INTERPRETING SNOW SURVEY DATA FOR USE IN ENVIRONMENTAL PLANNING 1/

By

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Introduction

From its inception, the Snow Survey Program has had as its primary function the job of forecasting water supplies for agricultural, municipal, and industrial uses. Dr. J. E. Church's early attempts to correlate snowpack in the Sierra Nevada Mountains with fluctuations in levels of Lake Tahoe is the basis for today's work in the Cooperative Federal, State, and Private Snow Survey Program. Until recently, observations of snowpack were made only on snow depth and water content at designated locations called snow courses. Today snow surveys have evolved into a data gathering program which encompasses collecting information on total precipitation, temperature, wind, radiation, relative humidity, snow density profiles, total snowfall in addition to snow depth, and water content. This information has been found necessary for refining forecast procedures to provide accurate and timely estimates of future water supplies to water managers and users.

Other groups, however, are requesting climatological and hydrological information in the mountainous West to facilitate planning for future growth and development. To gather data more efficiently to meet these ever-expanding needs, a revolution in methods and equipment has been required. While still relying on parties of snow surveyors using the standard snow sampling set to gather basic snow data in the mountains, the program has tested and installed new, sophisticated systems to sense, record, and reduce hydrologically important parameters at remote mountain sites.

Available Data

Since the West-Wide Cooperative Snow Survey Program began in the early thirties, snow course sites have grown to over 1900 in the West. These continue to be the backbone of the program. Snow course readings are generally taken three times a year: on March 1, April 1, and May 1. Snow pillows were introduced to obtain a complete picture of snowpack accumulation and depletion. To date there are about 175 snow pillows installed and operating in the western United States.

Storage precipitation gages were installed to obtain year round data at snow course and snow pillow sites to better define the annual precipitation regime. Some 400 precipitation gages are operating in this network at present. Recording precipitation gages as well as snow pillows yield data on storm intensities and durations in mountainous areas which hitherto had a paucity of data.

Using thermographs at the remote sites gives information from which melt rates can accurately be calculated. Wind run provides data to help compute snowpack depletion due to evaporation and sublimation. Soil moisture stations at 140 selected locations provide information on basin wetness which directly affects both surface runoff and groundwater. Soil temperature at these sites determine if soils are frozen, and this information is also useful in the classification of soils.

Radioactive profiling snow gages allow snow hydrologists to study snowpack stratigraphy in detail. Snowpack accumulation, metamorphism, and depletion can now be studied via this *in situ* measurement technique.

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Further advances in the field of snow surveys were made when many of the above-mentioned parameters were hooked directly into a radio telemetry system at the remote sites. Data became available on a real-time basis at a base station. Here the data is received, recorded, and reduced with the help of computer technology.

Future plans call for a further modernization of the data gathering and processing function with the implementation of a West-Wide SNOTEL System. This is a system whereby hydrologic data will be transmitted via meteor burst from some 500 plus remote data sites throughout the West to a central computer processing facility. Data on parameters such as snow water equivalent, precipitation, temperature, and others such as wind, humidity, and radiation will be received and stored for use in water supply forecasting, flood warning, avalanche warning, recreation, area accessibility, basin modeling, fire weather, and other studies.

Interpretations Based on Snow Survey Data

Reservoir Management Plans - Because 60 to 75 percent of the annual runoff in the West comes as a direct result of snowpack accumulation and melt, reservoir operations can be governed by this seasonal cycle. Farnes 4/ has shown that a proper combination of three variables--snow water equivalent, soil moisture, and spring precipitation can be used to predict runoff 3 to 6 months in advance with an acceptable degree of accuracy for reservoirs whose inflow is primarily from snowmelt.

The reservoir management plan is tailored to provide the reservoir operator with options to better realize project goals whether for multipurpose or single purpose impoundments. Multiple benefits of flood control, agricultural water allocation, recreation, fisheries, and power generation can now be incorporated more easily into a sound management scheme. The procedure relies heavily on an accurate forecast equation and timely snowpack and precipitation data. A family of curves is used to enable a reservoir operator to adjust his outflow level given a volume forecast and knowing the amount of storage left to fill at any given time. An example of a reservoir operations curve is shown in Figure 1 for Hebgen Lake in southwestern Montana. Daily data from the SNOWTEL System will be used as input to simulation models that can provide additional information helpful to the reservoir manager. A more complete analysis of reservoir operation procedures is available from the Montana Snow Survey Unit.

Snow Loads - The foothill and mountainous areas of the west have been and are continuing to experience rapid development. Accompanying this development are new summerhomes, recreation facilities, and even industrial buildings in and adjacent to heavy snowpack areas. Inadequate data or a complete lack of good data to design roofs to withstand a winter's buildup of snow has resulted in many crushed or damaged buildings.

Responding to this need, snow hydrologists in the Soil Conservation Service (SCS) have developed maps delineating snow loads in pounds per square foot in a number of states including Nevada 5/ and Oregon 6/. George and McAndrew 7/ present the rationale and procedure followed in compiling the maps for Oregon and Nevada. The snow load analysis was accomplished through a frequency analysis of maximum snow water equivalent and converting 25- or 50-year-frequency water equivalents to ground snow load. Using knowledge of storm patterns and topographic and orographic effects, the snow loads calculated at snow course sites were extrapolated to nearby regions where data was lacking. An example of a snow load map for the Gallatin River drainage in Montana is given in Figure 2.

Design criteria for converting ground snow loads to roof loads for various roof configurations has been published by the National Research Council of Canada 8/. Accurate snow load information becomes a valuable tool to the architect, engineer, and building official charged with the design or inspection of structures in new or existing developments.

Snowfall - Having data on the total amount of snow which falls during a winter is becoming increasingly more important. The cost of snow removal is a factor in the routing of interstate highways, planning of recreation areas, and maintaining county roads for rural residents in the winter. Obtaining data on total snowfall is important in the planning and design of water-spreading systems using snowmelt on frozen soils as a moisture supply for crops. Once again, snow course and snow pillow records as well as National Weather Service snowfall records are used to develop maps of average annual snowfall 9, 10/. In Montana, for example, it was found that existing maps greatly under estimated actual snowfall in mountain regions. In some areas, average annual snowfall was found to exceed published values by as much as 500 percent. An example of a snowfall map for the Gallatin River drainage in Montana is given in Figure 3. As an adjunct to the snowfall map for Montana, a curve was developed relating average annual snowfall to average annual precipitation as shown in Figure 4.

Evaluating snowfall at potential ski and snowmobile areas from snow survey data has also been undertaken. Farnes 11/ has described the methodology and criteria for ascertaining the suitability of a site for a ski area development. The SCS Snow Survey Program in Montana provides, upon request, an analysis of snow conditions at a given site as it relates to long-term snow course and snow pillow records. The frequency that an area can be open for skiing on the Thanksgiving and Christmas holidays is given for various base elevations. This information substantially reduces the risk for investors and developers when undertaking a project of this nature.

Generalized maps have been produced in Nevada 12/ and Montana 13/ outlining areas with adequate snowfall for winter recreation (skiing and snowmobiling), Soil Conservation Service Snow Survey hydrologists in Oregon, Utah 14/, Colorado, and New Mexico 15/ have obtained frequency analyses of snow courses in their respective states. These data are readily amenable to analyzing snowfall and snowloads in specific areas in these states.

Snowpack development and melt over a large area can be looked at in another simplified way. Figure 5 is a graph of the way in which the snowpack accumulates and melts in an "average" year in Montana. The graph is synthesized from 1958-1972 averages for some 200 snow courses and 35 snow pillows in Montana. Although this graph does not show extremes, it does give a norm against which yearly variations can be compared. In a similar vein, such graphs can be prepared for specific drainages and elevational zones for more localized application.

Hydrology Reports

By its very nature, the Snow Survey Program is a storehouse of hydrologic data including snow, streamflow, precipitation, temperature, and basin characteristics. Once this wealth of data is gathered, it becomes a relatively simple task to interpret it in a meaningful form. Hydrologic data can be presented in terms of averages or medians, long-term trends, frequency analyses, and maps to give valuable information in a non-technical manner.

Too often, irreversible decisions are made by planners and managers from data gathered over a limited span of time--not looking at the problem in terms of long-term natural climatic fluctuations. This short-sightedness can be disastrous both for people involved and for the natural environment. Major disruptions in the environment can occur when too little heed is paid to data in their historical perspective. To help alleviate some of the uncertainties and vagaries in the planning process, the Snow Survey Program in Montana developed and printed a report on the Hydrology of Mountain Watersheds 16/. In it are simplified relationships for arriving at reliable estimates of runoff and peaks from annual precipitation.

Several other reports have been issued by SCS in Montana analyzing the hydrology of individual drainage basins in Montana 17, 18/. The drainages are typical intramountain basins where the bulk of all streamflow leaving the basin is directly attributable to snowmelt. Information in the reports included the precipitation regime, peak flows, and average annual yields from small ungaged subbasins, average annual snowfall, snow loads, and areas with adequate snow for winter sports areas. Figure 6 is an example of how long-term snow and streamflow data can be presented simply and yet provide the historical perspective against which short-term data collections can be compared. Figure 6 shows 5-year moving averages for snowpack and streamflow in the Gallatin River drainage in southwestern Montana taken from reference 17/.

Annual Precipitation Maps

Basic to any hydrologic evaluation of a drainage basin is information on the precipitation falling on the basin. Expressing precipitation as an average and looking at runoff in the same way, deviations from the norm are more easily detected. Inspections of previously available precipitation maps in Montana and comparisons of runoff in some mountainous areas revealed that actual average annual yield exceeded reported average precipitation. Since generally this is impossible, revisions in the mountain precipitation map seemed in order. This was done in Montana 19/ using relationships developed between maximum snowpack accumulation, average annual precipitation, and elevation. Snow data sites in the mountains provided the key to rectifying errors in previously published maps.

The map developed has since been expanded in cooperation with the National Weather Service and State Department of Natural Resources 20/ to cover all areas of Montana. It has become the standard precipitation map for Montana. Richard A. Dirks in his Climatological Studies of Yellowstone and Grand Teton National Parks 21/ used this map. His comments on the map and its accuracy are worth noting: "Even though based on a short period of record (15 years), this is undoubtedly the most accurate analysis of mean annual precipitation available for the region. Recent studies in Yellowstone National Park by Despain show that vegetation zones are well differentiated by mean annual precipitation and, furthermore, these zones are closely aligned to the precipitation analysis given by Farnes."

Other Interpretations

The above mentioned uses to which snow data are being put is certainly not complete. Other studies include the relationship of snow and precipitation data to fish and wildlife population cycles, wintertime weather modification studies, river basin simulation models to evaluate effects of land use change, avalanche potential, water balance studies, regional inventories of water resources, planning of large scale coal and oil shale developments, climatic shifts, vegetation manipulation, and satellite imagery.

Summary

A vast amount of data has been collected in the Snow Survey Program for the expressed purpose of forecasting water supply. Additional interpretations of data collected in this program are now being made to aid planners, architects, engineers, conservationists, managers, and developers in making rational land use and investment decisions. A substantial degree of uncertainty has been removed from the planning process as a direct result of such interpretations. Opportunities for future in-depth studies or analyses are by no means exhausted. Procedures and studies developed to this point represent a good start but more remains to be done.

The cost of collecting the data is far higher than the cost of manipulating and interpreting the data once it is available. To obtain more for our money in these days of rising costs, we need to continue to seek sound methods to derive meaning and use from data already available or being collected.

Not all states in the West have been able to provide the degree of interpretations discussed. This is not due to any lack of data, but rather reflects the lack of skilled manpower available to devote the time needed for such an undertaking. As the demand grows, and it assuredly will for such interpretations, trained personnel must be prepared to provide them.

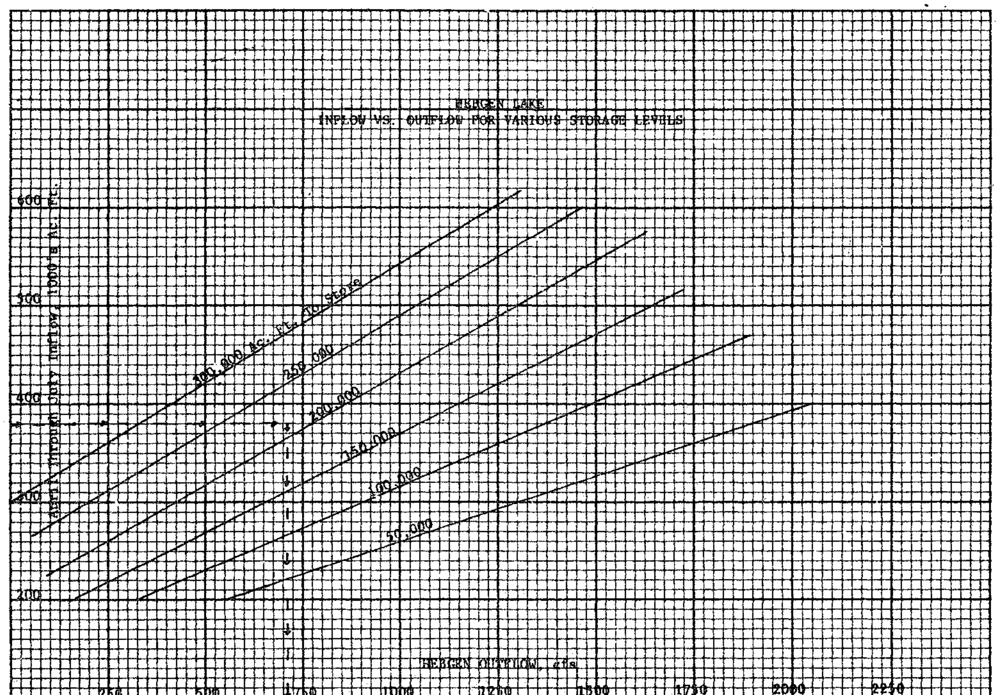
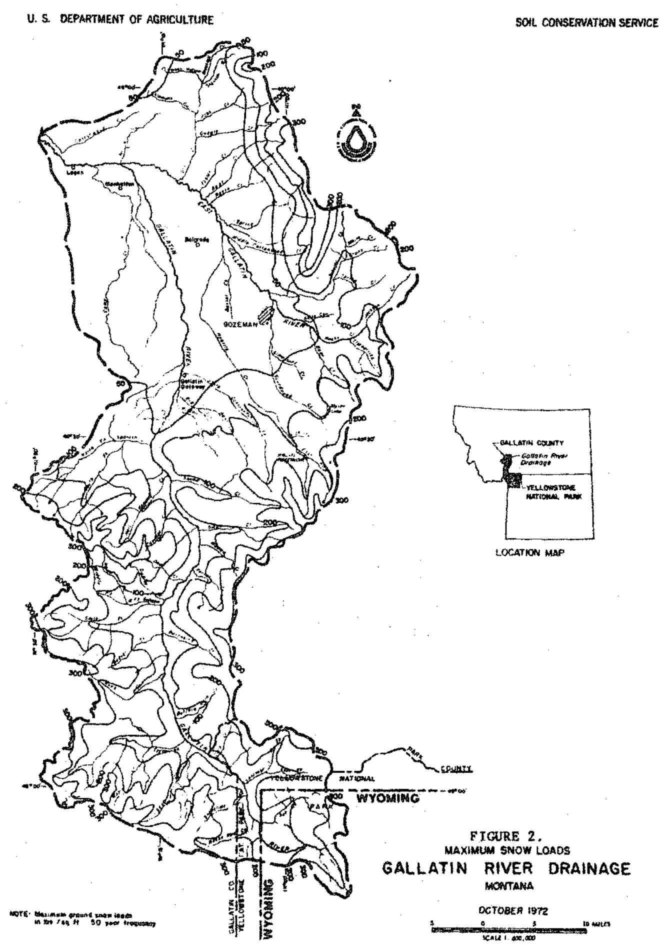


Figure 1. Volume inflow vs. outflow needed to obtain specified increase in storage.



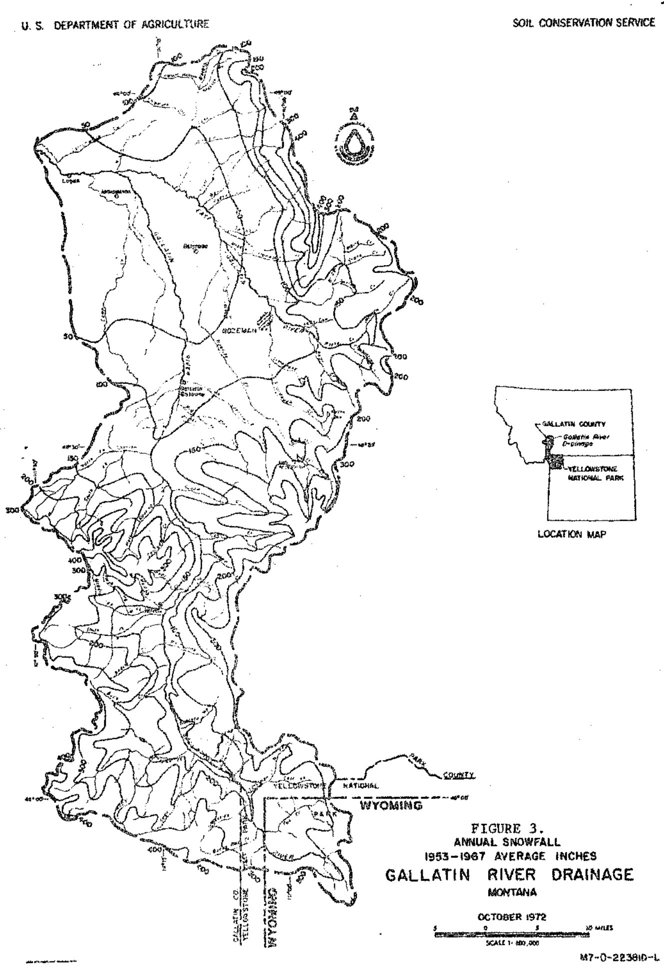


FIGURE 3.
ANNUAL SNOWFALL
1953-1967 AVERAGE INCHES
GALLATIN RIVER DRAINAGE
MONTANA

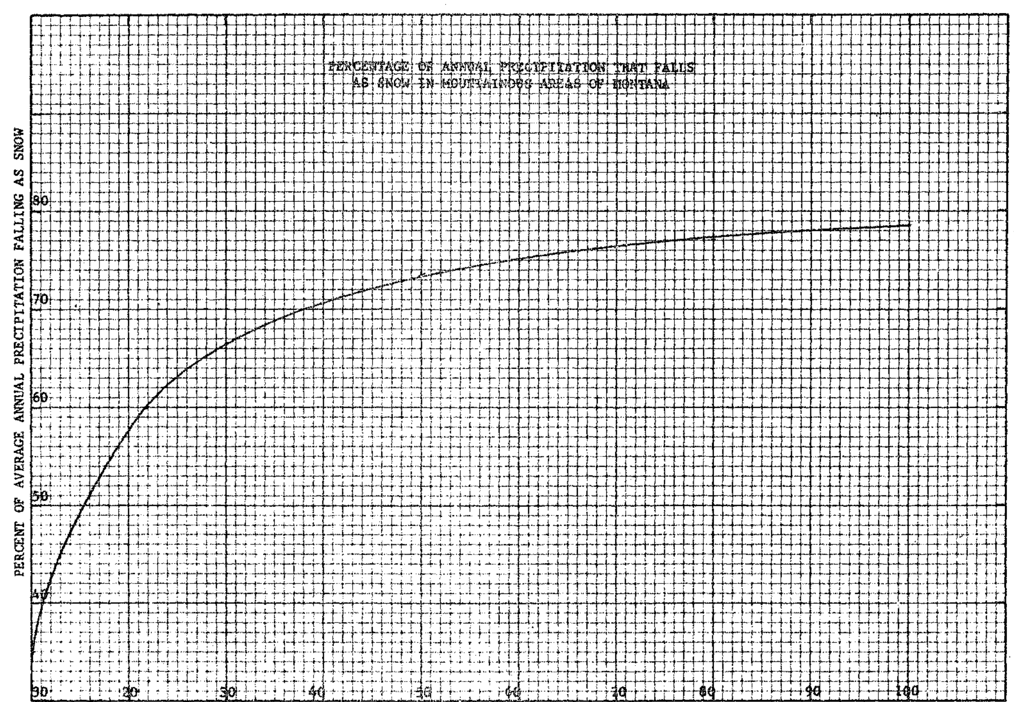


Figure 4. Relationships between snowfall and annual precipitation in Montana.

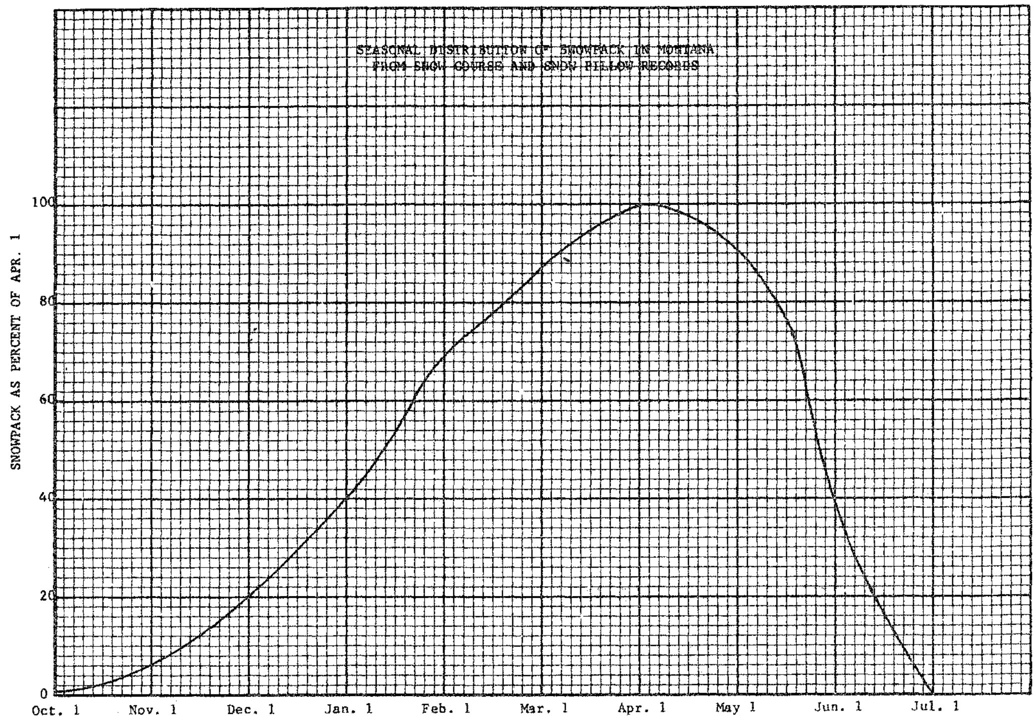


Figure 5. Snowpack accumulation and depletion in Montana.

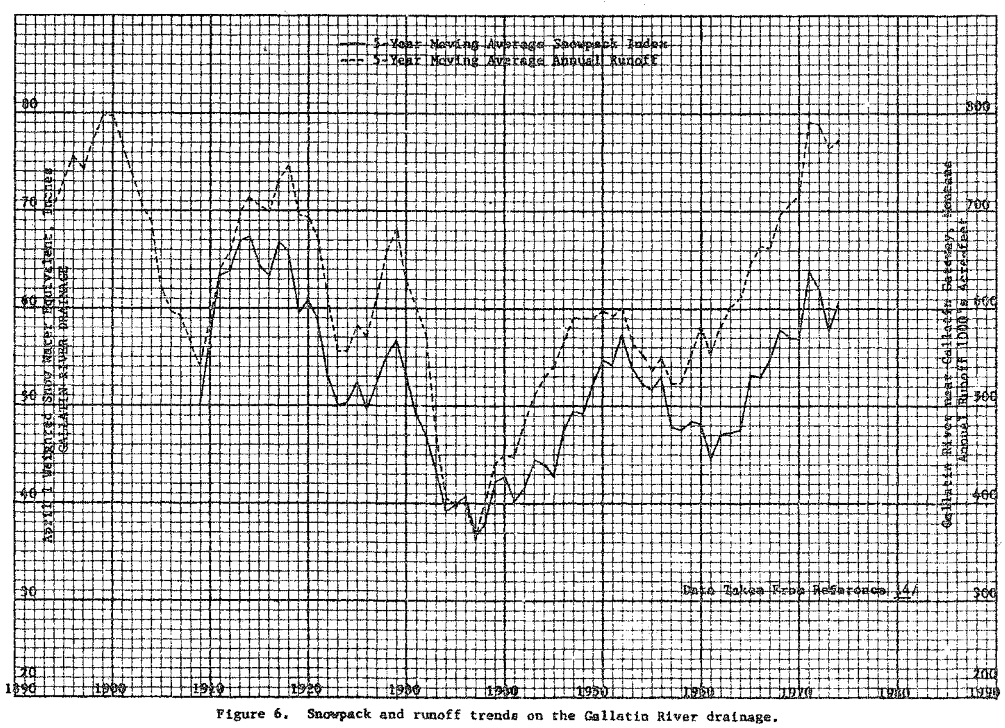


Figure 6. Snowpack and runoff trends on the Gallatin River drainage.

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