UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROGRESS REPORT ON THE EFFECTS OF SURFACE MINING ON THE SURFACE-WATER HYDROLOGY OF SELECTED BASINS IN THE FORT UNION COAL REGION, NORTH DAKOTA AND MONTANA

By Douglas G. Emerson

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SELECTED FACTORS FOR CONVERTING INCH-POUND UNITS TO THE INTERNATIONAL SYSTEM (SI) OF METRIC UNITS

For those readers who may prefer to use the International System (SI) of metric units rather than inch-pound units, the conversion factors for the terms used in this report are given below.

Multiply inch-pound unit	By	To obtain SI unit
Acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
Cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Foot (ft)	0.3048	meter (m)
Foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Inch (in.)	25.40	millimeter (mm)
Mile (mi)	1.609	kilometer (km)
Square mile (mi^2)	2.590	square kilometer (km^2)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order nets of both the United States and Canada, formerly called "Mean Sea Level."

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Douglas G. Emerson

ABSTRACT

The purpose of the investigation is to provide a means to assess the impacts on surface-water hydrology due to changes in land use resulting from surface mining of coal in the Fort Union Coal Region, North Dakota and Montana. The objectives of the study are to: (1) Determine premining hydrologic conditions in small representative drainage basins and provide historical data with which to compare the magnitude of changes resulting from mining, and (2) develop the capability of making reasonably accurate projections of hydrologic effects resulting from the various land-use changes caused by surface mining. Data collection has been underway since October 1976 for the West Branch Antelope Creek study area in western North Dakota and since March 1978 for the Hay Creek study area in eastern Montana. Data collected during the premining period are being analyzed using statistical methods for the evaluation of the premining conditions. A digital model with the capability of making hydrologic projections is being developed. Most of the model components have been tested during 1979 and 1980.

INTRODUCTION

In response to the Department of the Interior's call for leasing nomination of Federal coal land, eligible tracts were submitted by mining concerns for consideration of their leasing potential. The U.S. Bureau of Land Management has the responsibility of evaluating the leasing applications for mining of Federal coal and preparing environmental impact statements. They must address environmental impacts, which include those of hydrology.

The U.S. Office of Surface Mining Reclamation and Enforcement (1977) provisions outline the impacts in terms of the probable hydrologic consequences of the mining and reclamation operations both on and off the proposed permit area, and the reasonable assessment of the probable cumulative impacts of mining. These impacts include changes in flow regimes, flood peaks and volumes, sediment yields, water quality, soil-water relationships, and water-balance relationship for basins before, during, and after mining.

The basic problem to be addressed in the Fort Union Coal Region study is the assessment of impacts by surface mining on the surface-water hydrology of mined and adjacent unmined areas. The U.S. Geological Survey is funded by the U.S. Bureau of Land Management to collect and analyze hydrologic data for selected coal deposits on lands administered in North Dakota by the Bureau and to develop techniques and technologies for use in making the required impact assessments. This is a progress report on the Fort Union Coal Region research effort in North Dakota and Montana.

Two areas are being studied under the Fort Union Coal Region project (fig. 1). The West Branch Antelope Creek study area is an 8.46-mi^2 basin in Mercer County in west-central North Dakota. The area is one of rolling topography devoted largely to pasture and to the production of small grain crops. Coal mining and agriculture are the chief economic activities.

The Hay Creek study area is an 11.41-mi^2 basin in Wibaux County in east-central Montana. Most of the study area is characterized by rolling topography also devoted to pasture and the production of small grain crops. There currently is no commercial production of lignite in the Hay Creek area.

PURPOSE

Preliminary data indicate that the proposed expansion of strip-mining activities in the West Branch Antelope Creek area may result in changes in the streamflow regimen. Although there currently are no mining activities in the Hay Creek area, mining of coal is expected to begin in the future and to have probable attendant changes. Some changes will be temporary, but others will remain even after strip mining has ceased.

The purpose of the Fort Union Coal Region investigation is to provide a means for U.S. Bureau of Land Management personnel or others to assess the impacts due to changes in land use resulting from coal mining. The objectives are to: (1) Determine pre-mining hydrologic conditions in a small representative drainage basin and thus provide historical data with which to compare the magnitude of changes resulting from mining, and (2) develop the capability of making reasonably accurate projections of hydrologic effects resulting from the various land-use changes caused by surface mining.

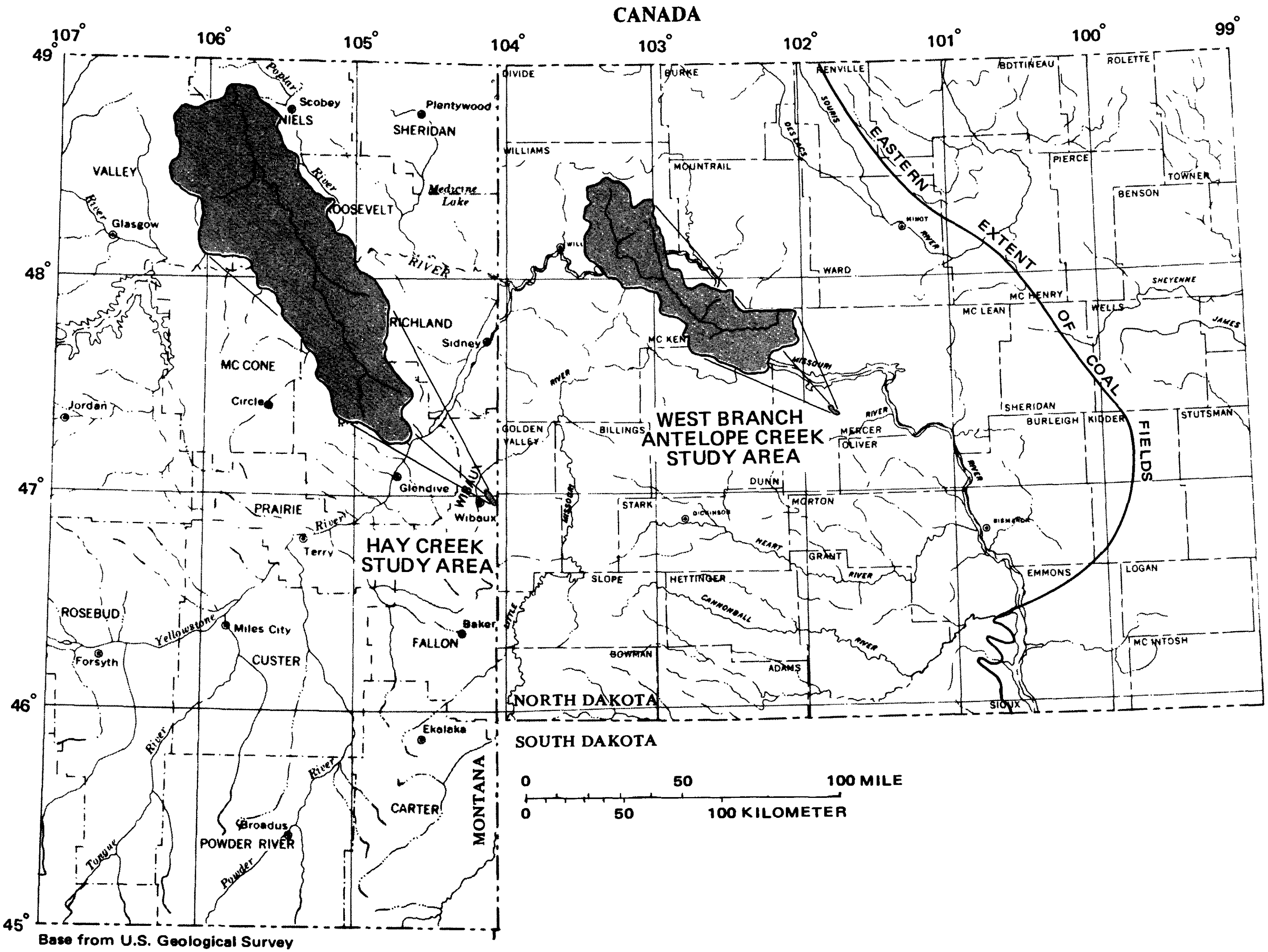


FIGURE 1.—Location of study area.

DATA COLLECTION

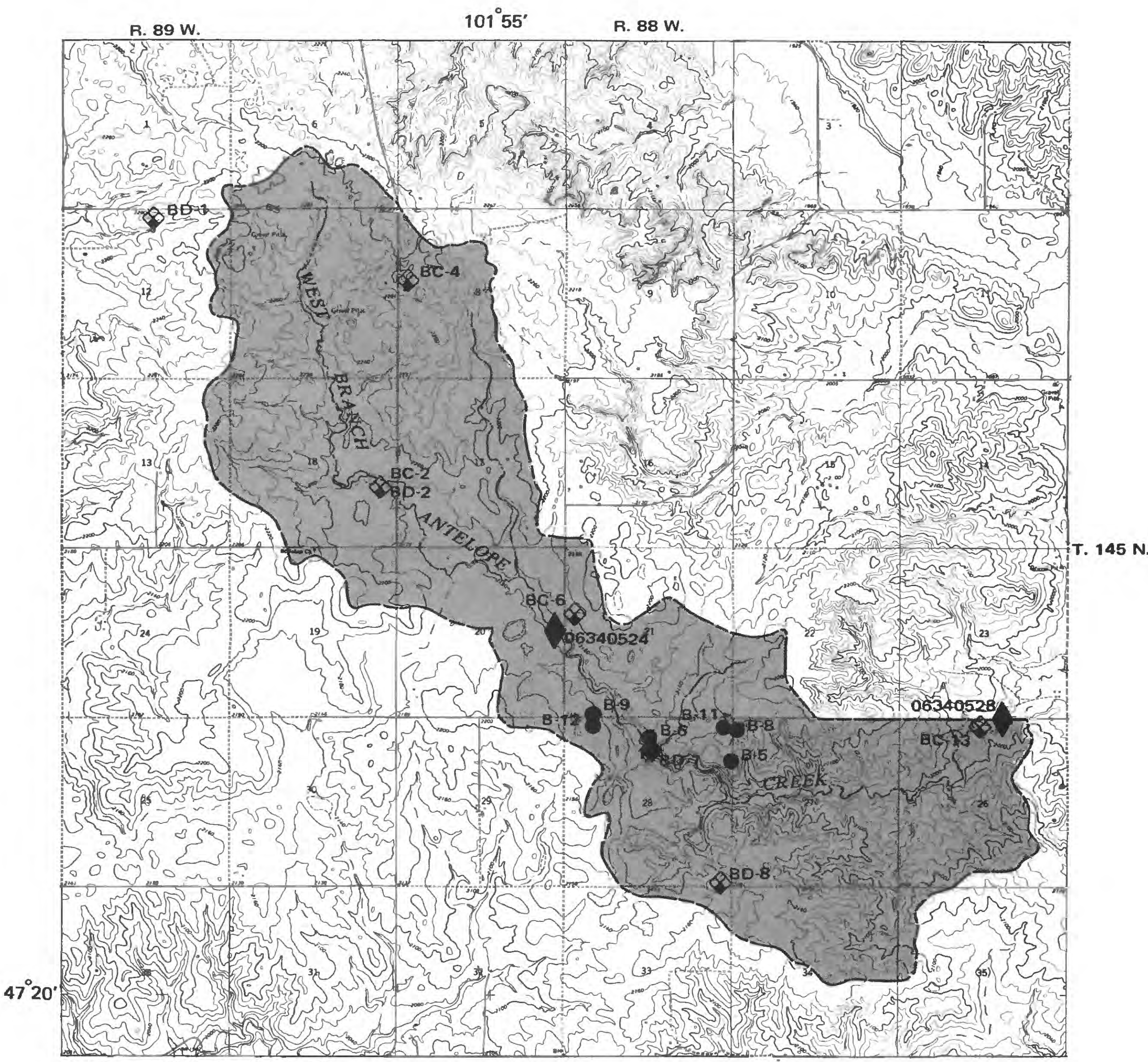
Early in the Fort Union Coal Region study, two small basins were selected as being representative of the Fort Union Coal Region in North Dakota and Montana. Collection of meteorological data, hydrological data, and basin characteristics was begun to provide the historical data base needed to compare the magnitude of surface-water hydrologic changes during and after mining in the basins. Analysis of the data currently being collected will be used to determine the premining hydrologic conditions of the basins. Also, the data will be used to predict the effects of mining on the surface-water hydrology.

Meteorological Data

A weather station was established in about the middle of each basin. For the West Branch Antelope Creek basin, the weather station is located in the SW1/4NW1/4NE1/4 of sec. 28, T. 145 N., R. 88 W. (fig. 2), in Mercer County, North Dakota, and for the Hay Creek basin, the weather station is located in the SE1/4NW1/4SW1/4 of sec. 34, T. 15 N., R. 60 E. (fig. 3), in Wibaux County, Montana. To facilitate the collection of meteorological data, data acquisition systems were established at both of these sites. A sketch of a representative data-acquisition system installation is shown in figure 4.

The data-acquisition system is a group of sensors, connected to a modular, data-logging microcomputer (J. W. Reid and G. E. Ghering, U.S. Geological Survey, written commun., 1981) and has the capability of: (1) Monitoring different types of sensors for (a) air temperature, (b) relative humidity, (c) solar radiation, (d) precipitation, (e) wind run, (f) wind speed, (g) wind direction, (h) soil temperature, (i) soil moisture, and (j) snow temperature; (2) partially reducing data onsite; (3) printing data, in engineering units, onsite at preselected time intervals; and (4) transferring the data to cassette magnetic tape for later transmittal through a data terminal to the U.S. Geological Survey's central computer system in Reston, Virgina. The data are then processed and stored in the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE).

To determine spatial and temporal distribution of precipitation over the basins, several recording precipitation gages have been installed. Location and distribution of the seven existing precipitation stations in the West Branch Antelope Creek study area are shown in figure 2, and the location and distribution of the six existing precipitation stations in the Hay Creek study area are shown in figure 3. The location, period of record, and



Base from U.S. Geological Survey
Beulah NW, 1969; Beulah, 1968;
Beulah NE, 1969; Zap, 1969

0 ½ 1 2 MILES
0 ½ 1 2 3 KILOMETERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

▲ 06340528 CONTINUOUS-RECORDING GAGING STATION—Number is downstream ordering number of U.S. Geological Survey

▼ CHEMICAL- AND SEDIMENT-MEASUREMENT SITE

◆ BD-7 COMPLETE WEATHER STATION AND NAME (TABLE 1)

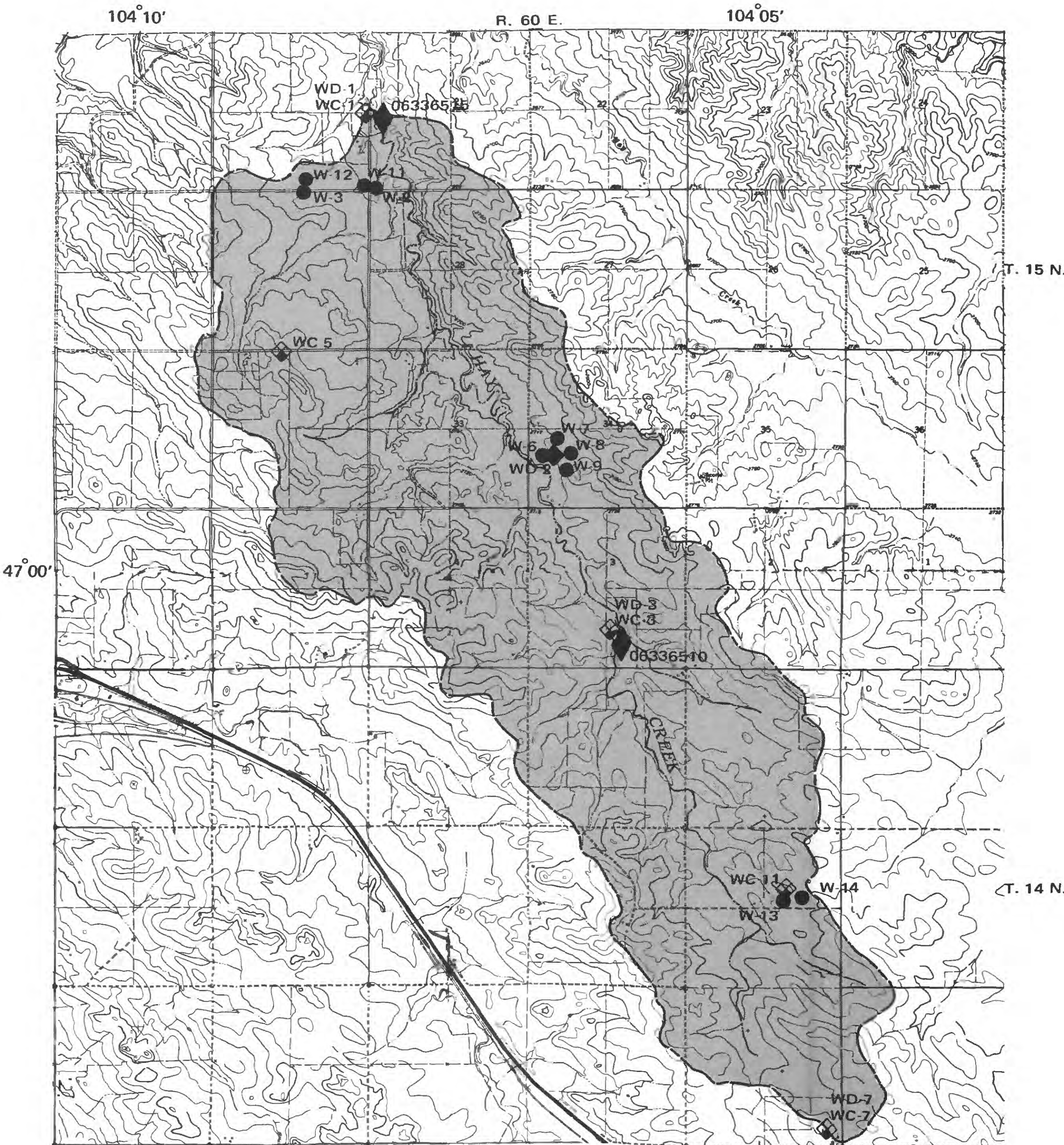
BD-8 PRECIPITATION STATION AND NAME (TABLE 1)

● B-5 SOIL-MOISTURE SITE AND NAME (TABLE 3)

STUDY AREA

——— BASIN BOUNDARY

FIGURE 2.—Data-collection stations in West Branch Antelope Creek study area, North Dakota.



Base from U.S. Geological Survey Odland Dam, 1974; Tokna 4SW, unedited advance print; Wibaux 1NE, unedited advance print; and Wibaux 1NW, unedited advance print

0 ½ 1 2 MILES
0 ½ 1 2 3 KILOMETERS
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

▲ 06336515 CONTINUOUS-RECORDING GAGING STATION— Number is downstream ordering number of U.S. Geological Survey

▼ CHEMICAL- AND SEDIMENT-MEASUREMENT SITE

◆ WD-2 COMPLETE WEATHER STATION AND NAME (TABLE 1)

◇ WC-5 PRECIPITATION STATION AND NAME (TABLE 1)

● W-12 SOIL-MOISTURE SITE AND NAME (TABLE 3)

STUDY AREA

BASIN BOUNDARY

FIGURE 3.—Data-collection stations in Hay Creek study area, Montana.

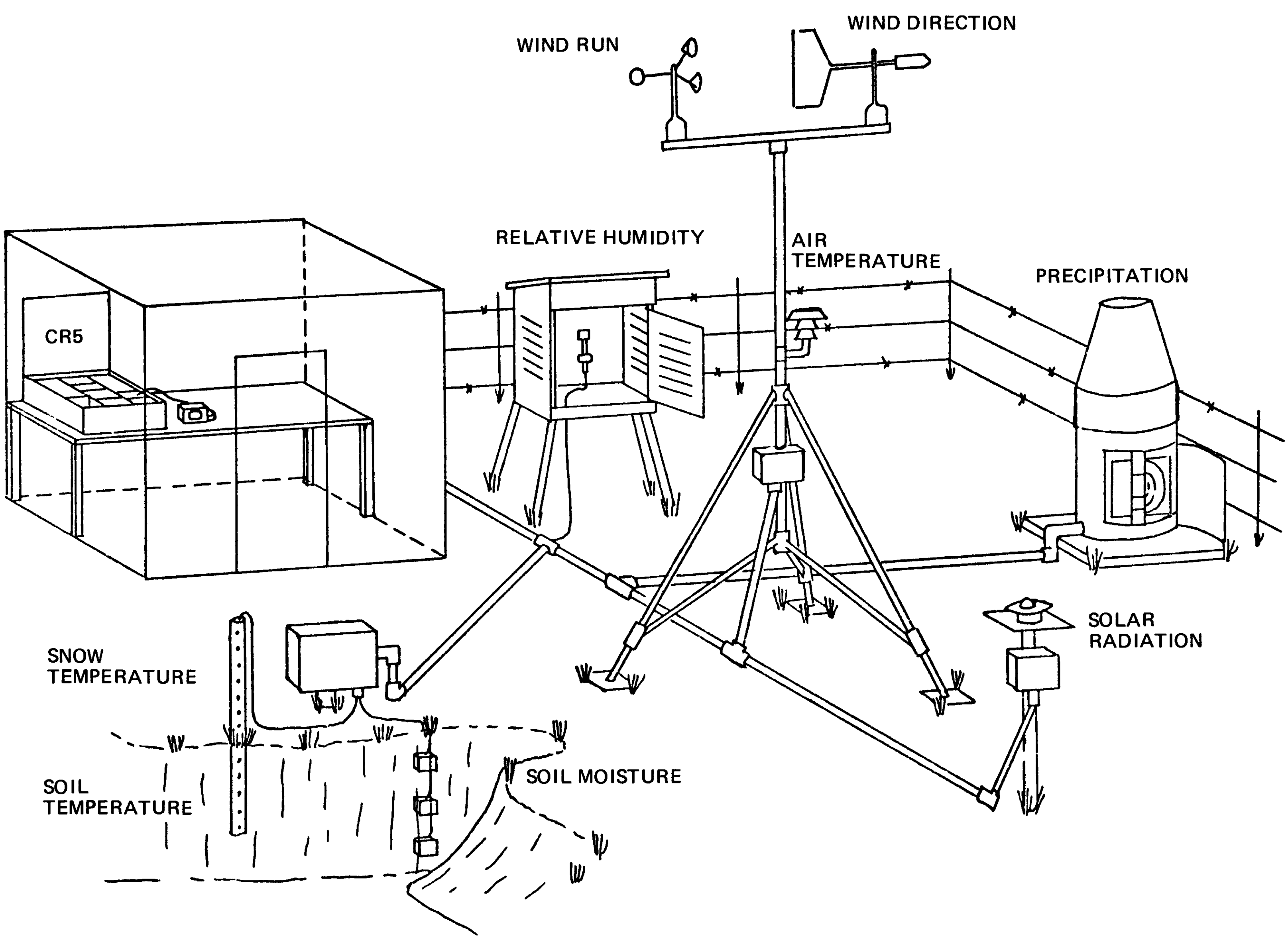


FIGURE 4.—Data-acquisition system installation.

type of gage for all the active and discontinued precipitation stations are shown in table 1.

Snow surveys are being conducted periodically to determine snow depth, density, and distribution characteristics in the basins. Previous investigations (Steppuhn and Dyck, 1974; and Steppuhn, 1976) for a prairie environment indicate similarities in the areal variations of snow cover within areal units that have similar landscape features. Snow accumulation tends to have recurring patterns unique to specific terrain and land use. Therefore, snow surveys consisting of stratified sampling techniques based on land use and terrain type are being used.

The two basins have been included in the National Weather Service's Airborne Gamma Radiation Snow Survey Program since the winter of 1978-79. The Weather Service's technique uses natural terrestrial gamma radiation to measure snow-water equivalent (Carroll and Vadnais, 1980).

To fulfill the need for snow distribution in the modeling program, however, this technique needed further research and expansion. Therefore, a cooperative program was established with the National Weather Service and Harold Steppuhn (consultant) to develop a technique that can be used to maximize the use of airborne snow-survey data to examine snow-water equivalent distribution and redistribution along a flight line and over a basin. Techniques to correlate snow-water equivalent for specific land uses to total annual snowfall will be examined. If this correlation can be accomplished, snow-water equivalents for specific land uses could be determined to simulate a homogeneous historical record of snowmelt-runoff periods.

Surface-Water Data

In each of the basins, two stream-gaging stations have been established to provide continuous-flow records. For the West Branch Antelope Creek study area (fig. 2), station 06340528 (West Branch Antelope Creek No. 4 near Zap) was established October 1976, and is located in the NW1/4NW1/4NE1/4 sec. 26, T. 145 N., R. 88 W., in Mercer County, North Dakota, at the outlet of the study basin. It has a drainage area of 8.46 mi^2 and a slope of 32.2 ft/mi. The elevation of the gage is about 1,960 ft NGVD of 1929. Station 06340524 (West Branch Antelope Creek No. 5 near Zap) was established October 1977, and is located in the NE1/4NE1/4SE1/4 sec. 20, T. 145 N., R. 88 W., in Mercer County, 4.6 river mi upstream from station 06340528. The basin upstream from the gaging station has a drainage area of 4.37 mi^2 and a slope of 22.4 ft/mi. The elevation of the gage is about 2,130 ft NGVD of 1929.

For the Hay Creek study area (fig. 3), station 06336515 (Hay Creek near Wibaux) was established March 1978, and is

TABLE 1.--Precipitation gages

[The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey]

West Branch Antelope Creek study area				Hay Creek study area			
Name	Location	Period of record	Type of gage	Name	Location	Period of record	Type of gage
BD-1	NW1/4NW1/4NE1/4 Sec. 12, T. 145 N., R. 89 W.	May 1978 to present	Highway type II with Stevens digital recorder	WC-1	SW1/4SW1/4NW1/4 Sec. 21, T. 15 N., R. 60 E.	March 1978 to present	Belfort universal rain gage
BC-2	NW1/4NE1/4SE1/4 Sec. 18, T. 145 N., R. 88 W.	July 1977 to present	Belfort universal rain gage	WD-1	SW1/4SW1/4NW1/4 Sec. 21, T. 15 N., R. 60 E.	May 1978 to present	Highway type II with Stevens digital recorder
BD-2	NW1/4NE1/4SE1/4 Sec. 18, T. 145 N., R. 88 W.	July 1978 to present	Highway type II with Stevens digital recorder	WD-2	SE1/4NW1/4SW1/4 Sec. 34, T. 15 N., R. 60 E.	Aug. 1978 to present	Fischer & Porter digital rain gage
BC-3	SW1/4SW1/4SW1/4 Sec. 18, T. 145 N., R. 88 W.	July 1977 to Sept. 1979	Belfort universal rain gage	WC-3	NW1/4SW1/4SE1/4 Sec. 3, T. 14 N., R. 60 E.	April 1978 to present	Belfort universal rain gage
BC-4	SW1/4SW1/4NW1/4 Sec. 8, T. 145 N., R. 88 W.	July 1977 to present	Belfort universal rain gage	WD-3	NW1/4SW1/4SW1/4 Sec. 3, T. 14 N., R. 60 E.	April 1978 to present	Highway type II with Stevens digital recorder
BC-5	SW1/4SW1/4SE1/4 Sec. 10, T. 145 N., R. 88 W.	July 1977 to May 1979	Belfort universal rain gage	WC-4	SW1/4NW1/4NW1/4 Sec. 8, T. 14 N., R. 60 E.	April 1978 to Sept. 1979	Belfort universal rain gage
BC-6	SW1/4SW1/4NW1/4 Sec. 21, T. 145 N., R. 88 W.	May 1979 to present	Belfort universal rain gage	WC-5	NE1/4NW1/4NW1/4 Sec. 32, T. 15 N., R. 60 E.	May 1978 to present	Belfort universal rain gage
BD-7	SW1/4NW1/4NE1/4 Sec. 28, T. 145 N., R. 88 W.	Feb. 1978 to present	Fischer & Porter digital rain gage	WC-6	NW1/4SW1/4SW1/4 Sec. 6, T. 14 N., R. 61 E.	April 1978 to Oct. 1978	Belfort universal rain gage
BD-8	SE1/4SE1/4SE1/4 Sec. 28, T. 145 N., R. 88 W.	June 1979 to present	Highway type II with Stevens digital recorder	WC-7	SE1/4SE1/4SE1/4 Sec. 23, T. 14 N., R. 60 E.	May 1978 to present	Belfort universal rain gage
BC-9	NW1/4NE1/4NW1/4 Sec. 26, T. 145 N., R. 88 W.	Jan. 1977 to May 1979	Belfort universal rain gage	WD-7	SE1/4SE1/4SE1/4 Sec. 23, T. 14 N., R. 60 E.	April 1978 present	Highway type II with Stevens digital recorder
BD-10	SE1/4SW1/4NE1/4 Sec. 6, T. 144 N., R. 88 W.	May 1978 to Nov. 1978	Highway type II with Stevens digital recorder	WOR-9	NW1/4NE1/4NW1/4 Sec. 33, T. 15 N., R. 60 E.	May 1978 to present	Observer read volume gage
BOR-11	SW1/4SE1/4SW1/4 Sec. 22, T. 145 N., R. 88 W.	Sept. 1977 to present	Observer read volume gage	WOR-10	SW1/4SW1/4SW1/4 Sec. 22, T. 15 N., R. 60 E.	May 1978 to Sept. 1978	Observer read volume gage
BOR-12	NE1/4SE1/4NE1/4 Sec. 12, T. 145 N., R. 87 W.	May 1978 to July 1978	Observer read volume gage	WC-11	SE1/4SW1/4NE1/4 Sec. 14, T. 14 N., R. 60 E.	Aug. 1979 to present	Belfort universal rain gage
BC-13	NW1/4NW1/4NE1/4 Sec. 26, T. 145 N., R. 88 W.	May 1978 to present	Belfort universal rain gage				

located in the SW1/4SW1/4NW1/4 sec. 21, T. 15 N., R. 60 E., in Wibaux County, Montana, at the outlet of the study basin. It has a drainage area of 11.41 mi^2 and a slope of 26.7 ft/mi. The elevation of the gage is about 2,610 ft NGVD of 1929. Station 06336510 (Hay Creek No. 2 near Wibaux) was established March 1978, and is located in the NW1/4SW1/4SE1/4 sec. 3, T. 14 N., R. 60 E., Wibaux County, 5.19 river mi upstream from 06336515. The basin upstream from the gaging station has a drainage area of 4.12 mi^2 and a slope of 28.8 ft/mi. The elevation of the gage is about 2,740 ft NGVD of 1929.

At each of the stations, water samples are collected during snowmelt runoff, base flow, and rainfall runoff. The samples are analyzed for the constituents and properties listed in table 2. Analyses of the water samples will be used to determine the suitability of the water for various uses, and to establish a base in order to detect changes with development.

At stations 06340528 and 06336515, PS-69 automatic sediment samplers are being used to ensure the acquisition of sediment data during spring runoff and infrequent summer runoff. Manually collected samples are used to develop a rating for the automatic samplers.

In addition, sediment samples are collected at the upstream stations and many miscellaneous tributaries in the basin during runoff to gather information on the study area and assist in focusing attention on areas that may present special sediment problems.

Basin Characteristics

Data are collected and analyzed to define basin soil properties, soil-water storage characteristics, infiltration characteristics, soil detachability, vegetation characteristics, and topography. A portable rainfall simulator has been used to define the infiltration rates, overland flows, and sediment yields from various combinations of topography, soil, vegetation, and land use. Data from the rainfall simulator will be used in the development and improvement of runoff- and sediment-model subroutines.

Soil-Moisture Data

A network of access tubes has been established for the purpose of collecting periodic soil-moisture data with a neutron probe meter. Reuben Miller, U.S. Geological Survey, helped select the sites, collect the soil samples, and analyzed the soil

TABLE 2.--Water-Quality analysis schedule

Alkalinity	Nitrogen Kjeldahl (dissolved)
Boron (dissolved)	pH
Calcium (dissolved)	Potassium (dissolved)
Chloride (dissolved)	Sodium-adsorption ratio
Dissolved solids	Silica (dissolved)
Fluoride (dissolved)	Sodium (dissolved)
Hardness	Sodium percent
Iron (dissolved)	Specific conductance
Magnesium (dissolved)	Strontium (dissolved)
Manganese (dissolved)	Sulfate (dissolved)
Molybdenum (dissolved)	Water temperature

samples for bulk density, hydraulic conductivity, and water-holding capacity.

Data collection began September 1978 with the installation of 6 access tubes in the West Branch Antelope Creek basin and 10 access tubes in the Hay Creek basin. All the sites were located either in road right-of-ways or pastures. The sites were selected to monitor the soil moisture in each of the major types of soils defined in the basins by the U.S. Soil Conservation Service. Additional sites in Hay Creek basin were established to monitor the soil moisture of areas of moderate slope and varying aspect.

During the spring of 1979, three additional sites were added in both the West Branch Antelope Creek and Hay Creek basins. These sites were located in both fallow and grain fields, and in grasslands.

During the spring of 1980, major modifications were again made to the network. Reuben Miller's anaylses of the soil samples showed that for each basin the soils could be grouped into two classes, each class having similar hydrologic characteristics. This grouping made the monitoring of the soil moisture for the basins simpler because fewer sites had to be measured to detect the major changes in soil moisture.

The network for the West Branch Antelope Creek basin consists of six soil-moisture access-tube sites (fig. 2). The first soil class is monitored at one site and at two pairs of sites. Each pair of sites consists of one access tube located in cropland and one access tube located in adjacent grassland. The second soil class is monitored at only one soil-moisture site located in grassland because the land use for this soil class is primarily pasture.

The network for the Hay Creek basin consists of 10 soil-moisture access-tube sites (fig. 3). The first soil class is monitored at three sites in grassland with varying slopes and at two pairs of sites. Each pair of sites consists of one access tube located in cropland and one access tube located in adjacent grassland. The second soil class is monitored at one site located in grassland and at a pair of sites; one access tube located in cropland and one access tube located in adjacent grassland.

All sites, their locations, land use, and period of record are listed in table 3. Soil-moisture measurements are scheduled every 2 weeks during the months of greatest rainfall (May-July) and once a month for the remaining non-snow-cover months. Measurements of the soil moisture at the surface (top 6 in.) with the Troxler Model 1255 neutron probe have considerable error. This error was anticipated; therefore, soil samples are taken from this surface each time a neutron probe measurement is made.

TABLE 3.--Soil-moisture sites

Name	Location	Cover type	Period of record	Name	Location	Cover type	Period of record
West Branch Antelope Creek basin				Hay Creek basin			
B1	NW1/4SW1/4SW1/4 Sec. 6, T. 145 N., R. 88 W.	Grass	Sept. 1978 to May 1980	W1	SW1/4SW1/4NW1/4 Sec. 21, T. 15 N., R. 60 E.	Grass	Sept. 1978 to April 1980
B3	SW1/4NW1/4NW1/4 Sec. 18, T. 145 N., R. 88 W.	Grass	Sept. 1978 to May 1980	W2	SE1/4SE1/4SE1/4 Sec. 20, T. 15 N., R. 60 E.	Grass	Sept. 1978 to present
B4	NW1/4NE1/4NE1/4 Sec. 18, T. 145 N., R. 88 W.	Grass	Sept. 1978 to May 1980	W3	SE1/4SW1/4SE1/4 Sec. 20, T. 15 N., R. 60 E.	Grass	Sept. 1978 to present
B5	SE1/4NE1/4NE1/4 Sec. 28, T. 145 N., R. 88 W.	Grass	Sept. 1978 to present	W4	NW1/4NE1/4NW1/4 Sec. 28, T. 15 N., R. 60 E.	Grass	Sept. 1978 to April 1980
B6	SW1/4NW1/4NE1/4 Sec. 28, T. 145 N., R. 88 W.	Grass	Sept. 1978 to present	W5	SW1/4SW1/4SW1/4 Sec. 28, T. 15 N., R. 60 E.	Grass	Sept. 1978 to April 1980
B7	NW1/4NW1/4NE1/4 Sec. 26, T. 145 N., R. 88 W.	Grass	Sept. 1978 to May 1980	W6	NW1/4NW1/4SW1/4 Sec. 34, T. 15 N., R. 60 E.	Grass	Sept. 1978 to present
B8	NE1/4NE1/4NE1/4 Sec. 28, T. 145 N., R. 88 W.	Crop	June 1979 to present	W7	SE1/4NW1/4SW1/4 Sec. 34, T. 15 N., R. 60 E.	Grass	Sept. 1978 to present
B9	NE1/4NW1/4NW1/4 Sec. 28, T. 145 N., R. 88 W.	Crop	June 1979 to present	W8	SE1/4NW1/4SW1/4 Sec. 34, T. 15 N., R. 60 E.	Grass	Sept. 1978 to present
B10	SE1/4SE1/4SE1/4 Sec. 28, T. 145 N., R. 88 W.	Grass	June 1979 to May 1980	W9	SE1/4NW1/4SW1/4 Sec. 34, T. 15 N., R. 60 E.	Grass	Sept. 1978 to present
B11	NE1/4NE1/4NE1/4 Sec. 28, T. 145 N., R. 88 W.	Grass	May 1980 to present	W10	NW1/4SW1/4SE1/4 Sec. 3, T. 14 N., R. 60 E.	Grass	Sept. 1978 to May 1980
B12	NE1/4NW1/4NW1/4 Sec. 28, T. 145 N., R. 88 W.	Grass	May 1980 to present	W11	SE1/4SE1/4SE1/4 Sec. 20, T. 15 N., R. 60 E.	Grass	July 1979 to present
				W12	SE1/4SW1/4SE1/4 Sec. 20, T. 15 N., R. 60 E.	Crop	July 1979 to present
				W13	NE1/4SW1/4NE1/4 Sec. 14, T. 14 N., R. 60 E.	Crop	July 1979 to present
				W14	NE1/4SW1/4NE1/4 Sec. 14, T. 14 N., R. 60 E.	Crop	May 1980 to present

The moisture content of the soil sample is then determined in the laboratory by the gravimetric method.

Land-Use Data

The two study areas consist mostly of farmland. The most common land uses are fallow, crop, pasture, and hay. The fields usually do not vary in size, but many of them vary in land use, not only from year to year but from summer to winter. Therefore, a land-use map is made during the early summer to account for the variation in evapotranspiration and infiltration, and another land-use map is made during the late fall to account for snow distribution.

DATA MANAGEMENT

In a study of this type, large quantities of data are acquired. With two study areas, the amount of the data doubles; therefore, data management is a major part of the study. The U.S. Geological Survey's WATSTORE system is being used to handle the computer storage and retrieval of the data. Data stored in WATSTORE are easily retrieved and are readily available for modeling or for use in other WATSTORE programs for analyses and publication.

The use of cassette tapes to record data from the data-acquistion system is more efficient than the use of charts or digital tapes; however, new techniques and programs had to be developed to process the data. Personnel of the U.S. Geological Survey were instrumental in adapting WATSTORE data-handling programs to process the data. Still, modifications were needed for adaption to the computer hardware in North Dakota.

Some of the data, such as snow depth and density and land-use data, are still collected and stored in hard copy form. New methods are needed for handling and storage of such data to make it more readily usable in data analysis and digital modeling.

METHODS OF EVALUATION

Data Analyses

Data collected during the premining period will be analyzed by statistical methods to evaluate the premining conditions. Many of the statistical methods are available as computer programs in WATSTORE, such as monthly and annual statistics, duration analysis, low- and high-value sequence summaries, and Log-Pearson frequency distribution. In addition, correlations and regressions will be developed for possible use in analysis of premining conditions and to estimate streamflow, water-quality, and sediment. Data analyses will identify critical hydrologic periods so future efforts of data collection, data analyses, and digital modeling can be directed to those periods.

Precipitation

Of the elements that comprise climate, precipitation is the most important in determining the hydrology of a basin. Most of the precipitation during the summer is from thunderstorms, which may produce large amounts of rainfall in a short period. Typical thunderstorms are only several miles wide, are of short duration, and affect relatively small areas; therefore, precipitation sites have been established to define the spatial and temporal variations of rainfall.

During the winter months, precipitation is in the form of snow. Several blizzards occur in North Dakota and Montana each year. Blowing and drifting snow, snow that is not falling from clouds, also is quite common. A large variation in snow distribution is produced; snow is blown free from some areas and piled high in drifts in other areas. For the prairies of North Dakota and Montana, this large variation is related directly to the type of terrain and land use. For example, snow will be blown off a fallow hilltop; whereas, a deep snow drift will form on a bushy, southerly, steep slope.

The average monthly and annual precipitation for Beulah, North Dakota and Wibaux, Montana are shown in table 4. There are pronounced seasonal variations in precipitation; June is the wettest month and December is the driest. About 50 percent of the precipitation normally falls during May, June, and July (Bavendick, 1952).

The largest amount of rainfall for the period of record in either of the basins was recorded at WC-1 in Hay Creek basin on May 30, 1978. A total of 2.67 in. of rain fell in 24 hours. The event would have about a 15 percent chance of occurring in any year as a 24-hour rainfall (fig. 5). Later that year, on June 29, the same precipitation gage recorded 0.79 in. of rain in about 1 hour. There is a 90 percent chance for a rainfall event of this size or larger to occur in any year as a 1-hour rainfall (fig. 5). Another precipitation gage (WC-6) in the Hay Creek basin recorded 2.00 in. of rain in about 1 hour for the June 29, 1978, rainfall event. There is a 4 percent chance for a rainfall event of this size or larger to occur in any year as a 1-hour

TABLE 4.--Average monthly and annual precipitation

Month	Precipitation, in inches	
	Beulah, North Dakota[1/]	Wibaux, Montana[2/]
Oct.	0.66	0.66
Nov.	.55	.44
Dec.	.32	.24
Jan.	.47	.36
Feb.	.43	.30
Mar.	.63	.51
Apr.	1.48	1.25
May	2.57	1.96
June	3.97	3.38
July	2.62	2.17
Aug.	2.08	1.59
Sept.	1.42	1.33
Annual	17.20	14.19

1/U.S. Environmental Data Service, 1973a.
2/U.S. Environmental Data Service, 1973b.

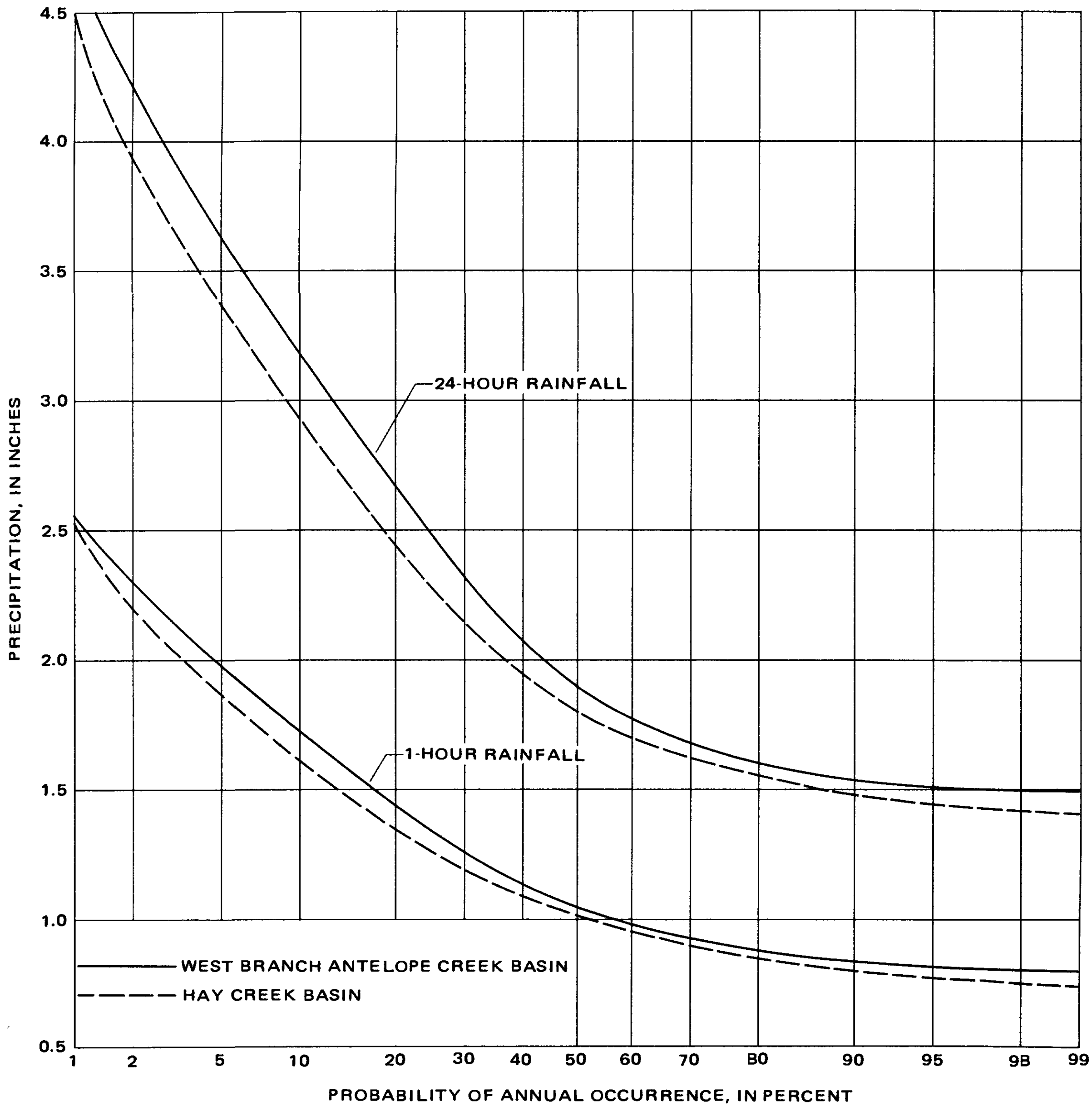


FIGURE 5.—Rainfall frequency curves for the study area (U.S. Weather Bureau, 1961).

rainfall (fig. 5). For the West Branch Antelope Creek basin, the largest 1-hour rainfall recorded was 1.85 in. at BC-3 on June 19, 1978. There is a 5 percent chance for a rainfall event of this size or larger to occur in any year as a 1-hour rainfall (fig. 5).

A list of rainfall amounts recorded during the two events at four precipitation gages in the Hay Creek basin is given in table 5. All the gages are within 5 mi of each other. The data show how rainfall varies over even a small area. The maximum difference for the May 30 event was 0.91 in., but for the June 29 event the maximum difference was 1.21 in. Although both events show significant variations, the June 29 variation was much greater because the storm was a thunderstorm with intense rainfall and a short duration.

The relationship of the rainfall intensity to runoff for the May 30 and June 29, 1978, events is shown in table 6. The peak discharge at station 06336515 (Hay Creek near Wibaux) for May 30, 1978, was 4.04 ft^3/s, and for June 29 the peak discharge was 15.5 ft^3/s.

The only measurable rainfall-runoff event for station 06340528 (West Branch Antelope Creek No. 4 near Zap) occurred June 15, 1977. The peak discharge was 36.0 ft^3/s. This event occurred at the beginning of the study when a precipitation network was not yet established in the basin. The National Weather Service in Beulah, N. Dak., recorded 0.88 in. of rain in 1 hour. Beulah is 10 mi from the study basin and, as shown before, especially for intense summer thunderstorms, rainfall cannot be extrapolated with any accuracy from one area to another.

Runoff

In the northern plains region, runoff may result from either rainfall or snowmelt. Initial data analysis has indicated that for the short records involved in this study, snowmelt-runoff events are more frequent. At station 06336515 (Hay Creek near Wibaux), 3 years of discharge data have been collected, and six peak discharges greater than the base of 10 ft^3/s have occurred. Of these peak discharges, only one has been from rainfall runoff, and the remainder have been from snowmelt runoff. At station 06340528 (West Branch Antelope Creek No. 4 near Zap), 4 years of discharge data have been collected, and four peak discharges greater than the base of 10 ft^3/s have occurred. Of these peak discharges, only one has been from rainfall runoff, and the remainder have been from snowmelt runoff.

Because the period of record for the four stream-gaging stations is only a few years, it is a very limited index as to the

TABLE 5.--Precipitation in Hay Creek area for May 30 and June 29, 1978

	Precipitation, in inches			
Gage	WC-1	WC-4	WC-5	WC-6
May 30, 1978 1/	2.67	1.90	1.76	2.29
June 29, 1978 2/	.79	.92	1.33	2.00

1/ Rainfall duration of 24 hours.

2/ Rainfall duration of 1 hour.

TABLE 6.--Rainfall intensity and runoff relationships

	May 30, 1978	June 29, 1978
Average total rainfall, in inches	2.16	1.26
Duration of rain, in hours	24	1
Average intensity, in inches per hour	.09	1.26
Peak discharge, in cubic feet per second, at station 06336515 (Hay Creek near Wibaux)	4.04	15.5

average annual discharge that could be expected. Therefore, a regression equation based on other small basins with less than 100 mi^2 drainage area in western North Dakota and eastern Montana was used to determine mean annual discharge (O. A. Crosby, U.S. Geological Survey, oral commun., 1980). The equation gives a mean annual discharge of 600 acre-ft at station 06340528 (West Branch Antelope Creek No. 4 near Zap), and a mean annual discharge of 1,100 acre-ft at station 06336515 (Hay Creek near Wibaux), with mean standard errors of 33 percent.

Without a sufficient period of record, the recurrence probabilities of peak discharges also need to be determined from regionalized data. The peak discharges for recurrence probabilities of 50, 20, 10, 4 and 2 percent for the four stream-gaging stations were computed using regression equations described by Crosby (1975). The computed and measured peak discharges are listed in table 7. The peak discharge at station 06340528 (West Branch Antelope Creek No. 4 near Zap) for the 1978 water year has about a 50 percent probability of being equalled or exceeded in a given year, and the peak discharge at station 06336515 (Hay Creek near Wibaux) for the 1978 water year has greater than a 50 percent probability of being equalled or exceeded in a given year.

A comparison of the ratio of rainfall-snowmelt peaks for several stream-gaging stations in North Dakota that have 10 years or more of record indicates that about 30 percent of all peaks are due to rainfall runoff. The records indicate that in small basins the largest peak discharges are due to rainfall runoff and in larger basins, the largest peak discharges are due to snowmelt runoff. Therefore, a large rainfall-runoff event in a small basin probably will have little effect on a large stream, which will be experiencing a small runoff event, and expected impacts due to mining will be small downstream. During a large runoff event in a large basin due to snowmelt, the runoff event occurring in the small basin may not be particularly large. Therefore, it is difficult to identify the hydrologic factors controlling the important water- and sediment-yielding processes for coal hydrology problems.

If the critical hydrologic events for coal hydrology problems can be identified, data collection, data analysis, and digital modeling can be directed to these events. For example, if snowmelt-runoff events could be identified as critical, the resulting model could be developed for snowmelt-runoff events only. If frozen ground could be assumed, soil-moisture accounting would be eliminated in the final model. Continuous simulations would not be required, and historical records could be simulated by simply using winter precipitation and climatological records.

Initial analyses of the data for the two study basins indicate that snowmelt-runoff events are the source of more than two-

TABLE 7.--Flood discharges at selected exceedance probabilities and maximum recorded discharges

Stream-gage station	Peak discharge (cubic feet per second)								
	Exceedance probabilities (percent)					1977 maximum	1978 maximum	1979 maximum	1980 maximum
	50	20	10	4	2				
06340528 (West Branch Antelope Creek No. 4 near Zap)	120	325	515	800	1,050	36	155	350	20
06340524 (West Branch Antelope Creek No. 5 near Zap)	70	190	300	480	630	--	125	435	11
06336515 (Hay Creek near Wibaux)	110	315	510	820	1,100	--	50	58	1.0
06336510 (Hay Creek No. 2 near Wibaux)	60	165	265	425	565	--	85	10	2.0

thirds of all peak discharges with annual exceedance probabilities of 5 percent or greater.

Sediment

Analysis of suspended-sediment data for snowmelt-runoff periods indicates very little sediment discharge. The maximum suspended-sediment concentration measured during snowmelt runoff at station 06340528 (West Branch Antelope Creek No. 4 near Zap) was 325 mg/L (milligrams per liter), at a discharge of about 300 ft^3/s. The maximum suspended-sediment concentration measured during snowmelt runoff at station 06336515 (Hay Creek near Wibaux) was 231 mg/L, at a discharge of 27 ft^3/s. The mean suspended-sediment concentration for snowmelt runoff was about 50 and 25 mg/L, respectively, at the two stations.

Based on one small rainfall-runoff event in each basin, analysis of the suspended sediment for rainfall runoff also indicates very little sediment discharge. The maximum suspended-sediment concentration measured during rainfall runoff at station 06340528 (West Branch Antelope Creek No. 4 near Zap) was 230 mg/L, at a discharge of 1.9 ft^3/s. The maximum suspended-sediment concentration measured during rainfall runoff at station 06336515 (Hay Creek near Wibaux) was 596 mg/L, at a discharge of 3.3 ft^3/s. However, given a large rainfall-runoff event, the suspended sediment could be considerably larger. For a complete analysis of suspended sediment due to rainfall runoff, more data are required.

Digital Model

Adequate evaluation of the hydrologic effects resulting from surface mining and predictions of variations in time and space with changes imposed by mining may best be accomplished by the use of hydrologic models. One of the major objectives of the study is to develop, test, and verify a hydrologic model package to predict impacts of surface mining on the surface-water hydrology of the basins in the Fort Union Coal Region.

Description

The model being used is a digital computer model consisting of a snowmelt-runoff model (Leavesley, 1973) and a rainfall-runoff model (Dawdy, Lichty, and Bergmann, 1972) coupled together for computing streamflow from a basin. The model is a modular-design program (fig. 6) with each segment of the hydrologic

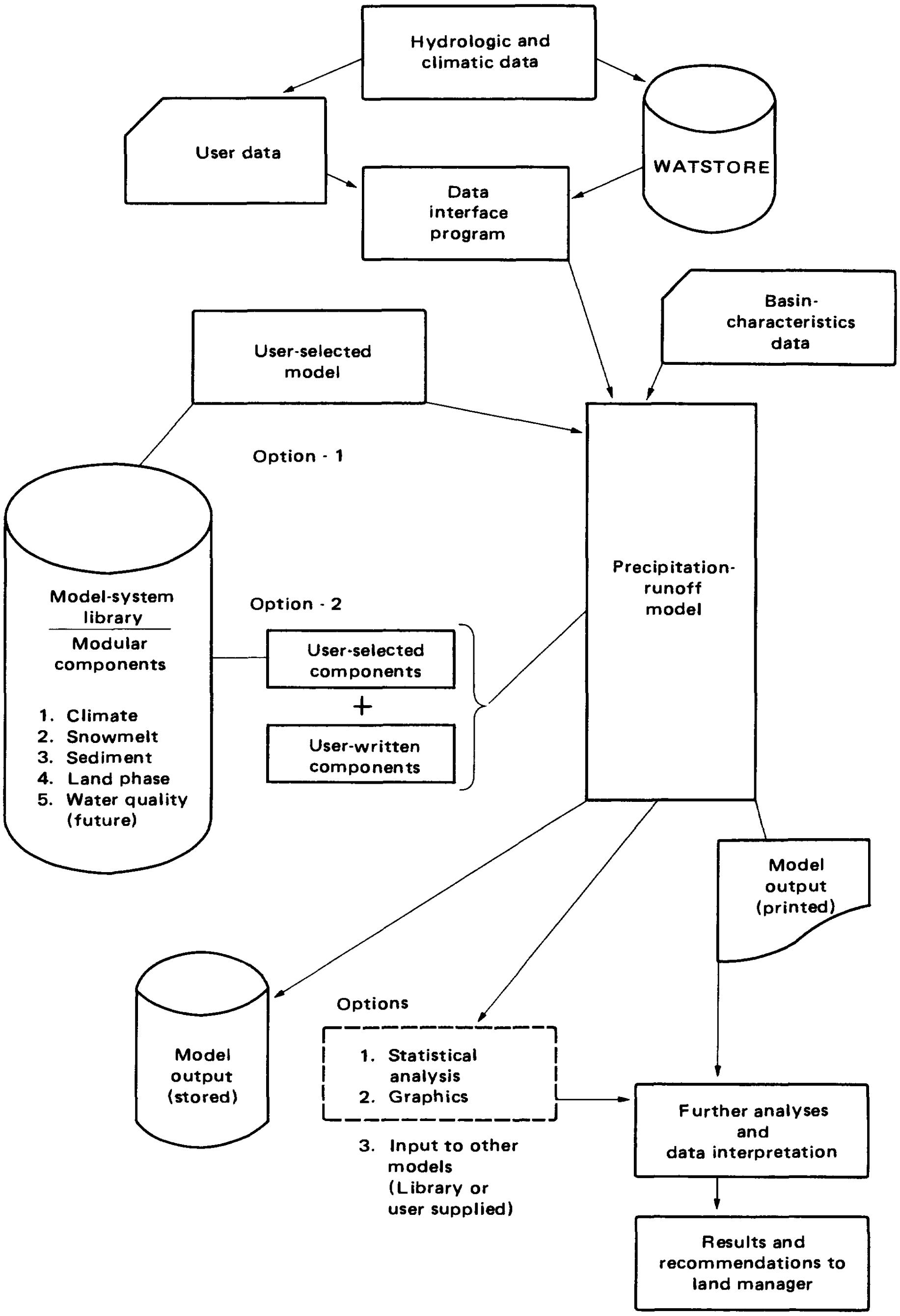


FIGURE 6.—Diagram of the modeling system showing all components and flow of information to the user group.

system being defined by a subroutine or a series of subroutines (G. H. Leavesly, U.S. Geological Survey, written commun., 1980). All subroutines will be compatible for linkage to each other, thereby having the capability of combining subroutines that best define the overall system. The model will have the capability of using user-written subroutines or modified subroutines. The modular concept will permit the application of this model to a wide range of hydrologic problems.

A distributed-parameter approach is used in this model--that is, the basin is partitioned into subunits based on slope, aspect, vegetation type, soil type, and snow distribution. Each subunit is considered homogeneous with respect to its hydrologic response and is called a hydrologic-response unit. Partitioning into hydrologic-response units will help account for the temporal and spatial variations of the hydrologic characteristics, climatic variables, and system response. Partitioning also will provide the ability to impose land-use changes on parts or all of a basin, and to evaluate the resulting hydrologic impacts on each hydrologic-response unit and on the total basin.

Input parameters to the model include descriptive data on the physiography, vegetation, soils, and hydrologic characteristics of each hydrologic-response unit, and the variation of climate over a basin. The driving variables of the model include daily maximum and minimum air temperatures, precipitation, humidity, wind, and solar radiation. The model also will operate with only precipitation and maximum and minimum air temperature data, but with less accurate results. The model can be run in daily mode, unit (time interval less than daily) and daily mode, or unit and daily mode with flow routing, depending on hydrologic and basin variables or the required output.

Status

During September 1979, the runoff model was made available to U.S. Geological Survey users, but not all components of the model were complete. The completed components made it possible to make initial modeling runs. During August of 1980, a draft copy of the model documentation describing most of the components developed and tested was made available to the users. The model-development team is constantly upgrading, refining, and adding components to the model.

Runoff in each of the two basins generally has been either from snowmelt with frozen soils or from snowmelt without frozen soils. Only one minor rainfall-runoff event has occurred in each basin since the beginning of data collection. Because of the lack of significant rainfall-runoff events, calibration and testing of the model using rainfall-runoff data has not been possible. However, the model has been set up and run using the 1977 water year data in a lumped-parameter approach.

Both basins have been delineated into hydrologic-response units to be further simulated with a distributed-parameter approach. Due to the lack of rainfall-runoff events, the snowmelt periods for each year will be simulated to calibrate the model for snowmelt runoff, which should simplify the simulation by eliminating the soil-moisture accounting variables used during the rainfall period. Initial simulations using the latest version of the model for station 06340524 (West Branch Antelope Creek No. 5 near Zap) have begun for the snowmelt periods. These simulations will be developed into more elaborate simulations using 36 hydrologic-response units and snow-survey data. Depending upon the results of these model simulations, modifications and retesting of some of the components will continue throughout the remainder of the study. Initial model simulations for the Hay Creek basin will be made during 1981.

The snowmelt-runoff component of the model probably will be the most significant component for western North Dakota and eastern Montana because of the importance of snowmelt runoff. However, the difficulty of defining the snow distribution, frozen ground, and other physical processes of the prairie snowmelt has been noted. Incorporating these processes into the model will require major modification of the subroutine for the snowmelt-runoff component. Following the development of a streamflow model for predicting runoff from snowmelt and rainfall events, the development of a sediment model will begin.

Because snowmelt-runoff events typically occur only once a year in a semiarid environment such as that of western North Dakota and eastern Montana, it is anticipated that at least 5 years of data with an adequate range of climatic and streamflow conditions will be needed to calibrate and verify the model for premined conditions. However, year-round data collection will be continued so that any large rainfall-runoff events that occur will be measured. After the model has been calibrated and verified, the transfer value to other gaged or, more likely, ungaged basins in the Fort Union Coal Region will be investigated. It is hoped that the model's prediction capabilities will be verified when land-use changes are made by coal mining in the study basins. However, verification of the model's prediction capabilities will be a function of the project's duration and the mining plan.

SUMMARY

Data have been collected since October 1976 for the West Branch Antelope Creek study area in North Dakota and since March 1978 for the Hay Creek study area in Montana. The data-management system is operational with regard to data input, storage, and retrieval.

The model development is well underway with most of the components tested during 1979 and 1980. The data retrieval and model interface capabilities have been developed. Initial estimates are that at least 5 years of data will be required for model calibration and verification. Verification at the end of the data-collection period will be based on model simulations of basins in a premined condition. After verification of the model, predictions regarding the hydrologic impacts of surface mining could be made by modifying selected model variables and parameters. However, full verification of the prediction capabilities will depend on the availability of data from mined and post-mined basins. Prediction verifications on the current study basins will be a function of the time and speed with which they are mined.

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