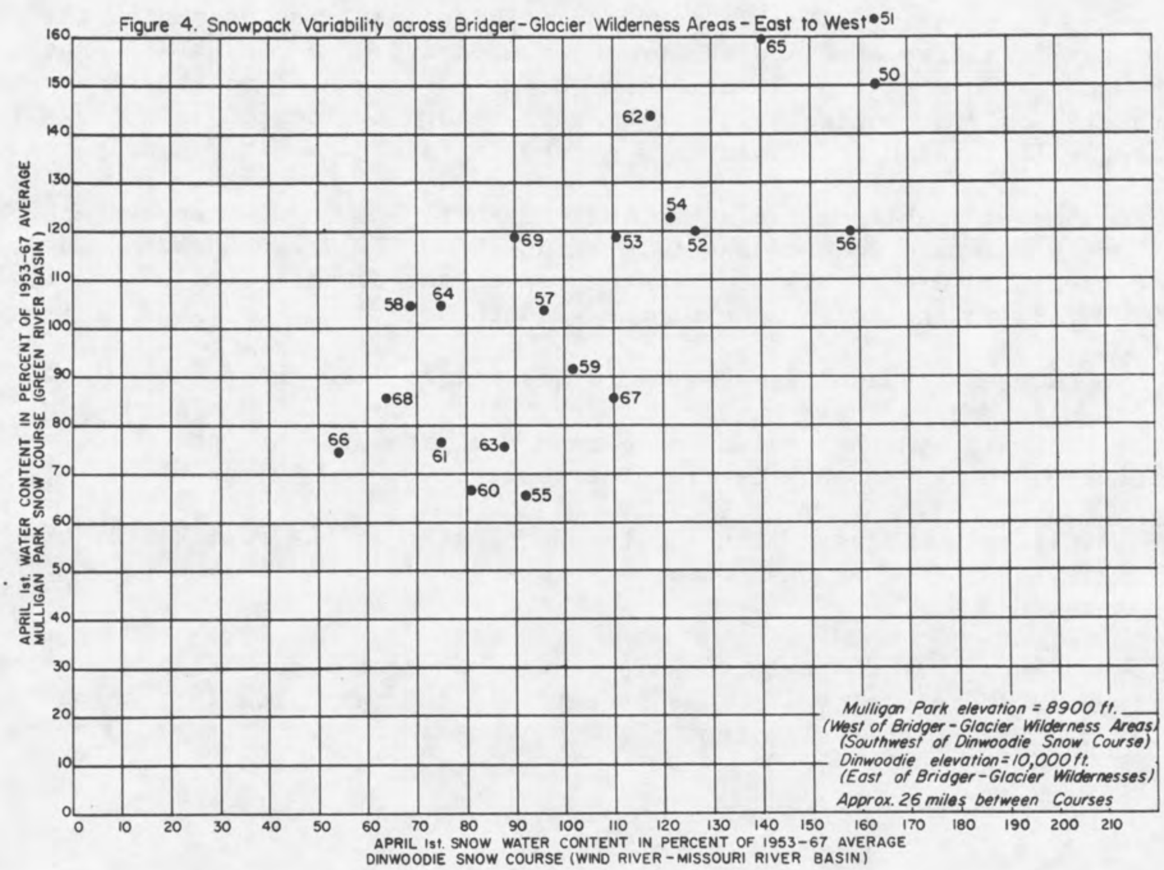


Figure 4. Snowpack Variability across Bridger-Glacier Wilderness Areas - East to West



26 miles across the Bridger-Glacier Wilderness Areas.

Figure 5 shows that snowpack conditions in the San Juan and Upper Rio Grande Primitive Areas of southwest Colorado were more stable during the 1950's and 60's than in the two areas discussed before. However the year 1958 raises serious questions as to the adequacy of the snow course network on these watersheds, particularly if this area should become subject to a series of years during which storm systems would experience changing climatic patterns. Such changing climatic patterns might be due to either natural causes or weather modification activities, as indicated in a further consideration of the High Uintas Primitive Area as given below.

As shown in Figure 5, the 1958 snowpack varied from 161 percent of average at the western end of the San Juan-Upper Rio Grande Primitive Areas to 105 percent at the eastern end approximately 52 miles away. Weather modification activities could affect precipitation patterns at one end of the primitive areas but not at the other, or could affect areas in between without showing any influence at either end.

Wilderness managers have proposed that portable recording instruments be temporarily placed on measuring points inside the wilderness. Then, after a calibration period of perhaps 5 years with telemetered data sites outside the wilderness area, measurements in the wilderness would be discontinued. The portable equipment would only provide data at the site which could be used for subsequent analysis.

Figures 6 to 9 show that climatic relationships in the Uinta Mountains of Utah which have been relatively constant for as long as 20 years can experience major changes due to changing climatic patterns. These mountains encompass the present High Uintas Primitive Area and the proposed expanded High Uintas Wilderness Area. Under such changing climatic conditions no length of calibration period is adequate--only a continuing, year-by-year record at locations in the wilderness area will furnish the basic data needed for accurate water supply forecasts.

Figure 6 shows a double mass plotting of the April 1st snow water content of the Lakefork Mountain snow course (elevation 10200 ft.) on the south side of the proposed High Uintas Wilderness Area versus the Hewinta G.S. course (elevation 9500 ft.) on the north side of the wilderness area.

These two courses are approximately 23 miles apart. They have had no environmental changes during their entire history. The record is continuous for Lakefork Mountain, whereas values have been estimated for Hewinta G.S. from other courses on the north slope for the years 1940, 41, 49 and 54.

Although this type of graph plotting tends to mask out the variability of individual years, it does show when major changes occur which are of continuing nature.

The figure shows that the relationship between these two snow courses, except for variations in individual years, was essentially constant from 1937 through about 1957. During this time the Lakefork Mountain course measured 35 percent more than Hewinta G.S. From 1958 (possibly 1957 should also be included) through 1965, readings at the two courses were essentially equal. During the last four years the relationship has essentially reverted to that of 1937 to 1957.

Utah Power & Light Company conducted cloudseeding activities upwind from this area which could have affected the snowpack from 1955 through 1963. Their intent was to increase the snowpack on the upper Bear River, a north slope stream upwind from Hewinta G.S. Allowing for some adjustments that were made in locations of seeding generators during the early years of the program and a possible random effect in 1964, the cloudseeding program may have caused this shift in relationship. However, the fact that the relationship during the 1930's was essentially the same as during the 1958-65 period indicates that an unidentified shift in climatic patterns may be responsible. Since there is no snowpack record for this area before 1931, there is no way of knowing how long this trend had continued before that year. Similarly, there is no way of knowing how far the relationship of the past four years will continue into the future.

Figure 7 shows a double mass plotting of the April 1st snow water content of the King's Cabin (upper) snow course (elevation 8730 ft.) on the south side of the Uinta Mountains versus the Spirit Lake course (elevation 10,300 ft.) on the north side of the mountains. These two courses are approximately 24 miles apart and have had no environmental changes during their history. Records at Spirit Lake commenced in 1961. As shown in the figure, Spirit Lake received 47 percent more than King's Cabin (upper) during the first five (5) years of record, but during the last four years it has received 8 percent less.

This shift is not due to a change in observers or measuring equipment, since the same snow-surveyors--using the same measuring equipment--have measured both of these snow courses on the same snow survey trip each year. This shift has to be due to a change in climatic patterns, either natural or induced artificially by weather modification activities.

Figures 8 and 9 confirm the fact that a climatic shift took place between 1965 and 1966. These figures show a comparison of the available record of accumulated October-March (incl.) precipitation at the same stations for which the snow cover is shown in Figures 6 and 7.

The question of major concern for water supply forecasting is this--where geographically does the shift in snowpack relationships occur between these snow courses, which are only 23 and 24 miles apart? Does the demarcation line in the snowpack remain at the same location from year to year across the watersheds in the proposed wilderness area, or does the line shift back and forth each year? Present knowledge indicates a constant shifting which can only be defined by a network of data collection sites within the wilderness area and adjacent areas on roughly a five mile square grid system (25 square mile area).

Figure 10 provides a further demonstration of the fact that snow and rainfall patterns on the watersheds of the High Uintas are extremely variable from year

Figure 5. Snowpack Variability across San Juan - Upper Rio Grande Wilderness Areas - East to West

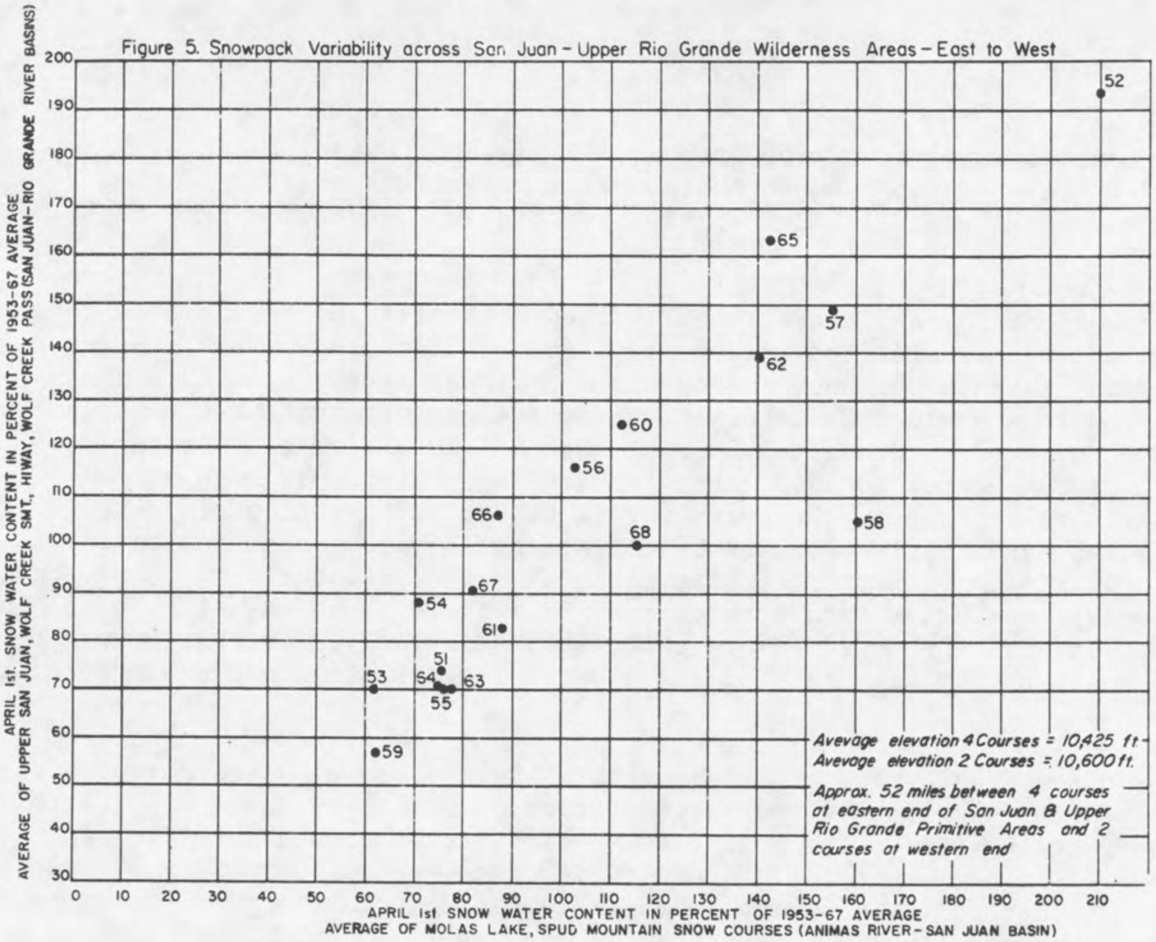


Figure 7. Time Trends in Snowpack Relationships - High Uinta Mountains, Utah

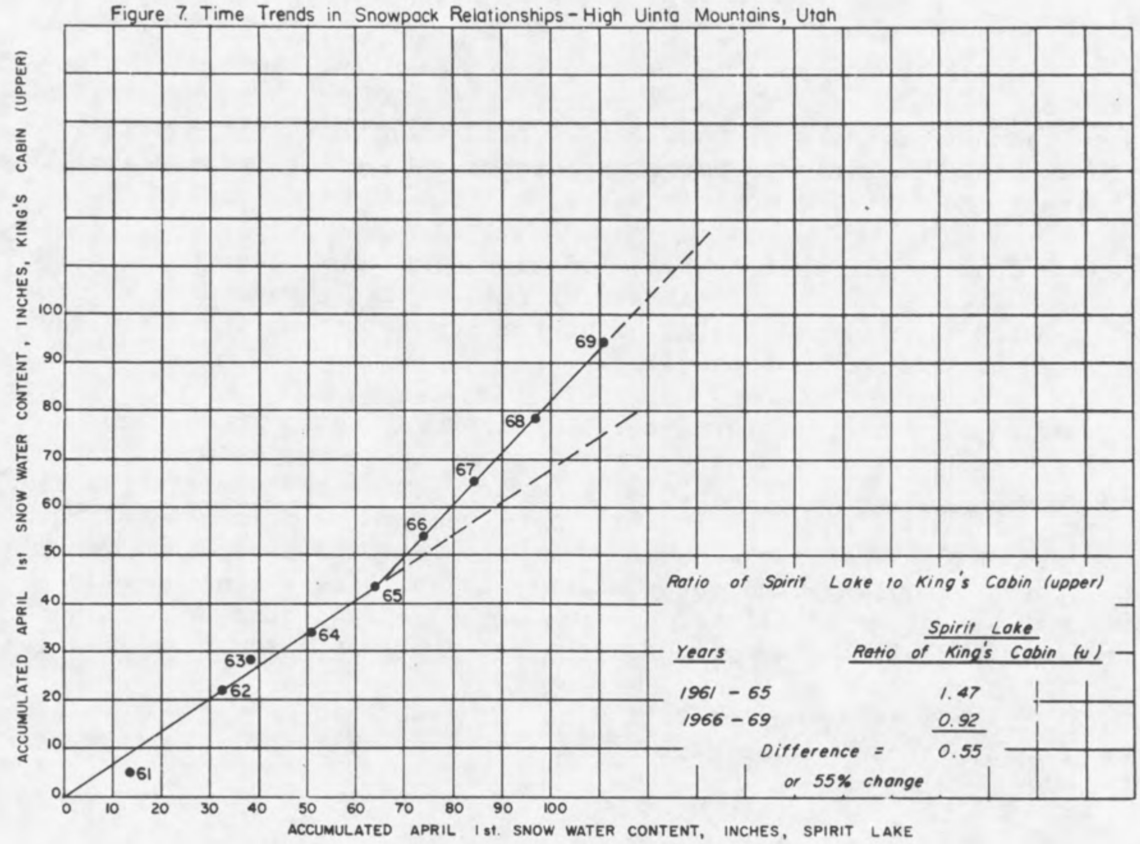


Figure 6. Time Trends in Snowpack Relationships – High Uinta Mountains, Utah

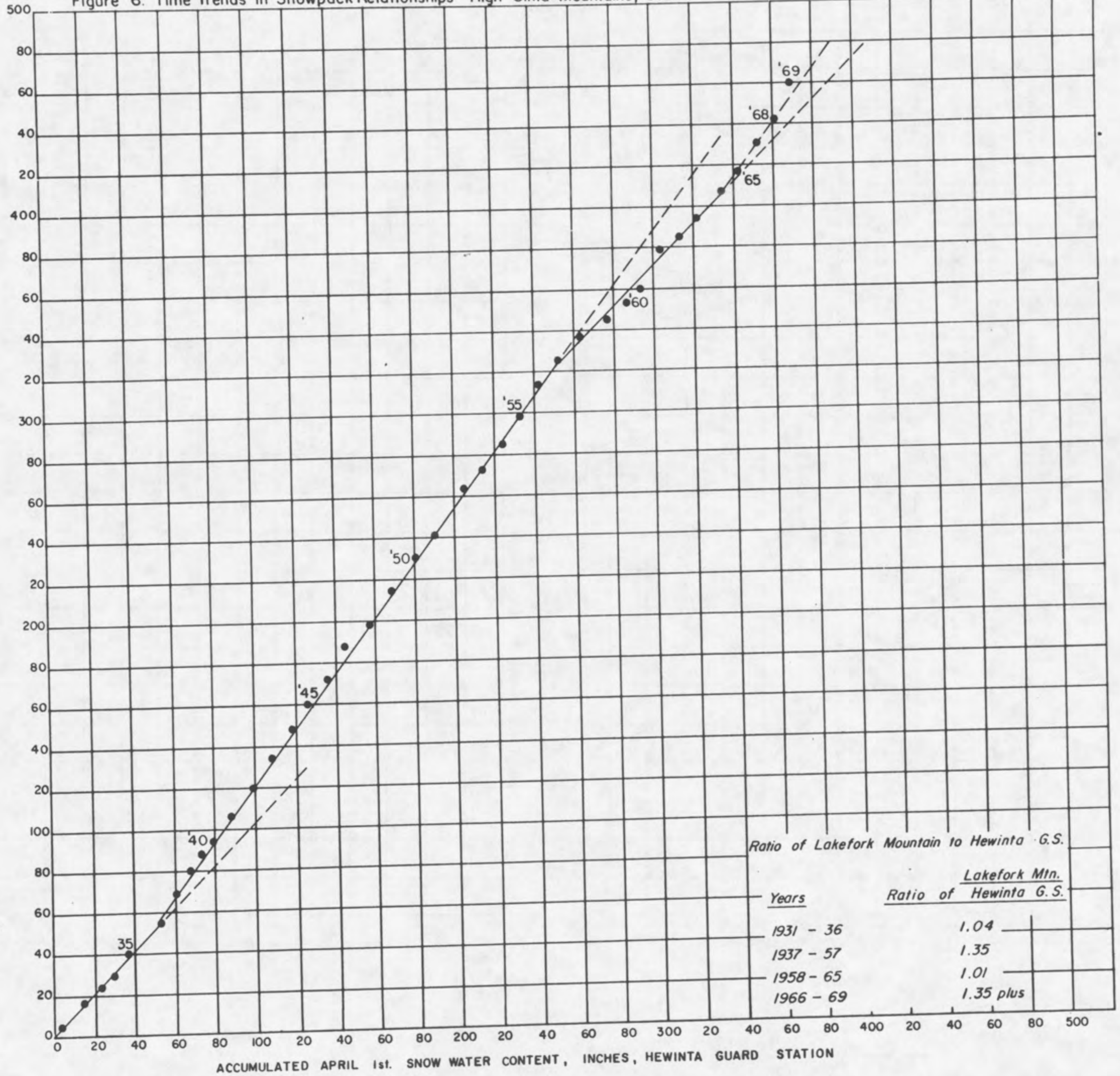


Figure 8. Time Trends in Winter Precipitation – High Uinta Mountains, Utah

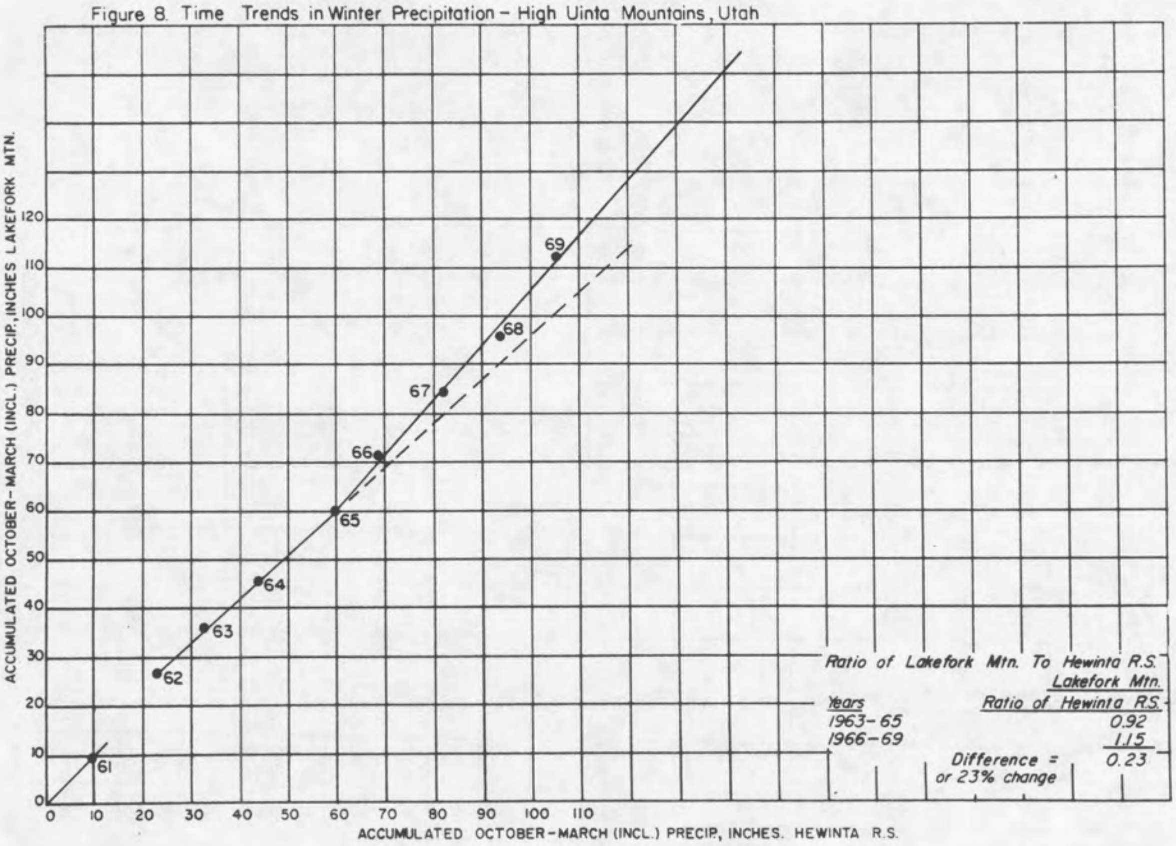
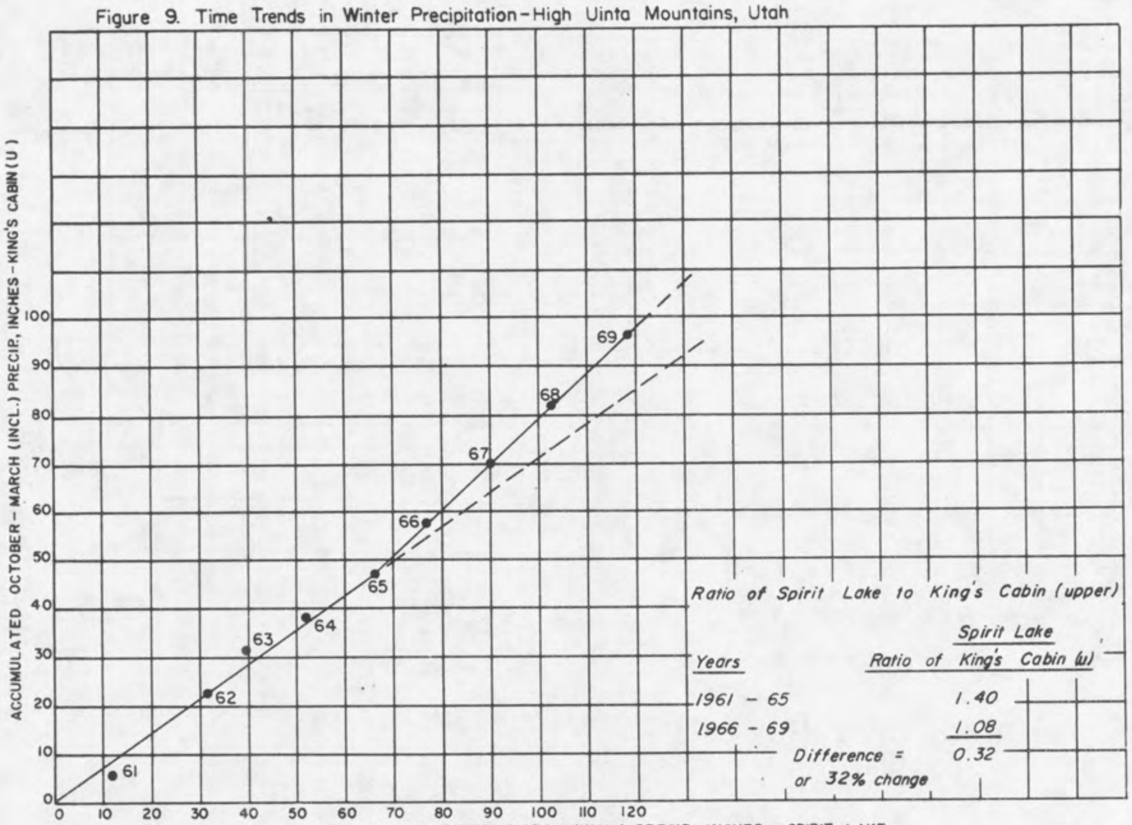


Figure 9. Time Trends in Winter Precipitation–High Uinta Mountains, Utah



to year, with shifting climatic patterns affecting the runoff of streams heading in this area.

The figure shows a double mass plotting of the April-July runoff of the Black's Fork River near Millburne, Wyoming (a north slope stream), versus the Uintah River near Neola, Utah (a south slope stream). The main water-producing areas of these two streams range from about 6 to 30 miles apart.

A comparison of Figure 10 with Figures 6 to 9 inclusive shows a similarity in the shifting relationships of streamflow and snowpack. However,it is significant that the breaks in slope occur at different years, indicating that other factors in addition to the snow are also experiencing shifting climatic patterns. For example, the last change in slope of the runoff plotting was in 1962 or 63 whereas the last slope change in snowpack and winter precipitation was in 1966.

Note that since 1940 there have been three major shifts in the relationship of these streams, the last one about 1962 or 63 when the cloudseeding program ended. The shift at this time was approximately 42 percent and was in the direction that would have been expected when cloudseeding ended, assuming the cloudseeding program had been effective in increasing the runoff of north slope streams. If cloudseeding was responsible for this major climatic shift, then the implication is that whenever and wherever weather modification activities are undertaken on an operational basis, the density of most existing networks should be increased considerably. This not only applies to watersheds heading in wilderness areas, but also to many other watersheds which now apparently have an adequate snow course network.

No possible explanation other than an undefined climatic shift is known for the slope change of 1945.

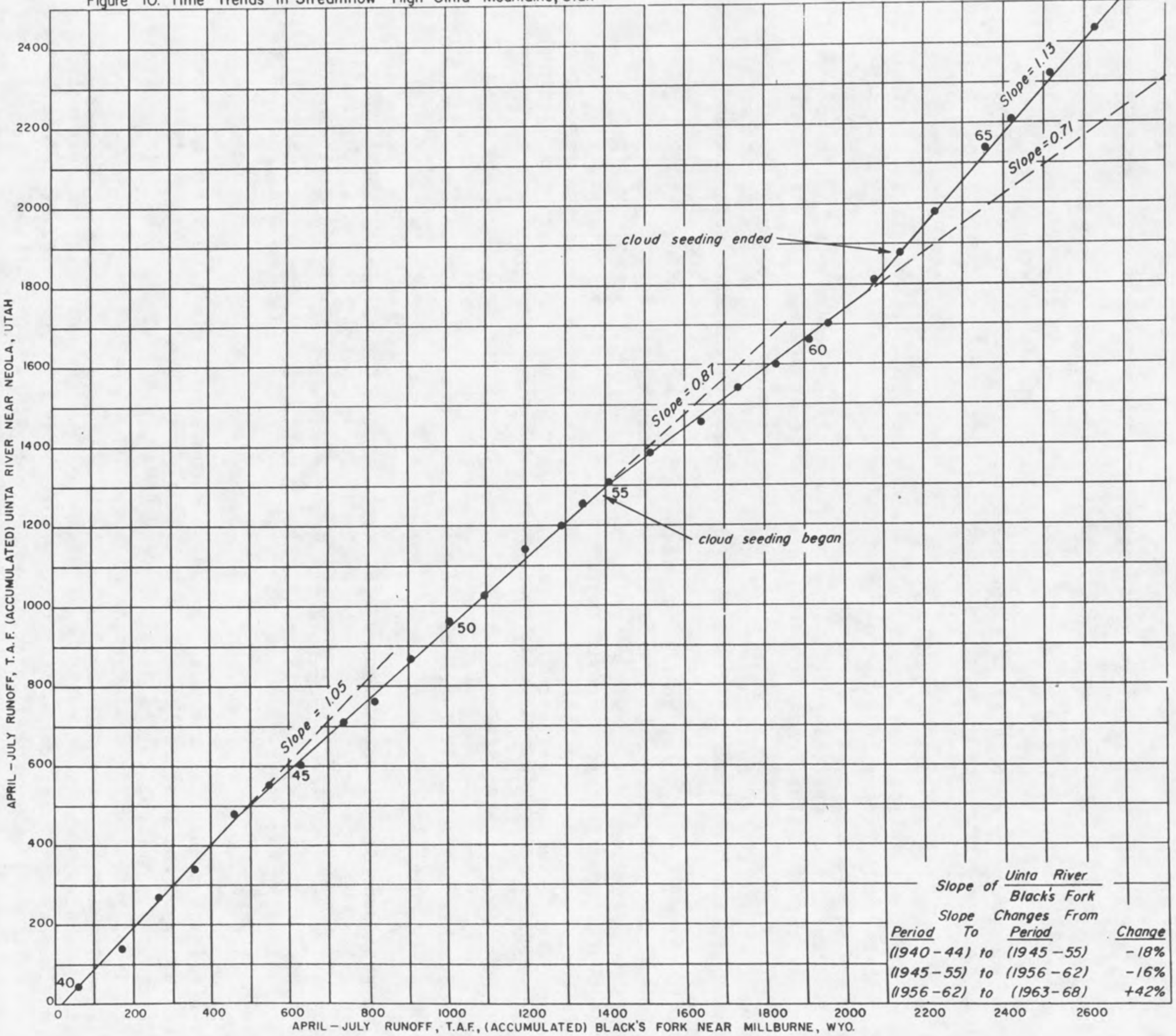
The proposed High Uintas Wilderness Area (expanded from the present primitive area) includes most of the watersheds which produce nearly the entire water supply for the Central Utah and Lyman, Wyoming units of the Upper Colorado River Project. The Bridger, Glacier, Popo Agie, Rio Grande, and San Juan Wildernesses include important water-producing areas of the Green, Wind, Rio Grande and San Juan Rivers.

Preliminary studies of the much larger wilderness and primitive areas of northwestern Wyoming, western Montana, and central Idaho are revealing similar unacceptable variability of data from existing peripheral networks. These areas are important water-producing areas of the Columbia and Missouri basins.

Basic data networks must not only be dense enough, but must also have essentially continuous monitoring capability during some periods of the year to determine and define the influence of hydroclimatological trends and variability in western mountains and their resultant impact on social and economic factors. Among other things, current hydrometeorological data are required for:

1. providing basic water resource and other hydrologic information for planning, designing, and operating works of improvement.

Figure 10. Time Trends in Streamflow - High Uinta Mountains, Utah



2. preparing daily streamflow forecasts required for flood warnings and for solving water management problems such as reservoir operations for flood control; optimized electric power production; industrial, agricultural, and municipal uses.

3. conducting weather modification research investigations designed to evaluate the effects of artificially induced nucleation (including air pollution) on storms moving across mountainous areas.

4. directing present and future operational programs in weather modification.

Recently developed remote sensors and telemetry equipment now provide the means to meet these needs. Their future use will help us to realize greater benefits and a better way of life.