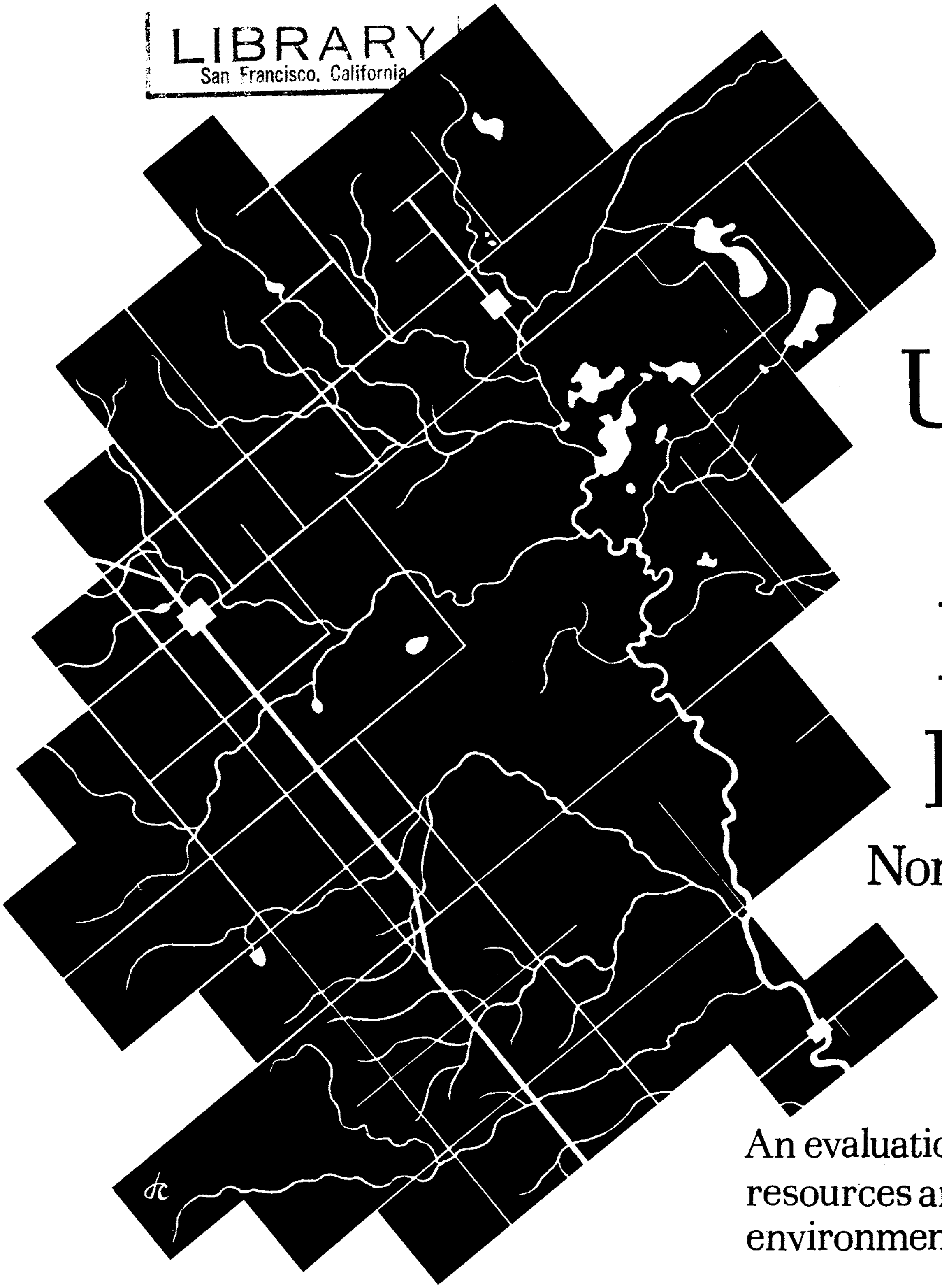
WATER INFORMATION SERIES

Report 1



Upper Rifle River Basin

Northeastern Lower Michigan

An evaluation of its water resources and hydrologic environment.

Prepared by the United States Geological Survey in cooperation with the Michigan Geological Survey

1971

WATER INFORMATION SERIES REPORT 1

U. S. DEPARTMENT OF THE INTERIOR
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UPPER RIFLE RIVER BASIN NORTHEASTERN LOWER MICHIGAN

AN EVALUATION OF ITS WATER RESOURCES AND HYDROLOGIC ENVIRONMENT

by:
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artwork by Jim Campbell

Prepared by the
United States Geological Survey
in cooperation with the
Michigan Geological Survey
Department of Natural Resources

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FIGURE 1.--Index map of the upper Rifle River basin.

FOREWORD

The upper Rifle River basin is unusually blessed with abundant springs, flowing wells, lakes, and cold-water streams. These water resources are attractive to light industries, to individuals seeking a pleasant place to live, and to recreationists who enjoy fishing and camping. The flowing wells are especially attractive for developing inexpensive private trout ponds.

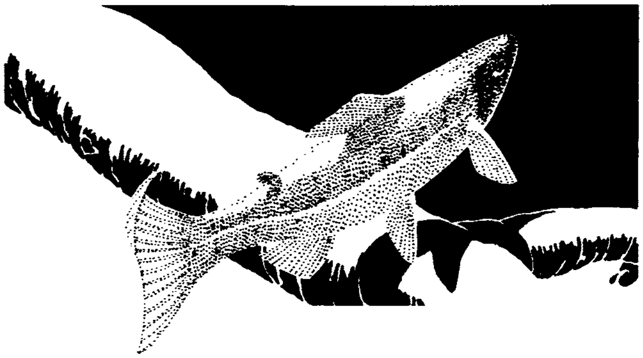
While these water resources are abundant, they are not inexhaustible, and careless exploitation may lead to hardship or even economic disaster. Overdevelopment of flowing wells, for example, will inevitably lead to lower artesian pressures; some wells will cease to flow, and others will decline in yield; the flow of some streams may decline, whereas others may increase. This report describes the natural water system in the upper Rifle River basin and shows how use and development changes this system. If the information provided here is used in planning future development of the area, water resources of the upper Rifle River basin should be adequate for many years.

In many ways the problems and opportunities associated with the Rifle River basin are common to other river basins in the north country. Thus, an understanding of the hydrologic setting of the Rifle River and the principles set forth in managing it, can also be applied to other streams to assure their continued high quality and extended use.

Users of this report will especially appreciate the lucid manner in which Messrs. Knutilla, Twenter, and Larson have conveyed their findings on a rather complex topic.

Arthur E. Slaughter
State Geologist and Chief
Geological Survey Division
Michigan Dept. of Natural Resources

Lansing
April 1, 1971



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Definition of Terms

Aquifer: A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian water: Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.

Base flow: The discharge entering stream channels as effluent from the ground-water or other delayed sources; sustained or fair weather flow of streams.

Bedrock: In this report, designates the consolidated rock underlying the glacial deposits.

Concentration: The weight of dissolved solids or sediment per unit volume of solution. Concentration is expressed in milligrams per liter (mg/l).

Cubic feet per second (cfs): A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, whose velocity is 1 foot per second; equivalent to 448.8 gallons per minute or about 0.65 million gallons per day.

Divide: A line of separation between drainage systems. The basin or topographic divide includes the land from which a river gathers its water, the ground-water divide is a line on a water table on each side of which the water table slopes downward in a direction away from the line.

Drawdown: Lowering of the water level by pumping or artesian flow.

Effluent seepage (effluent flow): Flow of water from the ground into a surface-water body.

Evapotranspiration: Water withdrawn from a land area by direct evaporation from water surfaces and moist soil and by plant transpiration, no attempt being made to distinguish between the two.

Flood frequency: Over a period of years, the average number of times a flood of a given magnitude is likely to occur.

Flow-duration curve: A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Gaging station: A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Ground water: Water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied.

Ground-water runoff: That part of streamflow which consists of water discharged into a stream channel by seepage from the aquifer.

Hydrograph: A graph showing stage, flow, velocity, or other property of water with respect to time.

Infiltration: The percolation of the water through the surface of the lithosphere; also, absorption by seepage.

Low-flow frequency curve: A graph showing the magnitude and frequency of minimum flows for a period of given length.

Partial-record station: A site where limited streamflow data are collected systematically over a period of years for use in hydrologic analyses.

Perched lake: A lake that is separated from the underlying ground water by a zone of aeration.

Permeability: The capacity of a material to transmit a fluid.

Recharge: Comprises the processes by which water is absorbed and is added to the zone of saturation.

Recurrence interval (return period): The average interval of time within which the given flood will be equaled or exceeded once; also, the average interval of time within which a flow equal to or lower than a given low flow will occur once.

Runoff: That part of the precipitation that appears in surface streams; the water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

Soil moisture: Water diffused in the soil or in the upper part of the zone of aeration from which water is discharged by the transpiration of plants or by soil evaporation.

Topographic depression: A low place of any size on a plain surface, having drainage underground or by evaporation; a hollow completely surrounded by higher ground and having no natural outlet for surface drainage.

Underflow: The movement of water in an aquifer reservoir.

Water table: The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

Zone of saturation: The zone in which the functional permeable rocks are saturated with water under hydrostatic pressure.

UPPER RIFLE RIVER BASIN NORTHEASTERN LOWER MICHIGAN

AN EVALUATION OF ITS WATER RESOURCES AND HYDROLOGIC ENVIRONMENT

by: R.L.KNUTILLA
F.R.TWENTER
R.W.LARSON

Abstract

The upper Rifle River basin, an area of 117 square miles in north central Ogemaw County, has a relatively unique hydrologic system. Streams in the system receive large amounts of ground water--water that maintains high streamflows even during extended dry periods. Springs are plentiful and flowing wells abound. The prime features relating to the basin's hydrologic system are broad sand and gravel areas and numerous topographic depressions along the basin's northern and western boundaries. These features facilitate the capture of precipitation and the recharge of ground-water reservoirs. This report describes the character of the basin's hydrologic system and provides information on the quality and quantity of water available from the system. In an average year, streamflow from the basin totals 140 cfs (cubic feet per second). Of this amount, about 103 cfs is derived from ground-water sources and 37 cfs is derived from overland runoff. An estimated 46 cfs reaches the basin from areas north and west of the basin's topographic divide. This subsurface interbasin flow accounts for the disproportionate runoff ratio of ground water to surface water. When combined with water received locally this flow maintains relatively high stream discharges, even during extended dry periods. Hence the streams are excellent for trout fishing and water supplies. For example, median annual 7-day low flows for most streams are generally more than 0.5 cfsm (cubic feet per second per square mile) and for many streams this index of low flow is more than 1 cfsm, considerably higher than that experienced in most other areas in Michigan. Ground-water supplies are obtained primarily from glacial deposits. It is estimated that more than 500 billion gallons of water are stored in these deposits. Water often flows freely from wells under the influence of artesian pressure--pressure that may be adequate to supply household needs without the use of pumps. This source supplies many trout ponds within the basin. Bedrock deposits are of minor importance as a source for water supply. Most water from bedrock is too mineralized for domestic use. In contrast, water from glacial deposits, as well as water from lakes and streams, is of good chemical quality.

INTRODUCTION

The upper Rifle River basin is in the northeastern part of Michigan's Lower Peninsula (figs. 1 and 2). The 117-square mile area is in a pleasant landscape offering a relaxing and recreational environment to its residents and to the tourists who frequent the area. Although not in a highly populated area, the basin's importance is enhanced by its proximity to industrial centers in the southern part of the State and by the tourist industry generated from these centers.

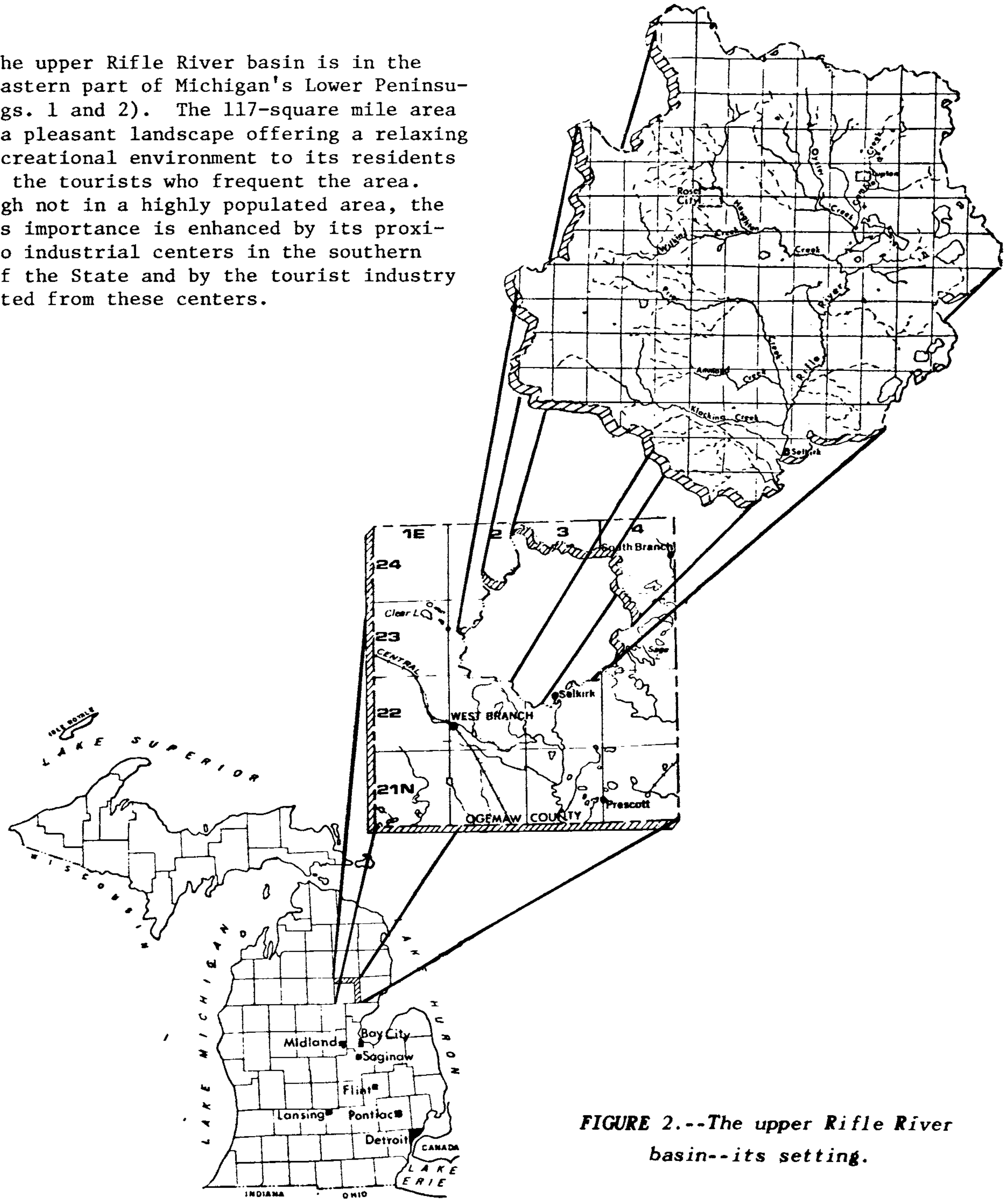


FIGURE 2.--The upper Rifle River basin--its setting.

THE NEED FOR A WATER RESOURCES STUDY

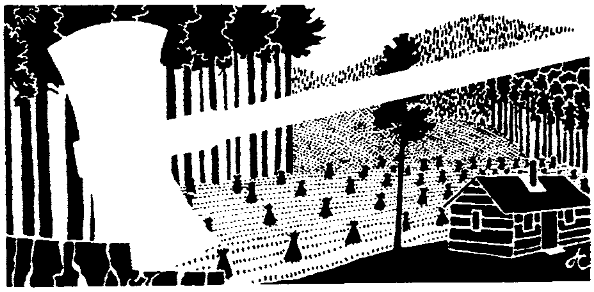
Streams in the upper Rifle River basin, today as in the past, provide an excellent water supply. Most streams have high sustained flows, are excellent trout streams, and are used widely for recreation. The streams have been used in the operation of small sawmills and a commercial power dam once was operated on Wilkins Creek.

Ground-water resources in the basin also provide an excellent source for water supply. Throughout much of the basin ground-water aquifers are under artesian pressure. Most homes, businesses, and small industries receive their water from this source, often attaining a water supply under sufficient pressure to furnish their needs without the use of pumps.

To date, the water resources of the basin have adequately served the needs and demands placed upon it. These needs, however, have not been great. Today, in a State where prosperity is high, this picture is changing. Tourism in the basin is growing. Land is being subdivided to provide summer homes, retirement homes, and other year-round residences. Light industry has been attracted and will continue to be attracted as the availability of water is recognized. In addition, changes are evolving from the realization that ground-water aquifers usually produce flowing wells, the water from which can satisfy many uses. As a result, individual trout ponds, for example, are becoming fashionable (fig. 3). So much so, that some parcels of land are being subdivided into lots which are sold with the stipulation that a flowing well and a trout pond stocked with trout are included in the purchase price. The ultimate end is obvious--a countryside containing numerous flowing wells that drain large quantities of water. Should we wait to see what might happen to the area's water resources? Or should we ask and answer questions relating to the water resource picture NOW? Is there enough water available to supply permanent flowing wells for everybody? Can wells continue to penetrate the supply system without reducing artesian pressures and altering streamflow? Will the added flow from wells increase the flow of some streams at the expense of others? What changes in ground-water levels might be expected to occur? What is the quality of water today and how must it be protected? Only through wise planning and development, based on a sound understanding of the available water supply, will continued growth without the consequences of serious water problems be assured. This report is intended to provide water facts necessary to meet these needs and to show hydrologic changes that may occur in the area as man develops and utilizes these resources. The report also will demonstrate the natural relationships between surface and ground water as they exist in the Rifle River basin. The nature of these relationships are duplicated to some extent at other places in Michigan. This report consequently will serve as a model that illustrates the nature of a hydrologic network where ground water is captured from areas beyond the basin divide.

FIGURE 3.--Trout ponds--an integral part of newly subdivided areas.

THE LAND AND ITS PEOPLE



PHYSICAL SETTING

More than 50 percent of the upper Rifle River basin is forest covered. Most of this forested land is publicly owned; the rest is in farm woodlots or other private holdings. Large areas of the north, west, and central parts of the basin lie within the Huron National Forest and the Ogemaw State Forest. Much of the central part of the basin is set aside as the Rifle River Recreation Area for public use. The forested lands are of prime importance to the basin in that they serve to stabilize water supplies and provide food and cover for game which abound in the area.

Lakes in the Rifle basin, about 40 in number, range in size from 1 to more than 180 acres. Most lakes are east of Rose City and most are accessible to the public.

The topography of the upper Rifle River basin is diverse, ranging from rolling to hilly highlands in the north and west to flat, gently undulating plains in the center and southeast parts (fig. 4). The northern, and to a lesser extent, the western parts of the basin are marked with numerous *topographic depressions* or pits some of which are as much as 100 feet below the level of the adjacent land. Some of these depressions contain water, forming *perched lakes*, but most are dry.

The highland areas vary in width from 4 to 5 miles and have altitudes generally above 1,300 feet. These highlands are flanked by hilly to rolling plains, 2 to 4 miles wide, which contain most of the agricultural lands. Areas near the Rifle River in the central and southeastern parts of the basin are interspersed with dense cedar and spruce swamps and contain numerous lakes. Altitudes here are generally less than 900 feet above mean sea level.

The highland areas extend beyond the basin divide to the north and west and are similar to those within the basin. Both areas restrict overland flow and form one vast area that promotes the infiltration of precipitation into the ground thereby supplying the ground-water reservoirs. The significance of these *recharge areas* will be demonstrated later in this report.

HISTORY AND ECONOMY

The early history of the upper Rifle River basin is typical of that in most areas in the northern part of Michigan's Lower Peninsula. Indians were its first occupants. They lived along the streams and utilized them for fish, fur, and transportation. A number of their earthworks still may be seen near the Rifle River.

Among the first visitors to the basin were the fur traders who reaped a bounty in furs. No important settlement occurred in the basin, however, until the early 1870's when the vast virgin tracts of white and norway pine attracted lumbermen. At this time, the settlements of Rose City, Lupton, and Selkirk sprang up. During the early part of the logging era, logs were floated down the Rifle River to mills in Saginaw. Subsequently, numerous sawmills were developed locally; these gradually phased out as the timber supply became exhausted.

As the timber industry faded near the turn of the century, farming became more widespread. Many who farmed were termed *lumberjack farmers*, farming in the summer and logging during the winter. Even with this dual existence some farms failed because much of the soil was sandy and unsuited to agriculture. Although some farms failed, others located on fertile soils succeeded, resulting in a stable farming industry which continues to date. Field crops, grains, vegetable produce, and dairying currently are the principal sources of farm income.

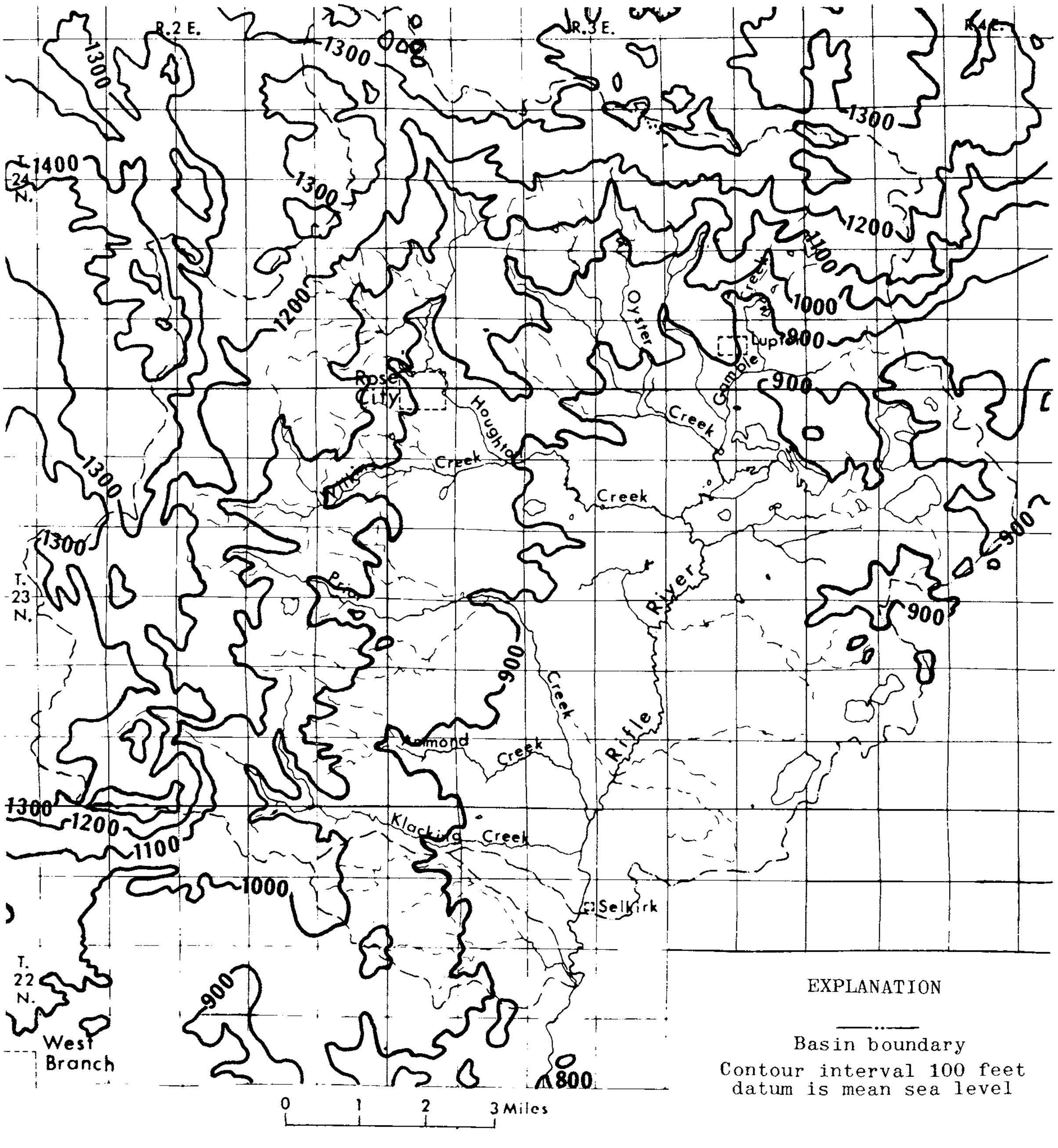


FIGURE 4.--Rolling to hilly highlands in the north and west and flat, gently undulating plains to the southeast characterize the basin's topographic features.

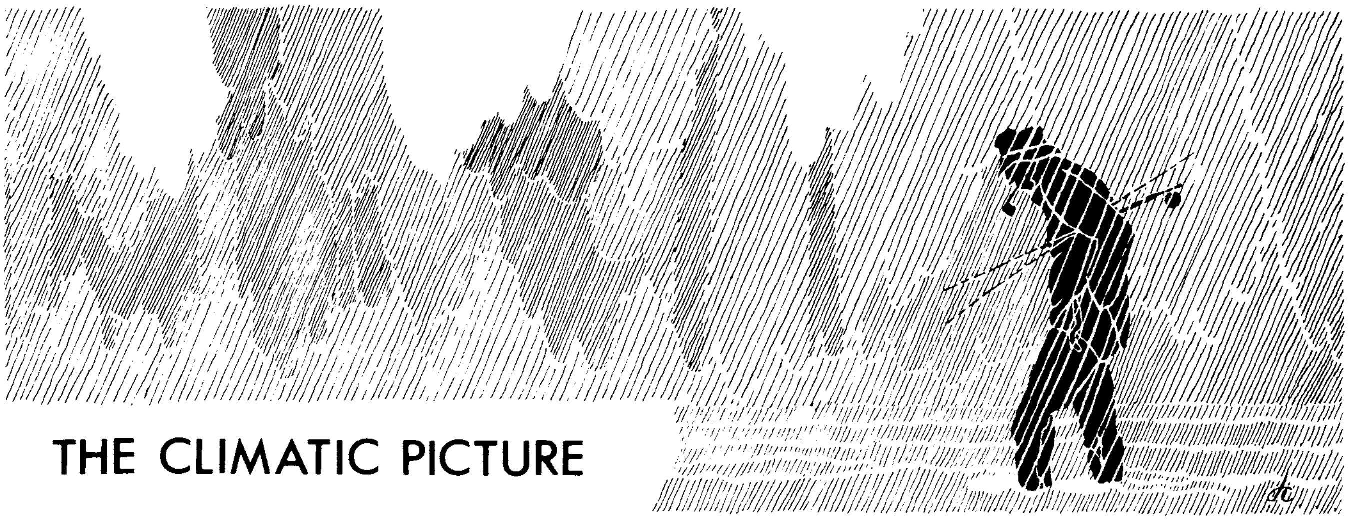
FIGURE 5.--The relaxing and recreational environment afforded by the Rifle River Recreation Area is enjoyed by many.

Since 1930, other industries have developed in the basin. The tourist industry is experiencing rapid development, forest production is making a comeback, oil fields are being discovered and developed, and small businesses and light industry have been established. Of these, perhaps the most significant is the tourist industry. New roads have greatly improved access to the area. Fishermen, hunters, canoeists, and campers (fig. 5) from larger cities to the south have availed themselves of the recreational pleasures provided by water and land resources in the basin. To help meet these needs large areas of second growth timber and abandoned farms have been acquired by the Michigan Department of Natural Resources and the U. S. Forest Service. In addition, many parcels of land having accessible stream or lake frontage are being developed. Also, many upland areas are being developed for building sites.

Rebirth of the forest industry, development of oil and sand and gravel industries (fig. 6), growth of the tourist industry, and settlement in the area by recreationists and retirees enhance the economic future of the area.

FIGURE 6.--Sand and gravel industries--another economic asset to the area.

THE CLIMATIC PICTURE



The influence of the Great Lakes on the climate of the upper Rifle River basin is weakened considerably due to the basin's inland location. Winter's cold is moderated only slightly by the lakes and below zero temperatures occur frequently. During an average winter, more than 20 days may be expected to have these low readings. Snowfall averages more than 50 inches each year and usually remains on the ground in sufficient depths for the winter outdoor enthusiast to enjoy skiing, snowshoeing, and snowmobiling.

Summers are warm and pleasant. Temperatures reach 100°F only about once in 10 years, and an average of only seven days each summer have temperatures of 90°F or higher. Nights are cool and comfortable. The average annual temperature is about 43°F. The coldest month is January, average temperature about 19°F; the warmest month is July, average temperature about 67°F (fig. 7).

Precipitation averages about 29 inches annually. More than 50 percent of the precipitation received falls during the 5-month period May through September.

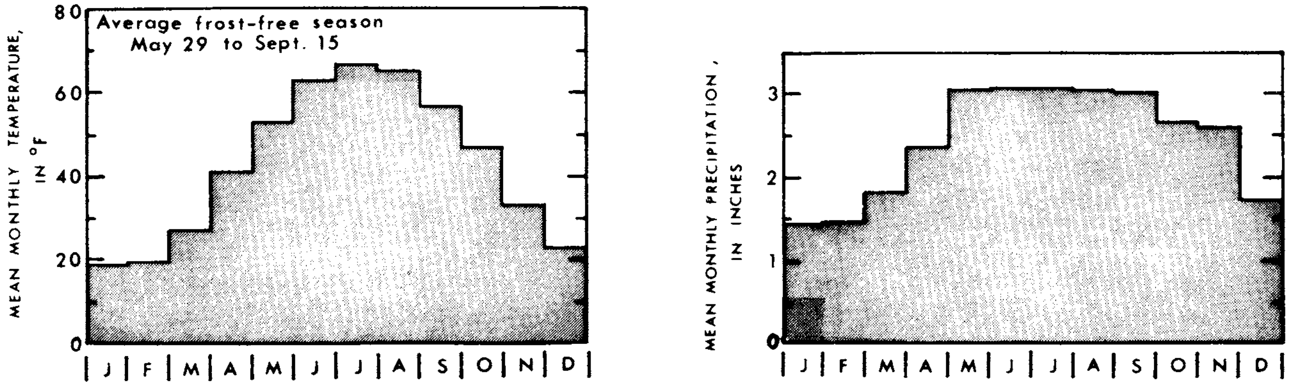


FIGURE 7.--Cool winters, pleasant summers, and uniformly distributed precipitation--a capsule picture of the basin's climate (means are those for West Branch, 12 miles southwest of Rose City, 1932-61).

SOURCE AND DISTRIBUTION OF WATER

HYDROLOGIC CYCLE

Water under natural conditions forms a complex hydrologic system (fig. 8). This system, as man might envision it, begins with precipitation in the form of rain, snow, sleet, hail, dew, frost or fog which falls upon the land. But water is a dynamic resource, continuously on the move. It does not remain long where it falls. Some runs off the land to lakes and streams, or to surface depressions where it may be stored for short periods of time. Some infiltrates into the ground, to replenish soil moisture, to be utilized by plants, and to replenish ground-water reservoirs. Within the ground-water reservoirs water continues to move. Some is captured directly by plants or is utilized in replenishing soil moisture. Some migrates down-gradient to return to the land surface in springs and seeps, and some continues to migrate as underground flow.

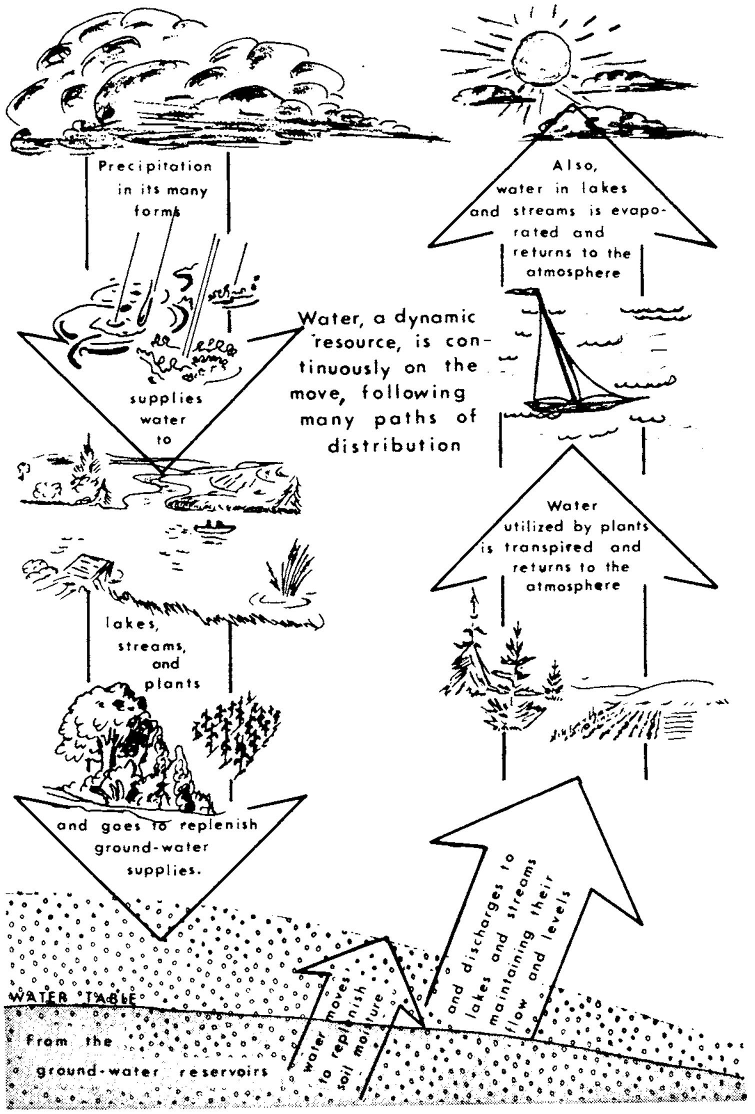


FIGURE 8.--The hydrologic cycle.

The distribution of precipitation to streams, lakes and ground-water reservoirs, however, is not a one-way street. Transpiration by plants and evaporation from lakes and streams returns water to the atmosphere, renewing the supply of water available for precipitation. Underground flow eventually discharges to streams and streams eventually discharge to the oceans where water again is evaporated and returned to the atmosphere. All of these events--precipitation, streamflow, underground flow, transpiration, and evaporation--are a part of the complex system known as the *hydrologic cycle.*

The foregoing is perhaps an over-simplification of the hydrologic cycle. In nature each phase of the cycle is occurring simultaneously, the quantities of any part varying through wide ranges. An understanding of the variations provides the background necessary for water resources management. For example, a temporary unbalance of the cycle in which great volumes of water are concentrated in the streams results in a flood. Conversely, small amounts indicate drought. The following discussion deals with the elements in the hydrologic cycle as they apply to the upper Rifle River basin, and illustrates the complex nature of the system.

PRECIPITATION--THE SOURCE OF WATER

The principal source of water in the Rifle River basin is precipitation. Water also is received in large amounts through underground flow from adjacent highlands, as will be discussed in later sections of this report; however, this water also is derived from precipitation. Because the principal source of water is precipitation, the quantity of water available is related to the amount of precipitation received.

Figure 9 shows a relation between annual precipitation and runoff for two stations.

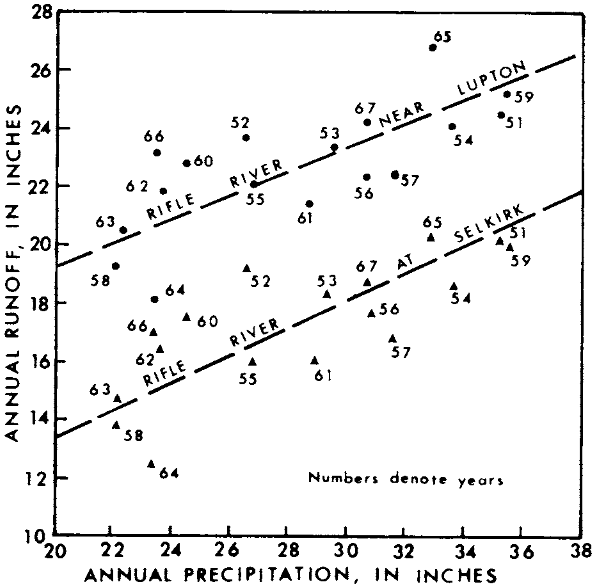


FIGURE 9.--Runoff is related to precipitation but often varies between stations as a result of differences in groundwater inflow.

The scatter of points reflects an inherent lag between time when precipitation occurs and when the precipitated water reaches the streams. This scatter is magnified in a basin such as the Rifle where water readily infiltrates into the ground and is stored for long periods. Also, the season of the year during which most precipitation occurs effects the relationship. When a greater proportion of precipitation occurs during the summer months, most of it will be lost to evaporation and transpiration and will not show up as streamflow. If more rainfall occurs during the winter months, overland runoff is enhanced and more precipitation will reach the streams, resulting in proportionately higher runoff. As seen in figure 9, there is a large spread between the rainfall-runoff relationship for Rifle River near Lupton, the upstream station, and Rifle River at Selkirk, the downstream station. Precipitation at the two stations during a given year is quite similar, yet, runoff at Lupton usually is 5 to 6 inches more than that at Selkirk. This spread reflects the difference in the amount of groundwater received per unit area at each station.

Precipitation in the Rifle basin is uniformly distributed and is proportioned fairly uniformly throughout the year and over the years. Figure 10 shows the year-by-year distribution and yearly rainfall probabilities as based on records for West Branch. Although West Branch is outside the basin, its precipitation patterns closely resemble those for the basin. For example, average precipitation based on concurrent record at West Branch, Rose City, and Lupton show averages of 28.04, 29.31, and 27.40 inches, respectively. The annual distribution is shown in figure 11. The annual average is about 29 inches: equivalent to 1.4 million gallons of water per day per square mile.

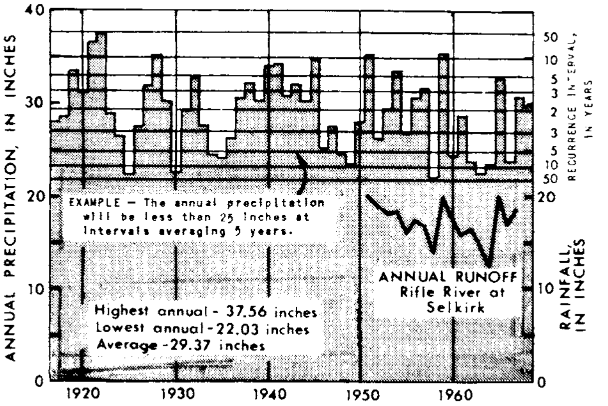


FIGURE 10.--Precipitation varies from year-to-year--a succession of wet or dry years resulting in the higher or lower streamflow.

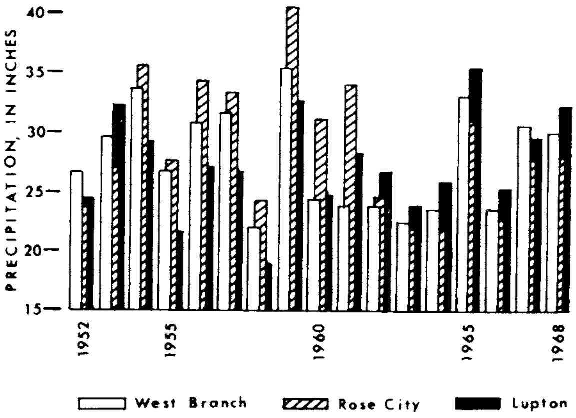


FIGURE 11.--Precipitation totals at West Branch, Rose City and Lupton reflect similarity in climatic conditions.

STREAMFLOW, GROUND-WATER RUNOFF, AND EVAPOTRANSPIRATION--PATHS OF PRECIPITATION DISTRIBUTION

The 29 inches of precipitation that fall annually in the Rifle River basin, if captured and fully utilized by man, would represent an abundant supply of water. Since capture and utilization of all precipitation is not possible, the total available supply of water depends upon the distribution of precipitation after it falls. Therefore it becomes necessary to know the answers to such questions as: What are the paths of distribution? What amount goes, as overland runoff, to streams? What amount infiltrates to ground-water reservoirs? and, What amount is lost to man's use through evaporation and transpiration?

Among the paths of precipitation distribution the one most readily perceived is *streamflow*. It is the parameter that can be monitored most readily; thus, its variations and volumes are readily delineated. Streamflow therefore, is the best beginning point for discussing precipitation distribution.

The gaging station on the Rifle River at Selkirk provides the record of total streamflow for the upper Rifle River basin. Records for the period 1951-68 show an average runoff of 140 cfs. But records of total streamflow alone provide only a part of the answer to precipitation distribution. The records must be evaluated to determine what paths precipitation took in getting to the stream. Therefore, let us evaluate the streamflow records at the Selkirk gage.

Basically, streams receive water by two diverse routes--overland runoff and ground-water runoff. The relative amounts of water received through these two routes can be delineated through evaluation of discharge hydrographs. Such an evaluation for the Rifle River at Selkirk is shown on figure 12. For

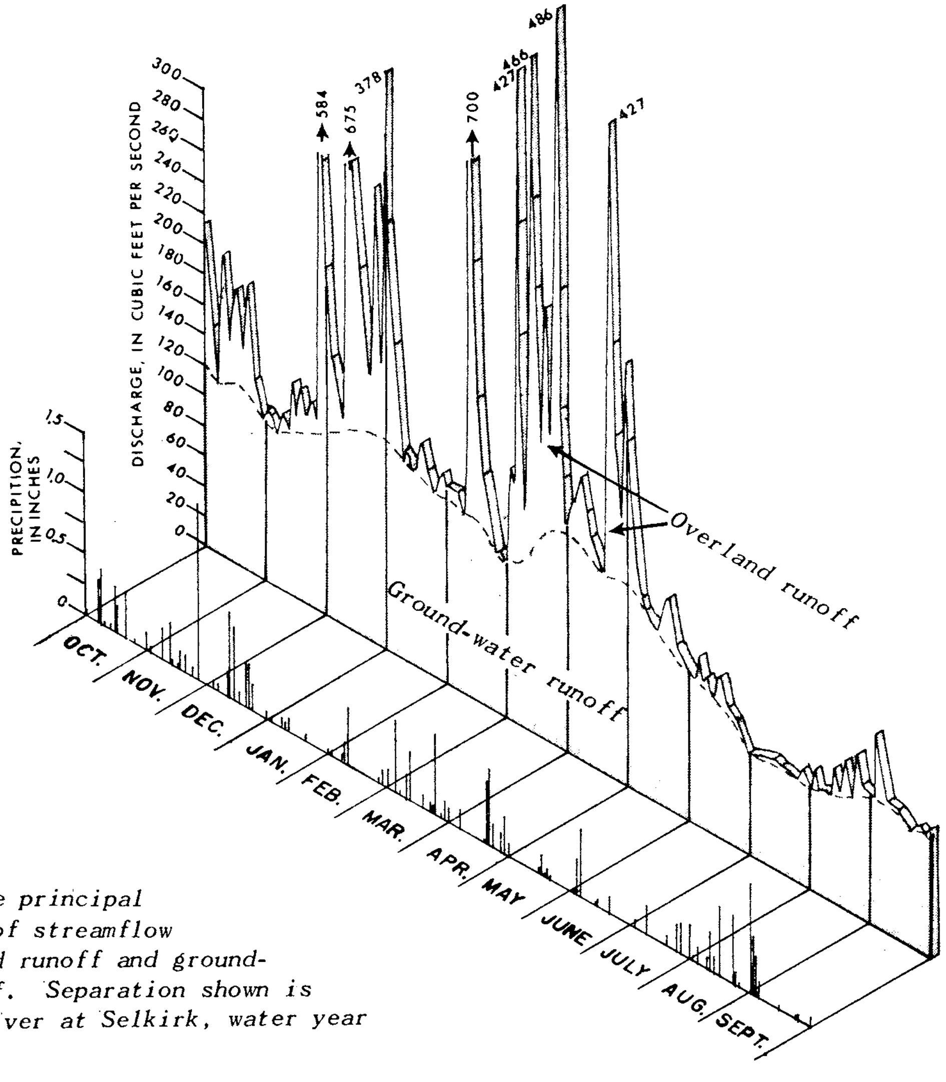


FIGURE 12.--The principal components of streamflow are overland runoff and ground-water runoff. Separation shown is for Rifle River at Selkirk, water year 1966.

the year illustrated, an average of about 110 cfs reached the stream as ground-water runoff. The remainder, an average of about 30 cfs, reached the stream as overland runoff. An evaluation for the entire period of record at the Selkirk gage indicates that an average of 103 cfs was ground-water runoff and 37 cfs was surface runoff.

The ratio of ground-water runoff to overland runoff, and the ratio of total runoff to precipitation in the Rifle basin, are vastly different than those normally expected in Michigan. These differences lead one to investigate further the basin's hydrologic situation--its paths of precipitation distribution. For a basin in which the topographic and ground-water divides are coincident, precipitation (input) equals surface- and ground-water runoff plus evapotranspiration (output). This assumes that the basin is in equilibrum (storage remaining unchanged) and ground-water underflow from the basin is insignificant. This situation may be depicted as shown in figure 13.

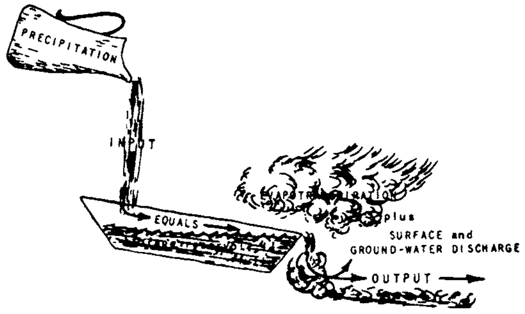


FIGURE 13.--Output equals input in a river system that is in equilibrum and has coincident surface- and ground-water divides.

If one were to equate the input-output values for the Rifle basin, assuming a normal hydrologic environment, the distribution shown in figure 14 would be expected. However, as shown earlier, the average flow out of the basin is 140 cfs--40 to 65 cfs higher than that which might normally be expected. What then is the source of this difference? As will be shown later in this report the Rifle River is receiving water as ground-water flow from areas north and west of its topographic divide.

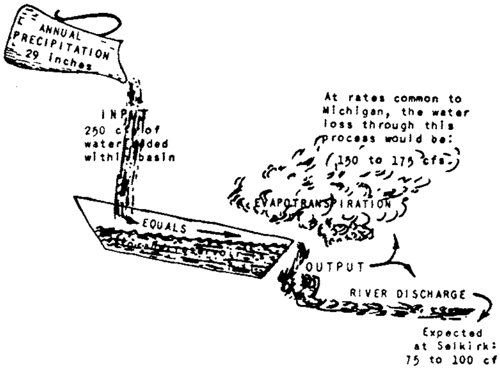


FIGURE 14.--Expected water distribution in the upper Rifle River basin under conditions typical to Michigan.

This "captured" ground water discharges into the headwaters of the Rifle River increasing the ground-water component of streamflow, and also increasing the total flow. It is this water that produces the higher runoff per unit area shown for the Lupton gage (fig. 9). Figure 15 depicts the type of condition that exists in the basin.

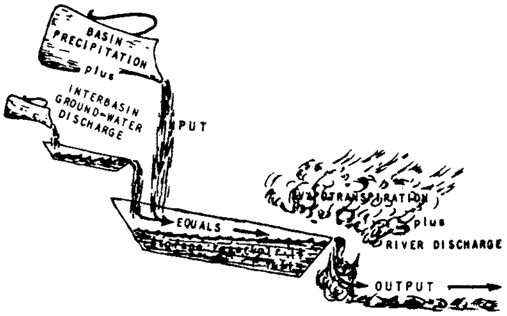


FIGURE 15.--Input to the basin includes inflow of ground water from outside the basin divide.

The primary paths of precipitation distribution, then, are streamflow, ground-water runoff, and evapotranspiration. Other paths, such as ground-water underflow south and east out of the basin, are small. In the area where underflow is likely to occur the topographic and ground-water divides appear to be coincident, ruling out the possibility of much underflow. Some reversals in flow paths occur locally, such as where water from streams migrates to the ground-water reservoirs. These variations, as well as the major paths of distribution and the quantities of water moving along each path, will be discussed in detail in later sections of this report. They are summarized, however, on figure 16, to aquaint the reader with the nature of water movement in the basin.

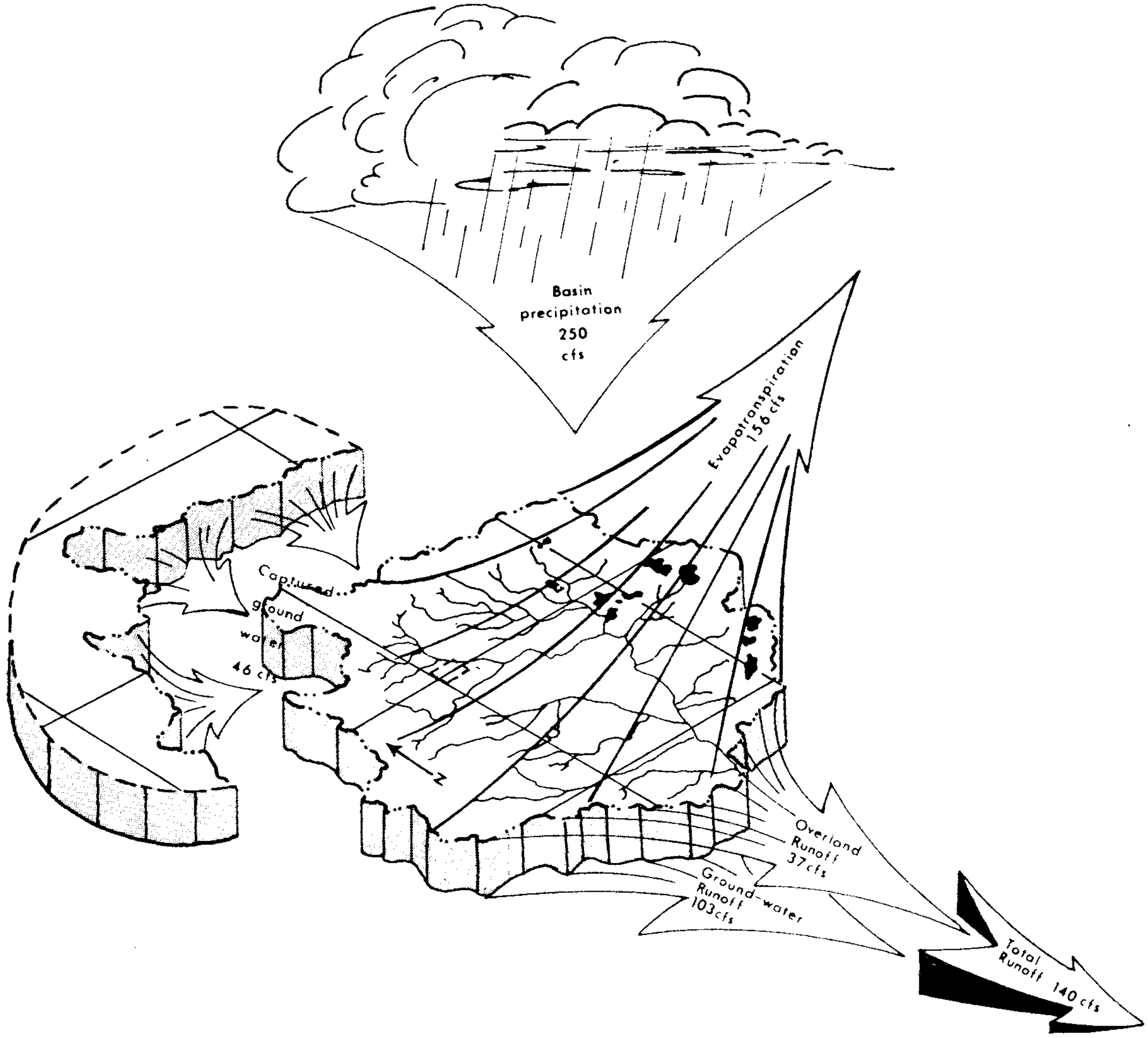


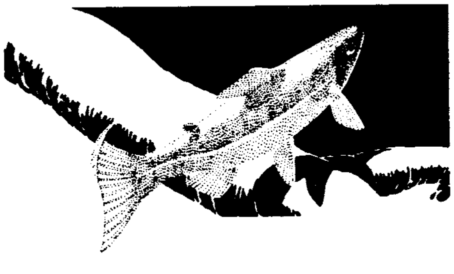
FIGURE 16.--An assessment of the water situation in the upper Rifle River basin.

WATER ON LAND--SURFACE WATER

Streams and lakes have played an important role in the development of the upper Rifle River basin. Streams have been utilized by Indians, trappers, loggers, and recreationists. Lakes, too, have served the area's residents in similar capacities. These resources will continue to play an important role in the area's future, but to be of greatest benefit their character must be understood. The nature of the flow of streams, the fluctuations of water levels in lakes, and the quality of water therein must be evaluated. Although streams and lakes are similar in many respects, they are treated as separate entities in the following discussion to provide clarity.

STREAMS

Meandering down from the wooded hills which blanket much of the upper reaches of the Rifle River watershed are numerous small streams. These streams, flowing generally south or east, following drainage networks developed during the glacial period, merge to form the Rifle River. Most streams have high sustained flows reflecting the unique topographic setting in which the basin lies. A setting in which, unlike most areas in Michigan, the basin's topographic divide does not delineate the total area contributing to streamflow. As shown in the preceeding section, the basin receives a significant amount of water from outside the basin divide. This ground-water inflow, in addition to water received locally, supplies the many small headwater streams making them, as well as the main stream, important for recreational use and as potential sources of water supply. The effect of ground-water inflow on streams and the nature and distribution of flow are discussed in detail in the following sections.



PATTERNS OF STREAMFLOW

The average annual discharge for the Rifle River at Selkirk is 140 cfs. But streamflow is variable and the average discharge does not present an accurate picture of a stream's character. The average represents only the maximum developable supply and depends on conditions that will permit sufficient storage to allow water to be released at a uniform rate--conditions that seldom are feasible. Evaluation of the variability of streamflow, therefore, becomes necessary to understand its usefulness as a source of water for water supplies or other uses.

Streamflow varies from day to day and from year to year reflecting changes in precipitation and weather conditions. Streamflow is generally highest during the spring (fig. 17) when snowmelt, often coupled with runoff from rain, flows to streams over frozen or partly frozen ground relatively unimpeded by vegetation. Following the high flows of spring, streams gradually recede to yearly lows occurring in late summer or early fall. This gradual decrease in flow is interrupted by periodic rains, but the general trend remains downward. After the first frost of fall, the downward trend is usually halted and streamflow increases slightly in response to reduced

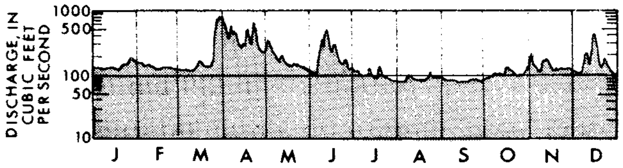


FIGURE 17.--Snow melt, spring runoff, and periodic rains are reflected in the shape of the discharge hydrograph. Record shown is for Rifle River at Selkirk, 1967.

evapotranspiration losses. Subsequently, winter flows remain fairly uniform, affected only by brief thawing spells and infrequent rains. Average monthly runoff and the range in monthly runoff, as shown in figure 18, illustrate the variability of flow on a monthly basis. Yearly variations are shown in figure 10.

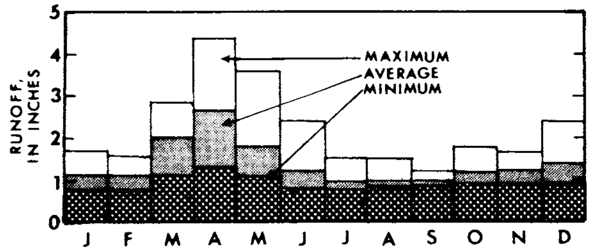


FIGURE 18.--Uniform minimum flows are produced by large ground-water yields, whereas, wide fluctuations in flow reflect climatic conditions. Variations in monthly mean discharge are for Rifle River at Selkirk(1951-68).

The foregoing provides a picture of the general pattern of streamflow in the upper Rifle River basin. In the following sections, data of a more detailed nature on the character of flow, expressed as flow duration and low-flow frequency, are presented. These data are indices of dependable flows and reflect the adequacy of streams for water supply or other uses.

FLOW DURATION

The variability of streamflow is most readily shown by a *flow-duration curve*. Such a curve combines the complete record of daily mean discharge into a single unit showing the percent of time specific flows were equaled or exceeded. The duration curve for Rifle River at Selkirk is shown in figure 19. Table 1 gives duration data for continuous and partial-record stations in the basin; location of the stations, as well as other data collection sites, are shown on figure 20. Data in table 1 are shown for five duration percentages, percentages most often used by water managers.

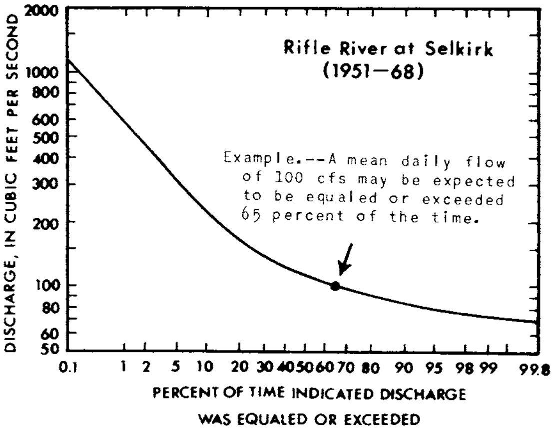


FIGURE 19.--Streamflow variability is most readily shown by a flow-duration curve.

TABLE 1.--A summary of flow-duration data.

Values shown are in cubic feet per second and, in italics, in cubic feet per second per square mile.

Station number	Stream	Drainage area *(sq mi)*	Discharge which was equaled or exceeded for indicated percent of time					Variability index Q_{30}/Q_{90}
			30	50	70	90	95	
1386*	Gamble Creek at Lupton	9.47	13 *(1.37)*	11 *(1.16)*	9.5 *(1.00)*	8.4 *(0.89)*	8.0 *(0.84)*	1.55
1387*	Bixby Creek near Rose City	2.68	1.9 *(0.71)*	1.2 *(0.45)*	.9 *(0.34)*	.7 *(0.26)*	.6 *(0.22)*	2.71
1388*	Houghton Creek at Rose City	13.3	22 *(1.65)*	20 *(1.50)*	19 *(1.43)*	17 *(1.28)*	17 *(1.28)*	1.29
1389*	Wilkins Creek near Rose City	9.15	19 *(2.08)*	17 *(1.86)*	17 *(1.86)*	16 *(1.75)*	16 *(1.75)*	1.19
1390	Houghton Creek near Lupton	29.7	49 *(1.65)*	44 *(1.48)*	41 *(1.38)*	37 *(1.25)*	36 *(1.21)*	1.32
1395	Rifle River near Lupton	56.8	88 *(1.55)*	77 *(1.36)*	71 *(1.25)*	64 *(1.13)*	61 *(1.07)*	1.38
1397*	Prior Creek near Rose City	4.70	6.8 *(1.45)*	5.4 *(1.15)*	4.5 *(0.96)*	3.8 *(0.81)*	3.6 *(0.77)*	1.79
1399*	Ammond Creek near Selkirk	3.10	2.1 *(0.68)*	1.6 *(0.52)*	1.3 *(0.42)*	1.0 *(0.32)*	0.9 *(0.29)*	2.10
1400	Prior Creek near Selkirk	21.4	15 *(0.70)*	11 *(0.51)*	8.0 *(0.37)*	6.3 *(0.29)*	5.8 *(0.27)*	2.38
1402*	Klacking Creek near Selkirk	7.51	15 *(2.00)*	14 *(1.86)*	13 *(1.73)*	12 *(1.60)*	12 *(1.60)*	1.25
1405	Rifle River at Selkirk	117	135 *(1.15)*	110 *(0.94)*	96 *(0.82)*	83 *(0.71)*	78 *(0.67)*	1.63
1410	South Branch Shepards Creek near Selkirk	1.15	0.2 *(0.17)*	0.1 *(0.09)*	.06 *(0.05)*	.03 *(0.03)*	.02 *(0.02)*	6.67
1411*	Shepards Creek near Selkirk	4.44	1.3 *(0.29)*	0.6 *(0.14)*	0.4 *(0.09)*	0.2 *(0.04)*	0.1 *(0.02)*	6.50

* Partial record stations--data for these stations determined through statistical correlation with continuous-record stations.

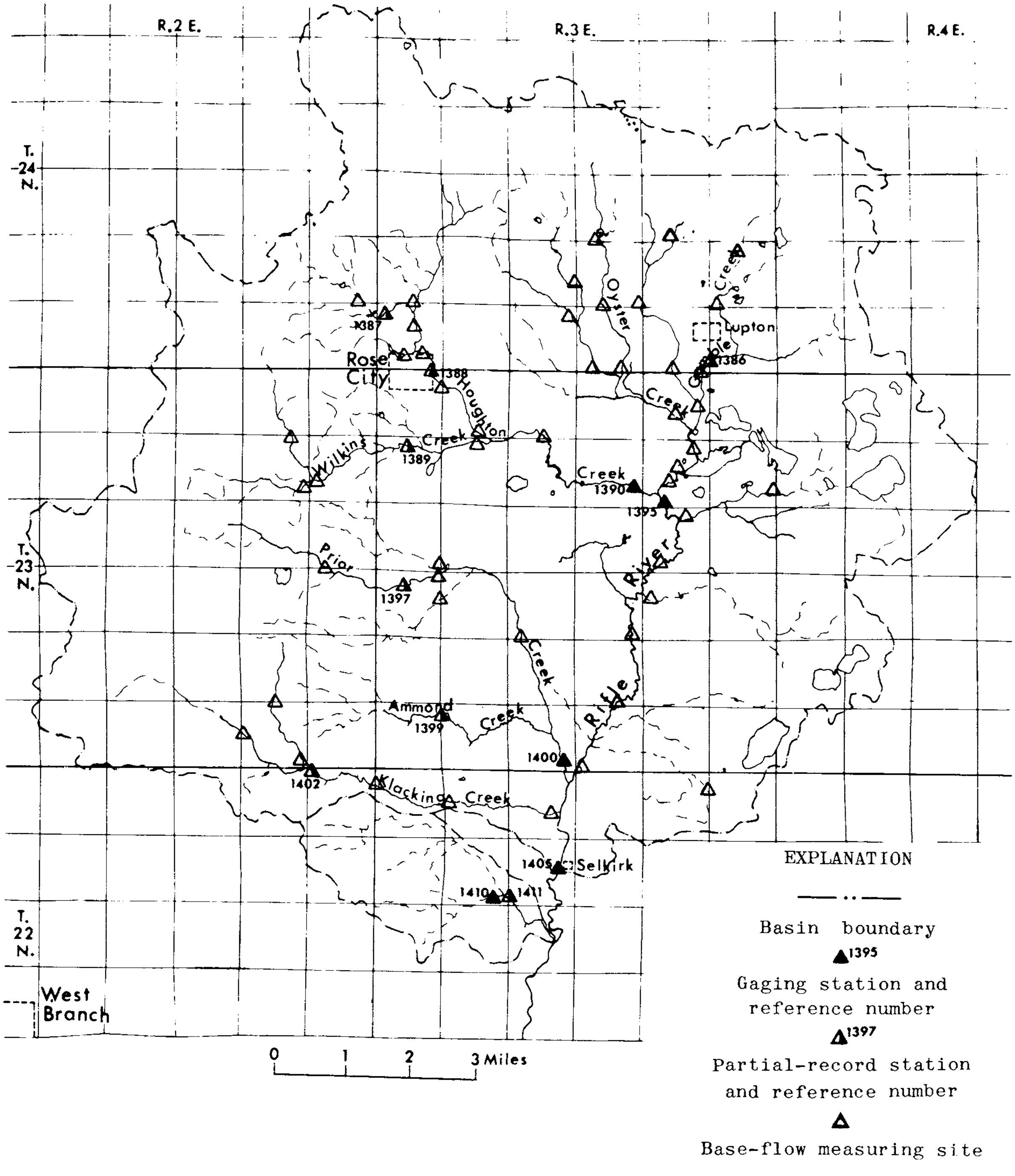


FIGURE 20.--Streamflow data are available for 61 sites.

Flow-duration curves are commonly used to make comparisons of flow characteristics between stations. Curves for five stations in the Rifle basin are shown in figure 21. The relative shapes and position of the curves present a picture of the basin physiography.

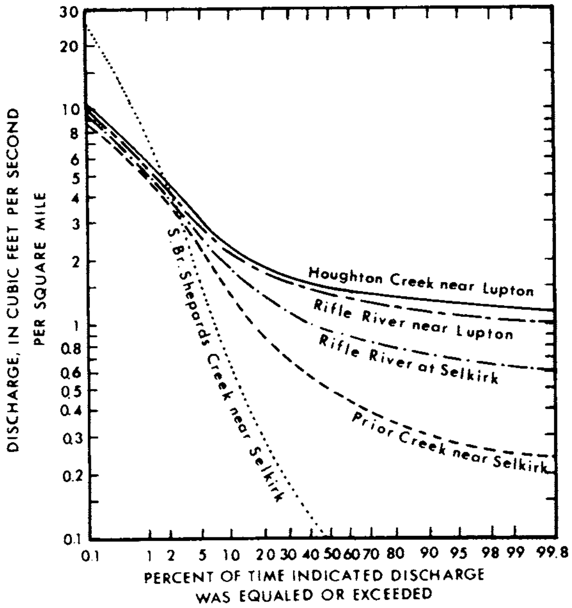


FIGURE 21.--Differences in streamflow characteristics are reflected in duration curves of five stations (data are plotted in cubic feet per second per square mile to eliminate most of the effect of basin size).

Steep curves, as for South Branch Shepards Creek, reflect rapid overland runoff, steep stream gradients, compact soils, sparse forest cover, and little ground-water storage. Shepards Creek has zero flow during part of most years. Flat slopes, as for Houghton Creek, and Rifle River near Lupton, and to a lesser degree Rifle River at Selkirk and Prior Creek, reflect large ground-water contributions and sustained base flows. Flat curves also reflect permeable soils and large basin storage--storage in swamps, lakes, or ground-water aquifers. All curves are relatively steep in the high discharge portion of the relations. This upward curvature reflects overland runoff from spring thaws and heavy rains. Clayey areas in the central and southeastern parts of the basin (fig. 35) contribute to the steepness of the curves. Houghton Creek near Lupton and Rifle River near Lupton have more ground-water inflow per unit drainage area than do the other streams; thus, the low discharge portion of the curves for these two streams is positioned somewhat above the other curves. Similar comparisons of runoff for other stations can be made by plotting the data or by comparing discharges per square mile given in table 1.

Shown in table 1 are values of *variability index*: values determined by dividing the 30 percent duration flow by the 90 percent flow. Low values reflect high base flows, little variation in flow, and flat duration curves; higher values reflect lower base flows, highly variable flow, and steep duration curves. In the Rifle basin, values of variability index for most streams are small, generally between 1.2 and 2.8. Elsewhere in Michigan, index values from 5 to 10 are most common although for some streams index values are as high as 50, sometimes more.

Flow-duration curves and data provide a capsule review of the variability of streamflow and other streamflow characteristics. The curves and data, however, are an expression of the flow regimen without regard to the sequence of occurrence of particular flows. What, then, are the extremes of flow?

STREAMS AT LOW FLOW

The suitability of a stream as a source for water supplies or other uses usually is dictated by the character of the stream's low flow. Under natural conditions, it is the magnitude of low flow that determines a stream's dependable supply. Of utmost importance then is the answer to the question "What are the dependable flows of streams in the upper Rifle River basin?"

Definition of low flows usually is expressed as the frequency that a stream will recede below certain amounts, the frequency being defined by *low-flow frequency curves*. Figure 22 presents a family of low-flow fre-

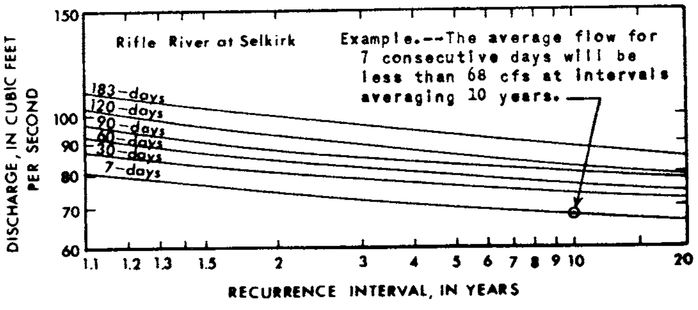


FIGURE 22.--The magnitude and frequency of low flows often define a stream's dependable supply.

TABLE 2.--A summary of low-flow frequency data.

Values shown are in cubic feet per second and, in italics, in cubic feet per second per square mile. Location of sites are shown on figure 20.

Station number	Stream	Lowest average discharge for indicated period of consecutive days and for recurrence interval shown					
		7-day			30-day		
		2-year	10-year	20-year	2-year	10-year	20-year
1386	Gamble Creek at Lupton	7.8 *(0.82)*	7.2 *(0.76)*	7.0 *(0.74)*	8.2 *(0.87)*	7.6 *(0.80)*	7.4 *(0.78)*
1387	Bixby Creek near Rose City	.6 *(0.22)*	.4 *(0.15)*	.4 *(0.15)*	.6 *(0.22)*	.5 *(0.19)*	.5 *(0.19)*
1388	Houghton Creek at Rose City	17 *(1.28)*	16 *(1.20)*	15 *(1.13)*	17 *(1.28)*	16 *(1.20)*	16 *(1.20)*
1389	Wilkins Creek near Rose City	15 *(1.64)*	15 *(1.64)*	15 *(1.64)*	16 *(1.75)*	15 *(1.64)*	15 *(1.64)*
1390	Houghton Creek near Lupton	36 *(1.21)*	33 *(1.11)*	32 *(1.08)*	37 *(1.25)*	34 *(1.14)*	34 *(1.14)*
1395	Rifle River near Lupton	60 *(1.06)*	55 *(0.97)*	54 *(0.95)*	63 *(1.11)*	58 *(1.02)*	56 *(0.99)*
1397	Prior Creek near Rose City	3.4 *(0.72)*	3.1 *(0.66)*	3.0 *(0.64)*	3.7 *(0.79)*	3.3 *(0.70)*	3.2 *(0.68)*
1399	Ammond Creek near Selkirk	.9 *(0.29)*	.8 *(0.26)*	.7 *(0.23)*	1.0 *(0.32)*	.9 *(0.29)*	.8 *(0.26)*
1400	Prior Creek near Selkirk	5.6 *(0.26)*	5.0 *(0.23)*	4.8 *(0.22)*	6.1 *(0.29)*	5.6 *(0.26)*	5.5 *(0.26)*
1402	Klacking Creek near Selkirk	12 *(1.60)*	11 *(1.46)*	11 *(1.46)*	12 *(1.60)*	12 *(1.60)*	12 *(1.60)*
1405	Rifle River at Selkirk	74 *(0.63)*	68 *(0.58)*	66 *(0.56)*	80 *(0.68)*	74 *(0.63)*	72 *(0.62)*
1410	South Branch Shepards Creek near Selkirk	.02 *(0.02)*	.01 *(0.01)*	.01 *(0.01)*	.03 *(0.03)*	.02 *(0.02)*	.01 *(0.01)*
1411	Shepards Creek near Selkirk	.2 *(0.05)*	.1 *(0.02)*	.1 *(0.02)*	.2 *(0.05)*	.2 *(0.05)*	.1 *(0.02)*

quency curves for the Rifle River at Selkirk. As shown, it can be stated that the average flow for 7 consecutive days will be less than 68 cfs at intervals averaging 10 years. That is, over a 100-year span 10 such events would be expected. However, the distribution of the events is not necessarily uniform and it is possible, for example, to have an expected 10-year low flow occur in two or more consecutive years. This possibility should be considered in any water-supply development.

Low-flow data for continuous and partial-record stations are given in table 2. Median-annual 7-day low flows (lowest average discharge for 7 days having a 2-year recurrence interval, 7-day Q_2), often used as an index of low flow, are shown by stream widths in figure 23. The stream widths are based on data from table 2 and on the relation of occasional measurements at selected sites to data at continuous and partial-record stations.

It will be noted from figure 23 that near the basin divide streams are intermittent and the 7-day Q_2 is zero. Farther downstream, principally in the foothill areas (between altitudes of 1050 and 950 feet above mean sea level), values of 7-day Q_2 increase rapidly. This increase in flow reflects the contribution to streamflow from groundwater sources. Water which percolates to the ground-water aquifers in the areas to the north and west, both within and beyond the basin divide, migrates down gradient and discharges in these foothills. Because of the vastness of the ground-water aquifer, the supply of water being discharged is large and base flows are high. Below altitudes of about 950 feet, which includes most of the central and southeastern parts of the basin, seepage to streams diminishes and streamflow remains relatively unchanged. Median annual 7-day low flows remain essentially the same in these areas (fig. 23) and increases in discharge are noted only where two streams come together. Although it is not readily evident from figure 23, some reaches of streams in the central and southern areas diminish in flow in the downstream direction. These diminished flows probably result from loss of water due to evapotranspiration and subsequent replenishment by streamflow. Losses occur principally in swampy and wooded areas. It is possible that some loss may be due to interbasin leakage but topographic and geologic conditions do not appear favorable for any significant loss of this kind.

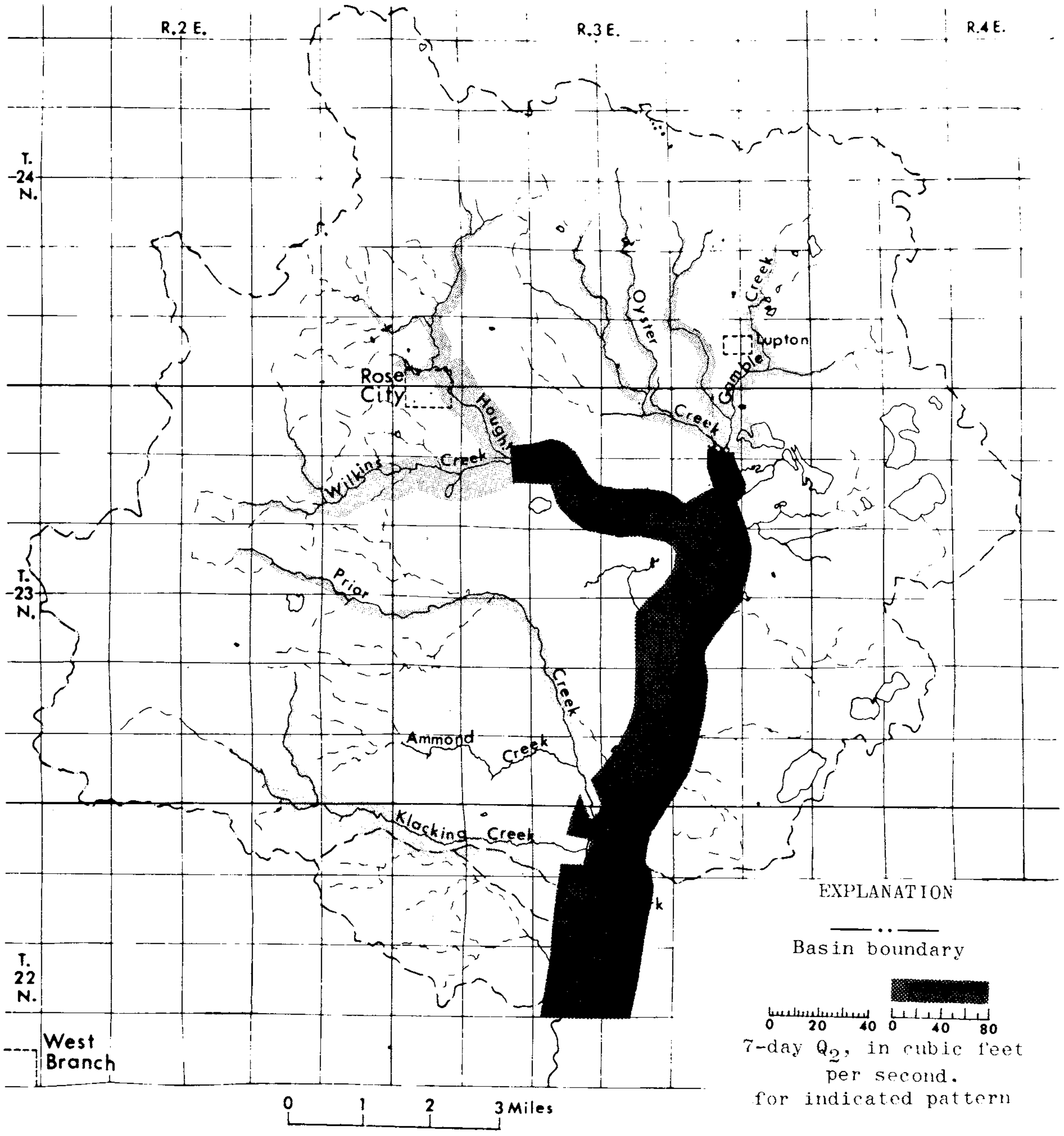


FIGURE 23.--An index of low-flow characteristics is provided by median annual 7-day low-flows.

STREAMS AT HIGH FLOW

Peak discharges can occur at any time during the year but most occur during March, April, and May (fig. 24). Also, during these months peak discharges generally are higher than those experienced during other times of the year. Peak flows rarely occur during January, August, and September. For example, no peaks above 150 cfs have been experienced during these months for the period of record at the Houghton Creek gaging station.

Peak flows in the Rifle basin are usually the result of snow melt or snow melt coupled with rain. However, the maximum flow of record at most gaging stations was the result of an extremely heavy rain which occurred on May 19-20, 1959. This storm began about 8 p.m. May 19 and lasted until about 2 a.m. May 20. During this period rainfall totaling 3 to 4 1/2 inches fell over the entire upper Rifle River area and runoff up to 1,750 cfs per square mile of drainage area occurred on small basins. Runoff and peak discharges resulting from this storm are shown in table 3.

No lives were lost as a result of the 1959 flood, but 5 bridges and 8 culverts were destroyed, and road fill was washed away (fig. 25). The total damage to roads maintained by the Ogemaw County Road Commission was estimated

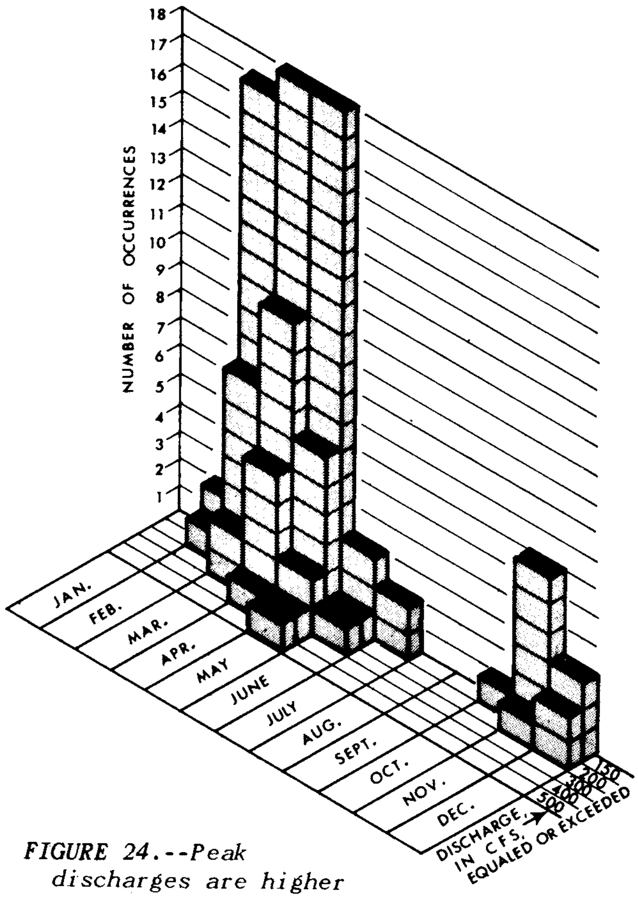


FIGURE 24.--Peak discharges are higher and occur more frequently during the spring months (distribution shown is for peak flows at Houghton Creek near Lupton, period of record 1951-68).

TABLE 3.--Peak discharges during the flood of May 1959 were the highest of record for most stations in the upper Rifle River basin.

Station number	Station	Drainage area (sq. mi.)	Non-contributing area* (sq. mi.)	Adjusted drainage area (sq. mi.)	Peak discharge		
					Cfs	Cfs per sq. mi.	Cfs per sq. mi.‡
1386	Gamble Creek at Lupton	9.47	1.65	7.82	223	23.5	28.5
1387	Bixby Creek near Rose City	2.68	0	2.68	423	158	158
1388	Houghton Creek at Rose City	13.3	3.43	9.75	1,090	82.0	112
1389	Wilkins Creek near Rose City	9.15	.27	8.88	748	81.7	84.2
1390	Houghton Creek near Lupton	29.7	3.43	26.1	955	32.2	36.6
1395	Rifle River at "Ranch" near Lupton	56.8	7.28	49.5	1,330	23.4	26.9
1397	Prior Creek near Rose City	4.70	.68	4.02	910	194	226
1398.9	Ammond Creek near Rose City	1.07	0	1.07	1,710	1,600	1,600
1398.95	Unnamed trib. to Ammond Creek near Rose City	.69	0	.69	1,210	1,750	1,750
1400	Prior Creek near Selkirk	21.4	2.75	18.7	584	27.3	31.2
1402	Klacking Creek near Selkirk	7.51	.94	6.57	738	98.3	112
1405	Rifle River at Selkirk	117	11.2	106	2,760	23.6	26.0
1410	South Branch Shepards Creek near Selkirk	1.15	0	1.15	125+	109	109
1411	Shepards Creek near Selkirk	4.44	0	4.44	726	164	164

* Area barred topographically from contributing to surface runoff.
‡ Adjusted for non-contributing drainage area.
\+ Maximum discharge of record 181 cfs, Apr. 3, 1956.

Gamble Creek, normally a placid stream, flows swollen with swiftly moving turbulent waters.

Unable to contain the flood waters within its banks, the Rifle River overflowed flooding the adjacent lands

Culverts, bridges, and roadfill yielded to the raging waters.

FIGURE 25.--Extremely heavy rains on May 19-20, 1959 caused streams to overflow flooding adjacent lands, and destroying highway facilities.

to be $108,000--a staggering amount to a small organization (Stoimenoff, 1960). In addition, rich soils were washed away, drainage channels were gullied, and stream improvement structures such as jetties were destroyed.

As evidenced by the 1959 storm and resultant peak flows, disastrous floods do occur in the Rifle basin. It is necessary therefore, to evaluate flood events, as in the following section, as part of a water-resources study.

FLOOD MAGNITUDE AND FREQUENCY

From the standpoint of geologic time, damaging floods such as that experienced in 1959 are common events. In terms of man's lifetime, however, such floods are rare occurrences, often considered to be only historical events--events not likely to occur again. But floods do recur and the likelihood of their happening must be considered where construction may be within reach of a stream's flood waters.

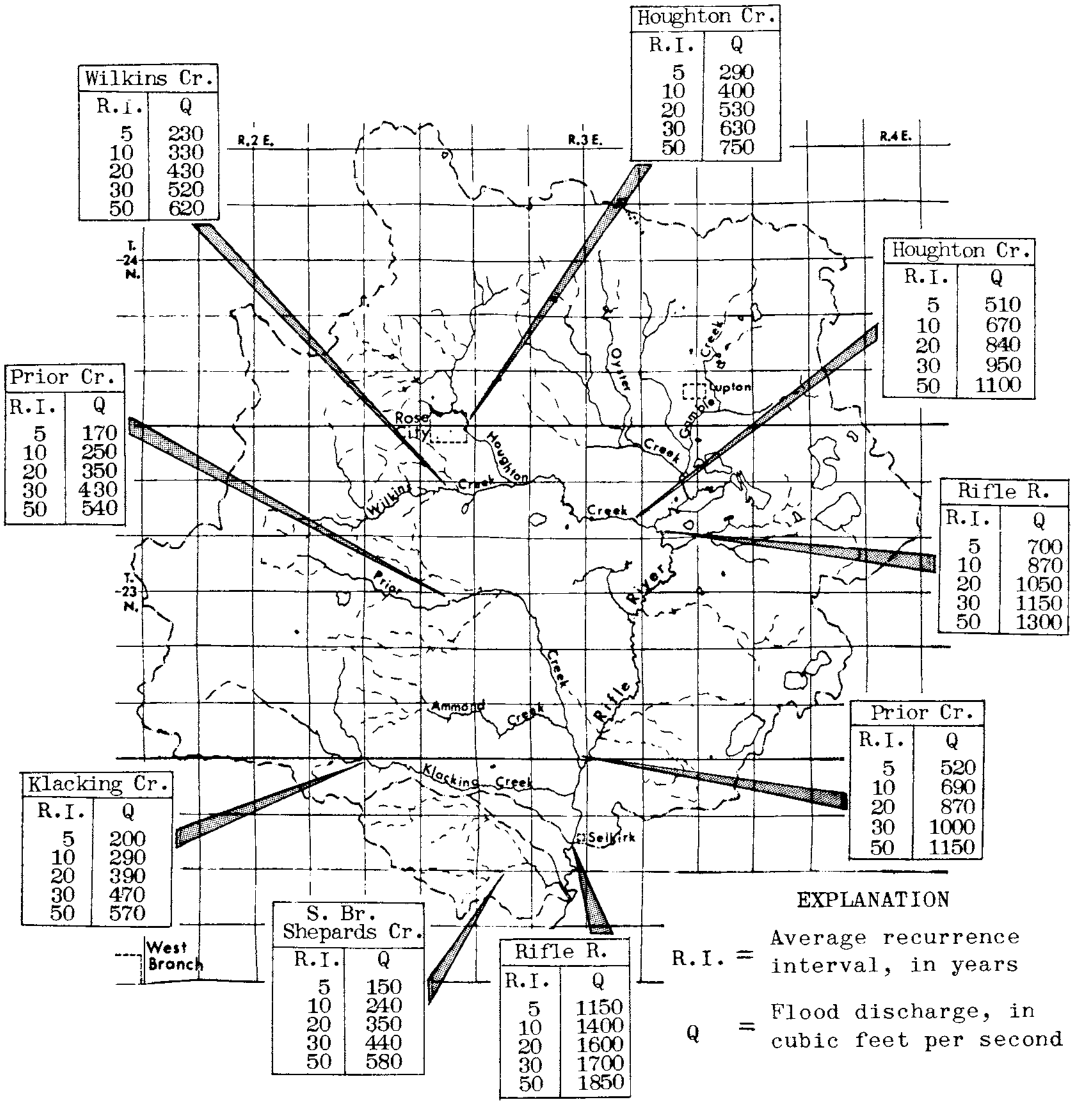
Being subject to the whims of nature, the time of occurrence of a flood cannot be predicted. It is possible, however, through evaluation of past streamflow records to predict with some assurance the frequency of occurrence; that is, the chance of a flood of a certain magnitude being exceeded in any year. Such an evaluation was made for this report by utilizing streamflow records in the upper Rifle River basin. The flood-frequency relations were defined by multiple regression techniques similar to those used by Benson (1962) and outlined below.

Flood frequency and magnitudes vary with differences in basin characteristics and climatic conditions. Streams which appear alike and have equal drainage areas often have dissimilar flood-flow characteristics. These differences are related to differences in stream slope, forest cover, basin altitude, and other parameters. Several such parameters were investigated to evaluate their affect on flood flows in the Rifle basin; area and forest cover were found to be the most significant. Equations for determining peak flows for selected recurrence intervals, as based on the parameters of drainage area and forest cover, are as follows:

Recurrence interval, in years	Equation for determining peak flow, in cfs
5	$Q=476\ A^{0.59}\ F^{-0.46}$
10	$Q=723\ A^{0.52}\ F^{-0.44}$
20	$Q=1,090\ A^{0.46}\ F^{-0.44}$
30	$Q=1,300\ A^{0.42}\ F^{-0.42}$
50	$Q=1,700\ A^{0.38}\ F^{-0.42}$

Where A is drainage area in square miles and F is forest cover in percent. Methods for determining drainage area and forest cover are explained below.

For easy reference, flood magnitudes for selected recurrence intervals are shown for several sites on figure 26. Also, because solution of the flood-frequency equations is somewhat laborious, simpler graphical solutions are presented in figure 27. To use the graphs, the following steps are necessary (the first two steps also are necessary to solve the equations shown above).



Wilkins Cr.

R.I.	Q
5	230
10	330
20	430
30	520
50	620

Houghton Cr.

R.I.	Q
5	290
10	400
20	530
30	630
50	750

Houghton Cr.

R.I.	Q
5	510
10	670
20	840
30	950
50	1100

Prior Cr.

R.I.	Q
5	170
10	250
20	350
30	430
50	540

Rifle R.

R.I.	Q
5	700
10	870
20	1050
30	1150
50	1300

Prior Cr.

R.I.	Q
5	520
10	690
20	870
30	1000
50	1150

Klacking Cr.

R.I.	Q
5	200
10	290
20	390
30	470
50	570

S. Br. Shepards Cr.

R.I.	Q
5	150
10	240
20	350
30	440
50	580

Rifle R.

R.I.	Q
5	1150
10	1400
20	1600
30	1700
50	1850

EXPLANATION

R.I. = Average recurrence interval, in years

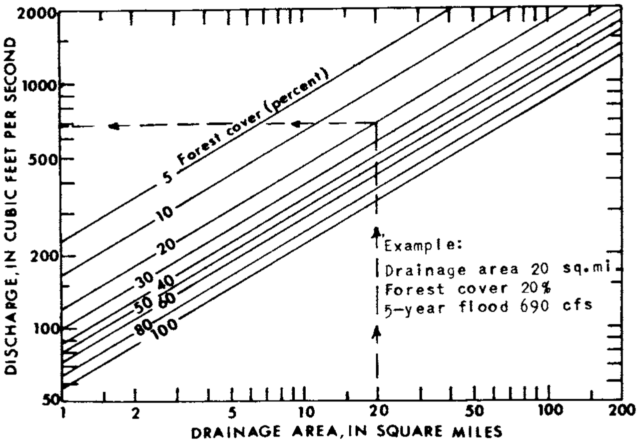
Q = Flood discharge, in cubic feet per second

FIGURE 26.--Flood magnitudes for selected locations as defined by parameters of drainage area and forest cover.

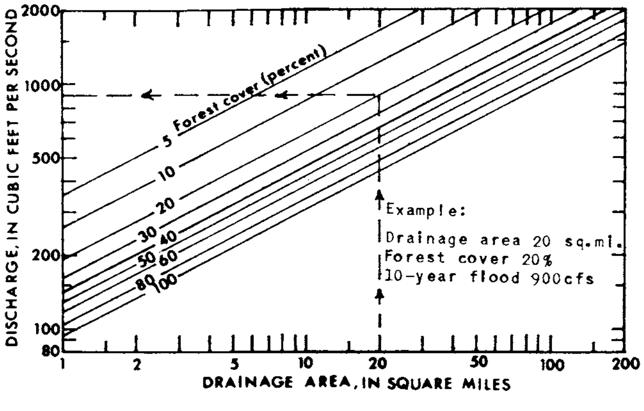
1) Determine the size of the drainage area upstream from point of use by planimetering the area from topographic maps. Because overland runoff is captured in topographic depressions in areas adjacent to the western and northern boundaries of the basin, drainage areas should be adjusted to include only areas which contribute directly to flood flows. Noncontributing areas for most major basins are shown in table 3.

2) Determine the percentage of the basin which is forest covered. Wooded areas may be estimated by using a grid and topographic maps.

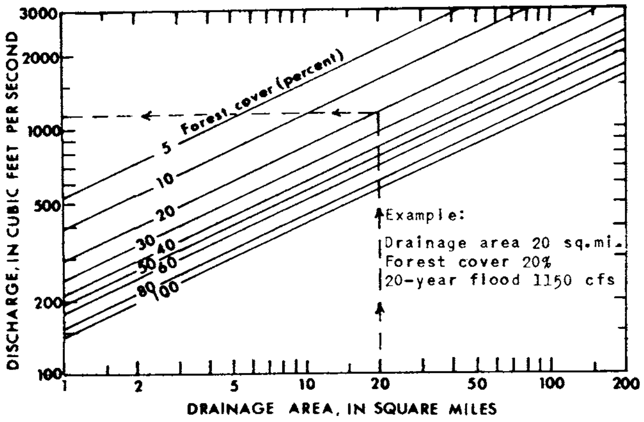
3) Enter these determinations in the graph corresponding to the selected design flood, and determine the peak discharge as shown by the example on the figures.



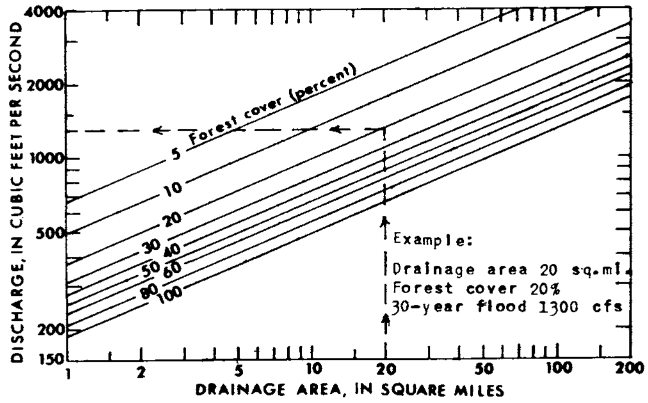
A. Regional flood-frequency curves for 5-year recurrence interval $(Q = 476\ A^{0.59}\ F^{-0.46})$.



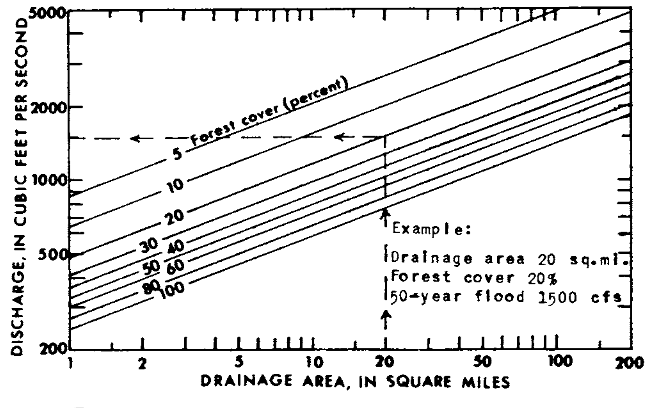
B. Regional flood-frequency curves for 10-year recurrence interval $(Q = 723\ A^{0.52}\ F^{-0.44})$.



C. Regional flood-frequency curves for 20-year recurrence interval $(Q = 1090\ A^{0.46}\ F^{-0.44})$.



D. Regional flood-frequency curves for 30-year recurrence interval $(Q = 1300\ A^{0.42}\ F^{-0.42})$.



E. Regional flood-frequency curves for 50-year recurrence interval $(Q = 1700\ A^{0.38}\ F^{-0.42})$.

FIGURE 27.--Regional flood-frequency curves can be used to make estimates of flood flows.

When estimating flood magnitudes and frequencies it must be recognized that the streamflow records, upon which this flood-frequency analysis is based, represent but a small sampling in both space and time. The reliability of flood estimates depends on the representativeness of the sample period and on the closeness of fit of data in the regression analysis. The closeness of fit was evaluated as part of the regression analysis and statistical tests were applied to determine the significance of the several parameters investigated. Similarly, the final regression equations were evaluated. These tests showed that reliable estimates of flood magnitudes and frequencies can be obtained by use of the equations, but that the relative reliability of flood estimates becomes smaller for the less frequent floods. The equations and graphs are based on records for streams unaffected by regulation and should not be applied where extensive man-made changes may alter flood flows.

LAKES

There are about 40 lakes and ponds in the upper Rifle River basin. Most are small, less than 15 acres in size, although a few such as George (186 acres), Rifle (183), Henderson (172), and Devoe (125 acres) Lakes are fairly large. George, Rifle, and Henderson Lakes have substantial development around them; most other lakes have only a few homes or cabins or are undeveloped. Fifteen lakes are within the Rifle River Recreation Area.

Lakes in the upper Rifle have been of great importance for recreation and esthetic values. They probably will continue to serve in that capacity rather than to serve as a source for water supplies. To continue supplying the recreational and esthetic needs of the area, awareness of the character of lakes with respect to their hydrologic environment is necessary. Such an awareness will provide a basis for retaining the usefulness of lakes for future generations.

LAKE LEVELS

Lake levels in the upper Rifle River basin fluctuate in response to variations in precipitation--a response similar to that of streamflow. Fluctuations in lake levels are of concern to owners of lakeshore homes and to users of camping sites where bank erosion and damage to piers and shore lines are likely to occur. To minimize shore line damages, the nature of lake level fluctuations must be understood. Records of fluctuations in lake levels have been obtained and evaluated for Devoe and Jewett Lakes. These records indicate the nature of variations of lake levels for other lakes in the basin.

Hydrographs for Devoe and Jewett Lakes are shown in figure 28 and 29, respectively. Jewett Lake has no inlet or outlet; changes in its levels are in response to precipitation falling on the lake and to changes in groundwater levels. Jewett Lake has an average annual fluctuation of about 1 1/2 feet. Its long-term range in stage is about 3 feet. Devoe Lake has both an inlet and an outlet. A dam at the outlet is used to regulate the lake's level. Because of this regulation, minimum levels remain fairly constant over the years. Inflow from Gamble Creek, however, produces high levels in response to spring freshets or runoff from heavy rains. Consequently,

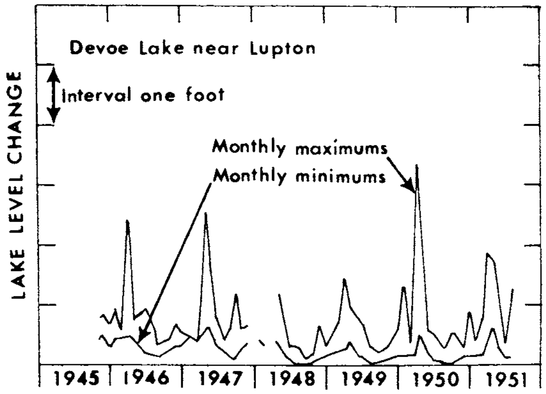


FIGURE 28.--Levels of Devoe Lake are regulated; however, variations in level are caused by changes in inflow from Gamble Creek.

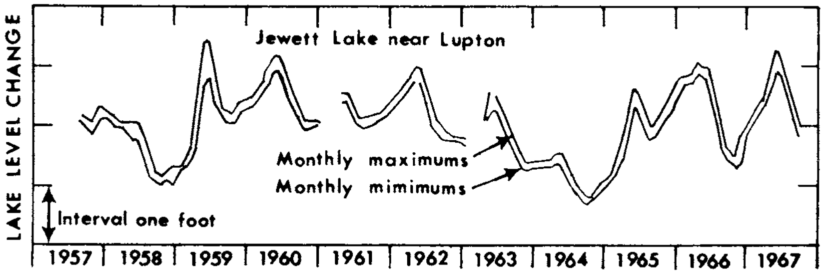


FIGURE 29.-- Jewett Lake has no inlet or outlet and changes in its level reflect changes in precipitation and ground-water levels.

a range in stage of about 3 1/2 feet has been recorded, although annual fluctuations are only about 1 1/2 feet. A diversion canal, constructed to by-pass most of the flow of Gamble Creek around Devoe Lake, will help to prevent large fluctuations in levels in the future. The by-pass also serves to retain lower stream temperatures by minimizing the discharge of warmer lake water.

About half the lakes in the upper Rifle basin have no outlet and, like Jewett Lake, respond to precipitation falling on the lake and to changes in ground-water levels. Their probable range in levels is about 3 feet.

Some lakes without outlets do have small intermittent inlet streams. Levels of these lakes have a wider range in stage as they respond to both changes in ground-water levels and overland runoff.

Lakes, such as Devoe, with inlets and outlets offer the greatest potential for maintaining a set level by construction of dams at their outlets. However, they will have a wider range in stage reflecting overland runoff into them. The range will depend upon the size of the lake and the amount of area from which runoff is received.

QUALITY OF LAKE WATER

The chemical quality of water in lakes often is affected by the same factors that affect lake levels. Chemical analyses of water from six lakes in the upper Rifle River area (table 4) illustrate the effect of the hydrologic setting on the chemical composition of lake water. Lakes such as Jewett and Henderson, which have no inlet or outlet and receive their water principally from precipitation falling directly on the lake, have low concentrations of dissolved minerals. Another lake of this type, Horseshoe Lake, probably receives more ground-water inflow and consequently has a higher concentration of dissolved minerals. Also, as indicated by the chloride concentration, Horseshoe Lake may be receiving effluent seepage from septic tanks. Bear Lake is perched and therefore receives little or no ground water. However, dissolved minerals concentration is higher in Bear Lake because there is more overland drainage into it.

Devoe and Prior Lakes have inlets and outlets and receive water from the inlet streams and from ground-water sources. Thus, these lakes generally have higher concentrations of dissolved minerals and their chemical quality is similar to that of streams under base-flow conditions or to that of ground water.

The chemical analyses of water from the lakes sampled indicates that their water is of excellent quality and suitable for recreation and most other uses. To maintain the high quality, concern should be centered on their degree of *nutrient enrichment*. This enrichment enhances growth of aquatic vegetation and, in turn, increases the rate of lake decay. The concentration of nitrogen, one of the principal nutrients necessary for aquatic growth, was low in the lakes sampled. However, the lakes were sampled during the growing season when aquatic plants remove most nitrates from water. Most of these nitrates are again released when the plants die and decay.

In future management of lakes, care should be taken to prevent nitrogen, phosphorus, and potassium from entering the lakes. Commercial fertilizers and septic tank effluent will contribute significant amounts of these substances to lakes. Lawn fertilizers used on lake-shore property often are washed into lakes by rains and therefore, are potentially the greatest source of nutrients to lakes.

TABLE 4.--Chemical quality of water from lakes having different hydrologic settings.

(Analyses by field methods, concentrations are in milligrams per liter except where noted. All samples collected at the surface of the lakes on Aug. 27-28, 1969.)

Lake	Sampling site	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	Dissolved solids (calculated)	pH
							Carbonate	Noncarbonate			
Bear	NW 1/4 sec.8, T.24 N.,R.3 E.	106	1	11	1.0	0.1	98	10	190	124	8.3
Devoe	SE 1/4 sec.11, T.23 N.,R.3 E.	168	0	24	2.5	.1	156	18	305	198	8.1
Henderson	NW 1/4 sec.31, T.23 N.,R.4 E.	72	0	3.0	3.5	.1	65	6	135	88	7.7
Horseshoe	NE 1/4 sec.2, T.23 N.,R.1E.	129	0	5.0	10	.1	112	6	240	156	7.9
Jewett	SE 1/4 sec.11, T.23 N.,R.3 E.	32	0	4.0	1.0	.1	34	8	68	44	7.1
Prior	NE 1/4 sec.23, T.23 N.,R.2 E.	146	0	4.0	1.0	0.0	118	0	225	146	7.5

Bear, Henderson, Horseshoe, and Jewett Lakes have no inlets or outlets. Devoe and Prior Lakes have both inlets and outlets.

WATER UNDER THE LAND--GROUND WATER

Drill a well in the upper Rifle River basin and you'll probably get water. This water from below the land we call *ground water*. In general, it doesn't appear much different than water in a rainbarrel or water from a stream. And in reality, it isn't. Its basic makeup is the same. In fact, water in streams during periods of dry weather is water that seeped from the ground. Yet, because parts of the ground-water environment are affected by the interaction of forces that are different than those affecting water in other environments, some phases of the ground-water picture must be discussed separately.

A UNIQUE WATER-SUPPLY SYSTEM

Many areas in Michigan have abundant surface and ground-water resources. However, few if any, areas are more blessed with these resources than the upper Rifle River basin. Not only are water supplies abundant but they appear to have a long-lived future. Water flows year around in the streams, natural springs are common, and wells tapping ground-water aquifers flow freely (fig. 30)--each mode of occurrence reflects the nature of the ground-water system. The importance and the unusual character of this system are expressed by the volume of flow in streams and from wells. For example, the discharge of the Rifle River at Selkirk is seldom less than 70 cfs, even during extended periods of dry weather when streamflow is derived entirely from ground-water sources. The total discharge of water from wells is not known exactly, but is estimated to be at least 20 cfs. In effect, the base flows of streams and the water obtained from wells represent a large volume of water--a significant portion of the total water resources available in the Upper Rifle River basin.

FIGURE 30.--Water flows from the ground.

As important as the volume of water supplied from ground-water sources to maintain streamflow and supply wells is the fact that many wells in the basin flow. Such wells are a valuable asset and are being developed at an increasing rate throughout the basin (fig. 31).

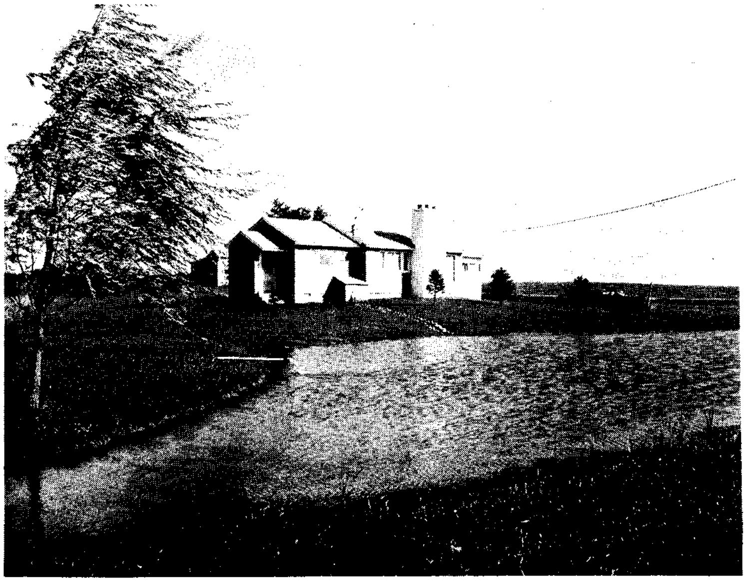
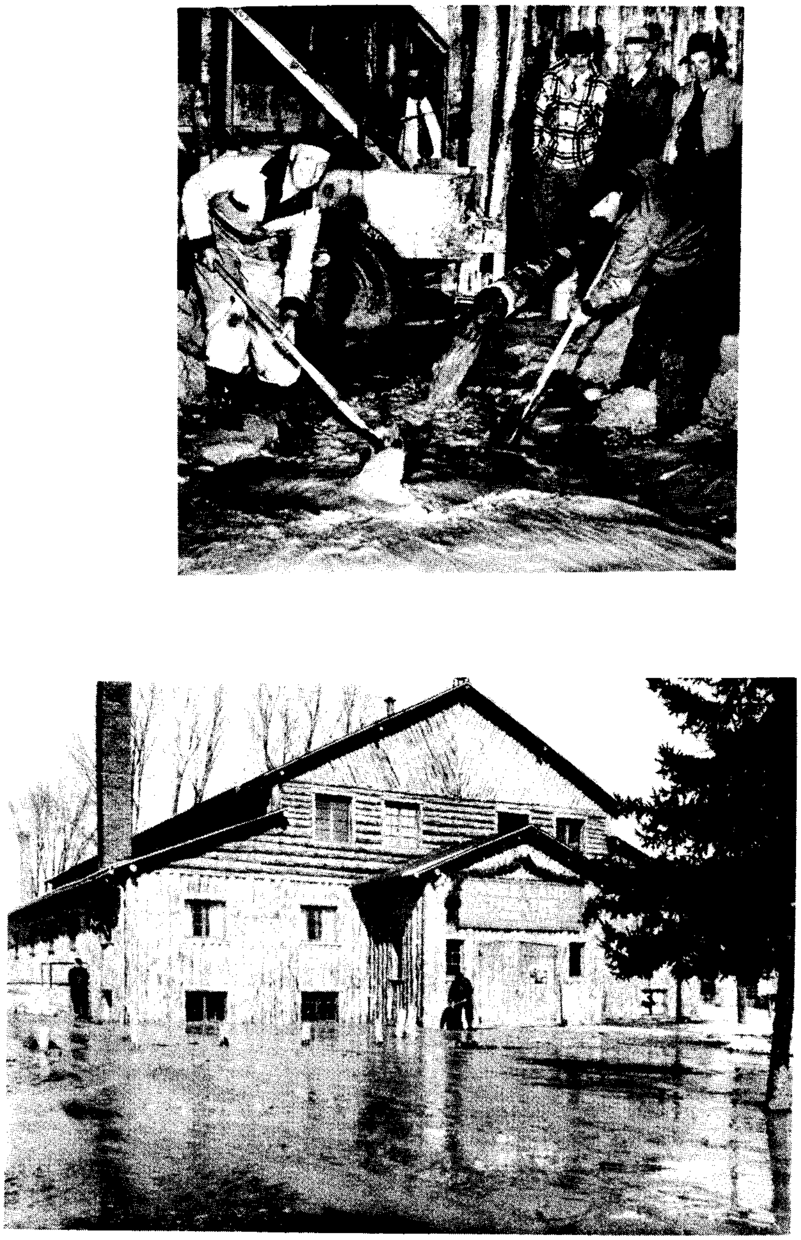


FIGURE 31.--Fish pond and flowing well--a common sight.

Most water supplies for individual homes and businesses come from flowing wells. A private fish hatchery near Lupton is supplied by flowing wells as are many private trout ponds. The old town hall at Rose City also was supplied by water from a flowing well--a well that gushed forth huge quantities of water (fig. 32) when it was reconditioned in 1954 (State Journal, 1954). Finally, the significance of the ground-water resource is being dramatically illustrated by a recent innovation where a subdivision-like development includes with the purchase of a lot, a flowing well and a trout pond stocked with trout.



AT ROSE CITY

Well Goes On Rampage

Water and Sand Bogging Down Whole Community

ROSE CITY, Feb. 27 (AP)—A rampaging artesian well began to slow down last night after gushing huge quantities of water and sand for 24 hours. Since Thursday afternoon, the well had been gushing at a rate of 130 barrels an hour, pouring its water into the main street and dampening basements of several homes in this small Ogemaw county community.

But this town of 400 still has a problem. The sand tossed up by the gusher is spread over the lawn of the community hall.

State Conservation Officer Robert Van Camp estimated there was five or six truckloads of fine sand dumped on the lawn.

Van Camp said that well-diggers were drilling down a four-inch casing of an artesian well suppyling the hall with water. The old well had been losing its pressure. The diggers ran into a rock at the bottom of the pipe and managed to drill through it Thursday. That released a terrific amount of pressure, shooting water and sand up the pipe so fast that drillers were unable to cap the flow. A crew of 25 men and two bulldozers battled the gusher around the clock until the flow began to slow down last night.

Van Camp said the well now could be capped. However, he said, the well-digging crew will let it flow until the sand has settled.

The city gets most of its water from similar wells and Van Camp said the community might be in for more trouble since the release of the pent-up pressure might tend to lower pressure in other wells.

FIGURE 32.--Well goes on rampage.

SOURCES OF GROUND WATER

Large quantities of water lie below the land surface. However, just because the water is there does not mean that it serves any useful purpose to man. To be useful, the water has to be retrievable. And to be so, it has to be able to move with some degree of freedom. Thus, the ground water in which we are most interested occurs in materials that are permeable; that is, materials that store and permit easy movement of water. Therefore, to evaluate the availability of ground water it is necessary to define the nature of the materials in which ground water occurs.

GLACIAL DEPOSITS-- A PRIME SOURCE OF WATER

Glacial deposits, which cover the basin, form the framework for the basin's water-supply system. These materials were deposited many years ago when large glaciers covered much of North America. The glaciers, rasping away at existing landforms, broke and pulverized large rock masses into particles which were carried by the ice and subsequently deposited beneath the ice, or near and along its waning edge. This process continued until all parts of the basin were covered by gravel, sand and clay; a covering ranging up to 700 feet in thickness (fig. 33). This glacial material, existing

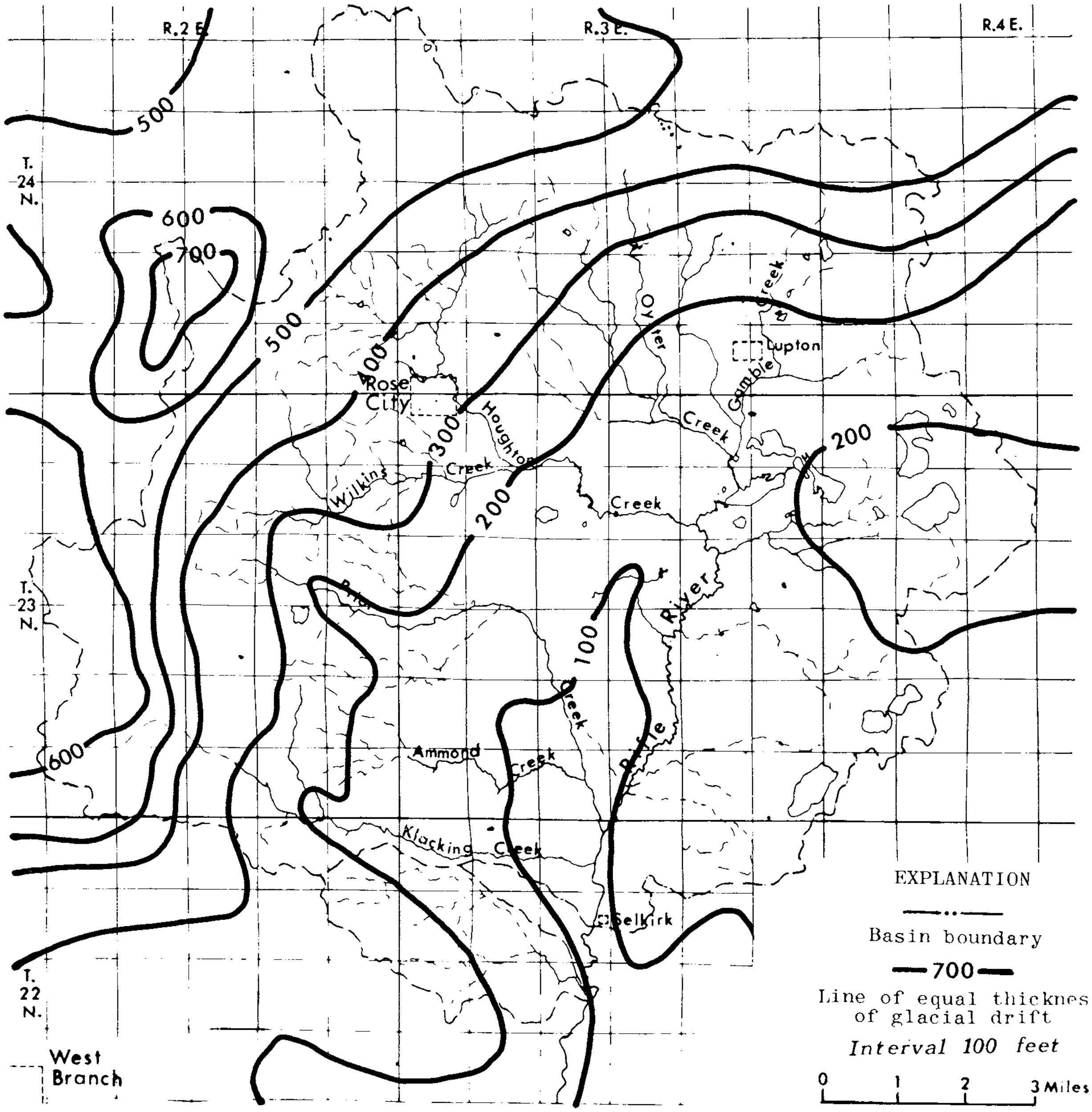


FIGURE 33.--Glacial deposits range in thickness from less than 100 to more than 700 feet.

either in a well-sorted state or as a mixture, forms the system which supplies water for wells and for maintaining the flow of streams.

Relative to providing a good water-supply system, nature did a marvelous job in its distribution of the glacial materials (fig. 34). The upland areas consist mostly of sand or gravel and, thus, readily absorb large quantities of water from precipitation. These *recharge areas* provide most of the water that issues from wells, springs, and seeps within the basin. The low-lying areas are mostly alternating layers or lenses of sand and gravel

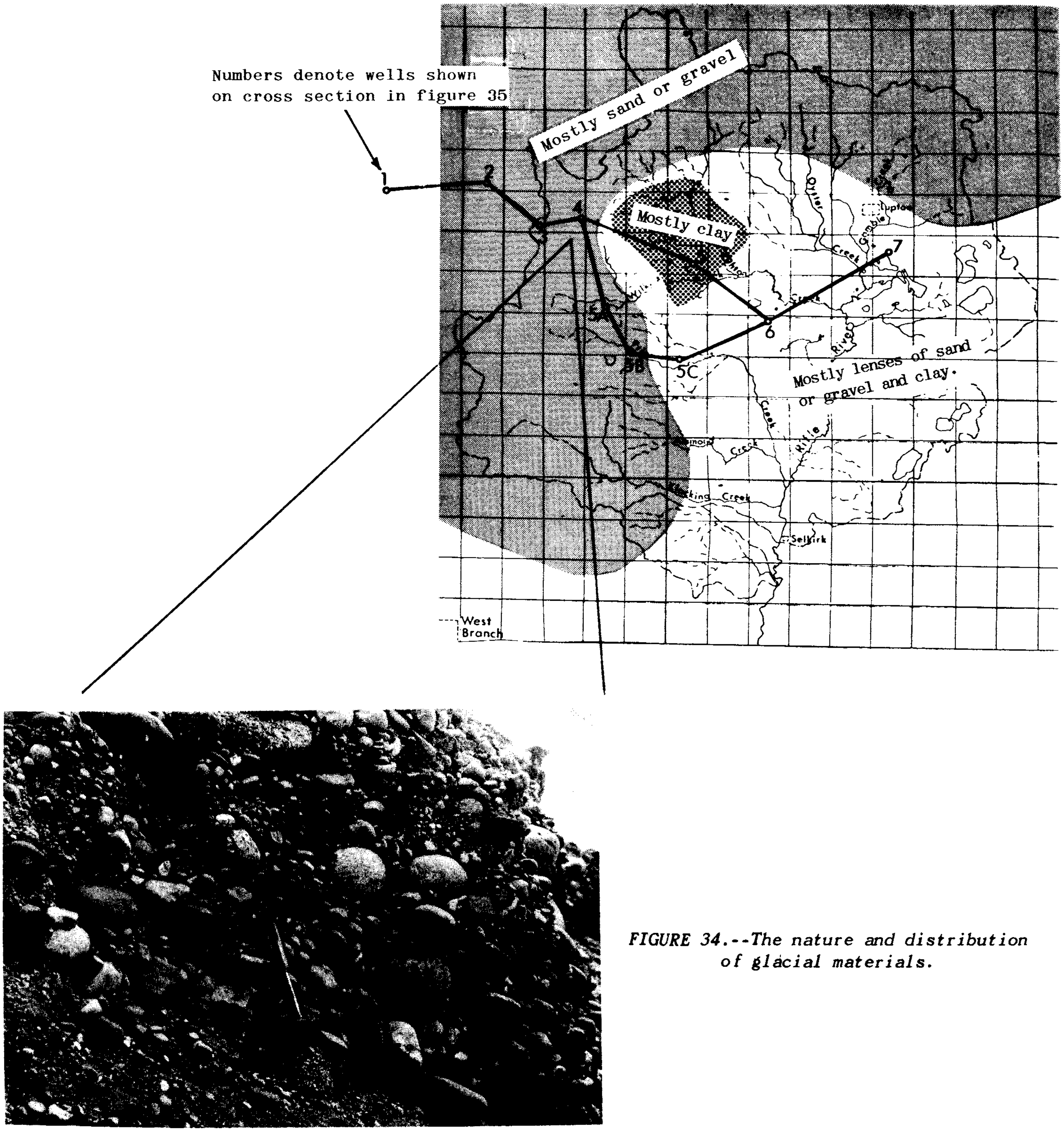


FIGURE 34.--The nature and distribution of glacial materials.

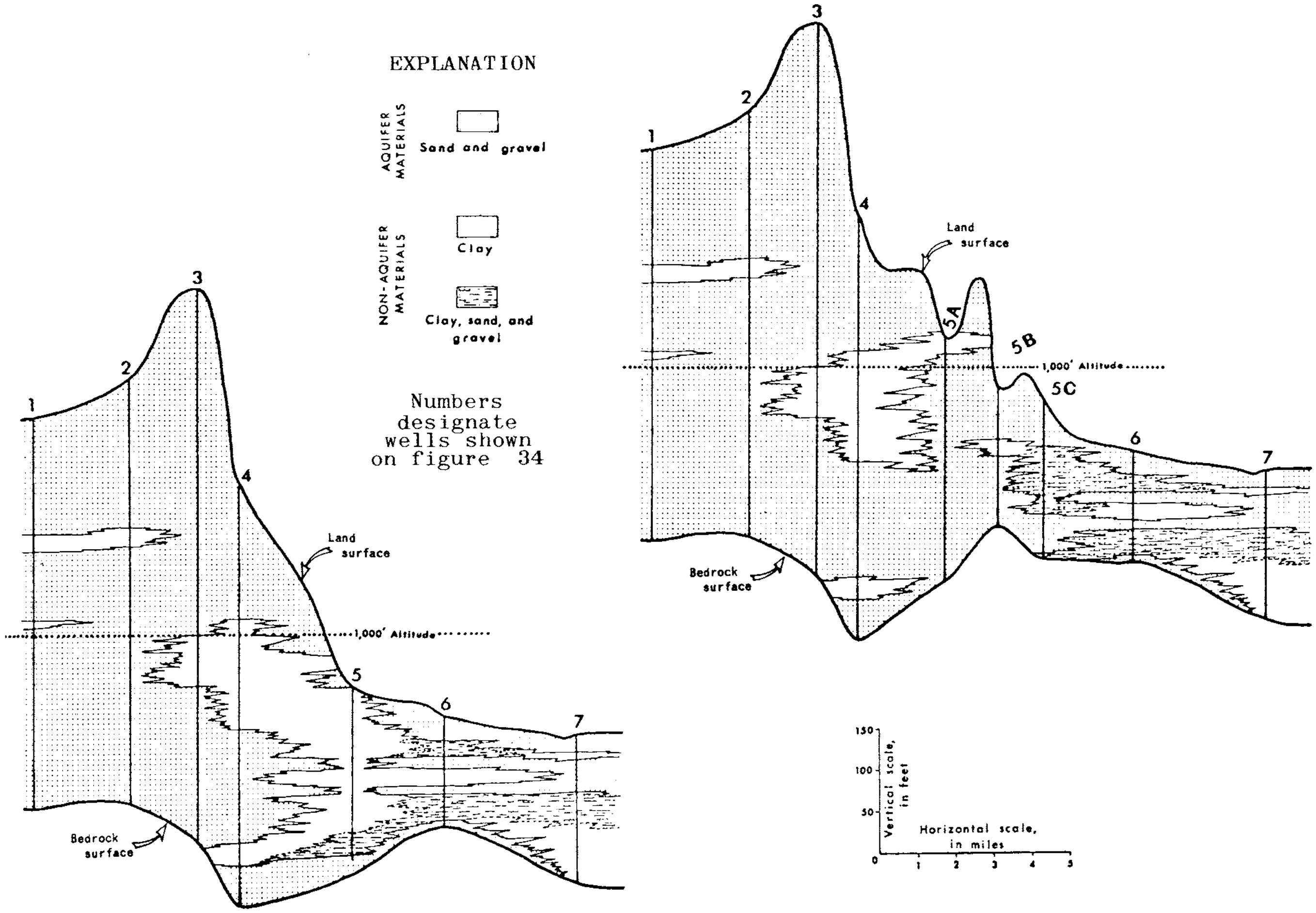
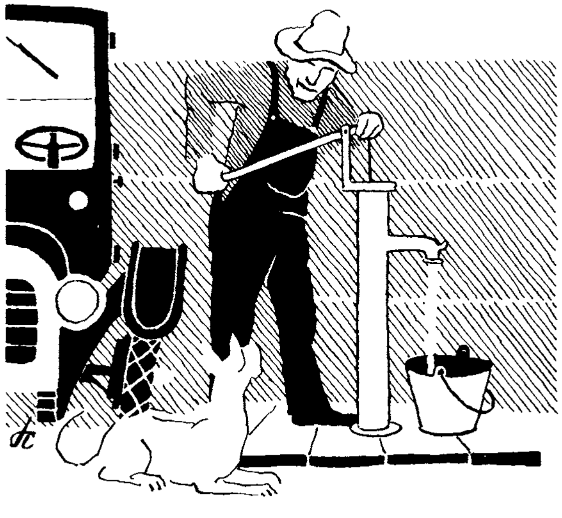


FIGURE 35.--A view of the glacial materials below the land (location of cross sections are shown on figure 34).

or clay. Water from the upland areas flows through the sand and gravel lenses often becoming confined by the clay layers (fig. 35). The water, thus confined, is under pressure, and when tapped by a well, will rise to, or above, the land surface providing a ready supply of water. Vast recharge areas, sand and gravel lenses providing avenues for water transmission, and artesian pressures for flowing wells--all are factors which provide for a prime source of water and factors that are common to the upper Rifle River basin.



BEDROCK DEPOSITS-- A POOR SOURCE OF WATER

Underlying the glacial deposits are layers of sedimentary rock that are more than 11,000 feet thick. These *bedrock materials* were deposited on the floor of shallow seas that covered the area millions of years ago. The uppermost surface of these deposits was sculptured by water and ice into ancient land forms similar to the hills and valleys that exist at land surface today.

The highest points on the bedrock surface, more than 800 feet above mean sea level, occur along the northern and western parts of the basin (fig. 36). The lowest points, having altitudes of less than 700 feet, are in valleys that drain to the east and south.

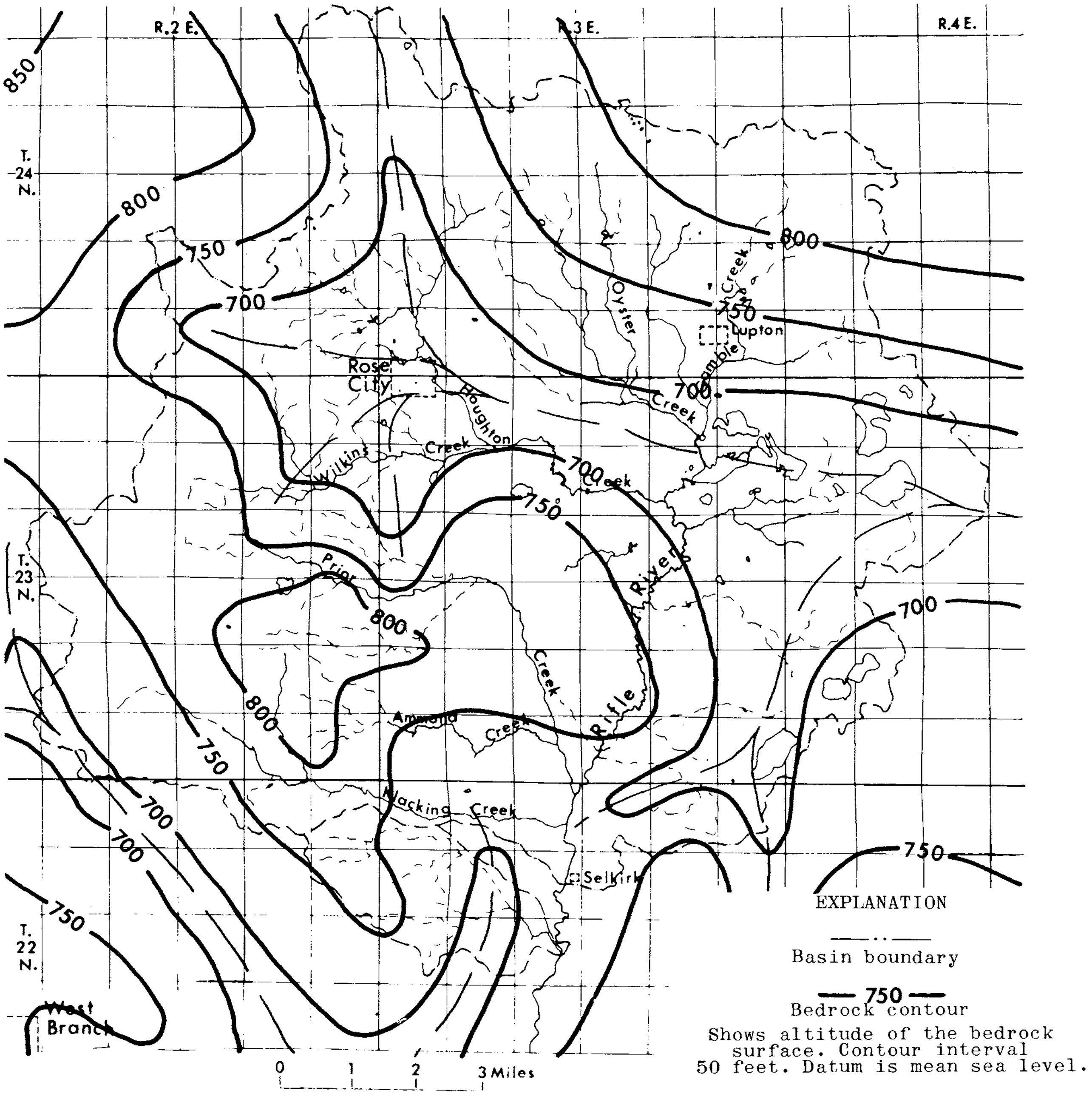
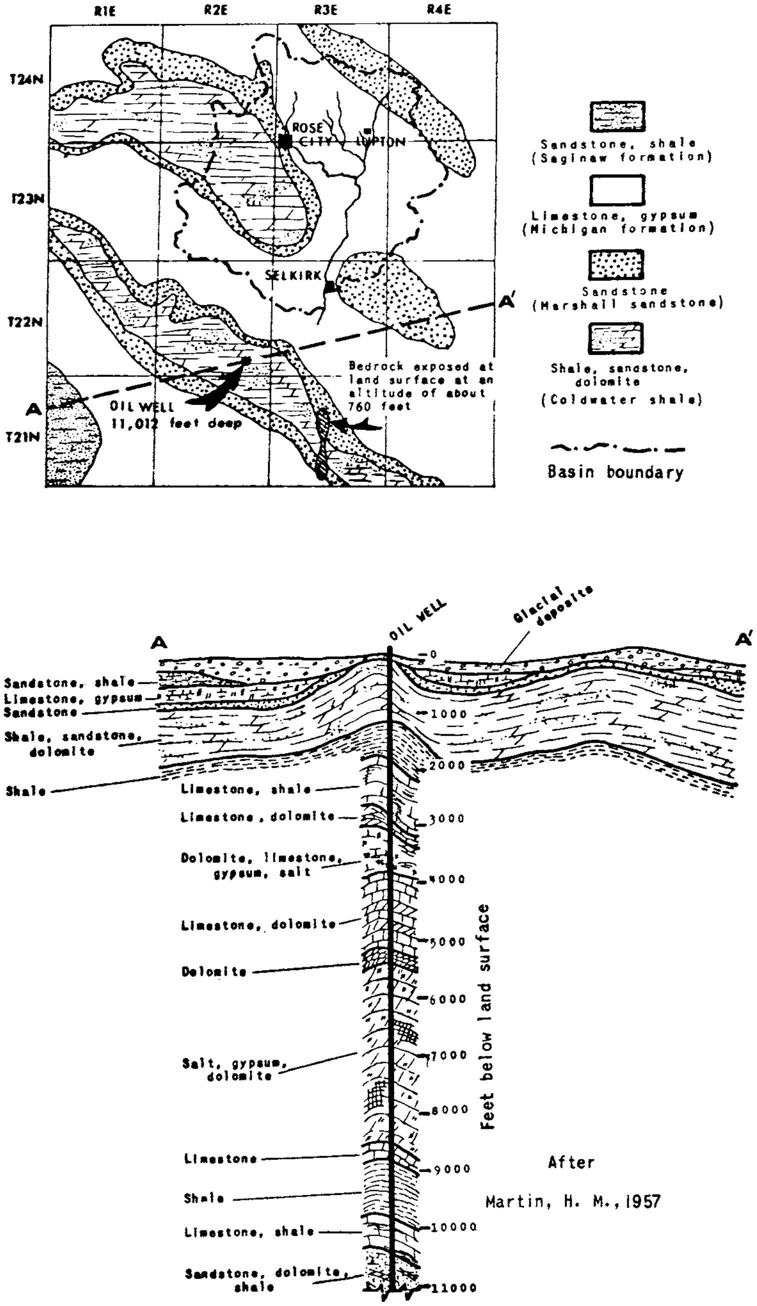


FIGURE 36.--The bedrock surface in the basin occurs at altitudes ranging from less than 700 to more than 800 feet.

Bedrock consists primarily of beds of sandstone, shale, limestone, and dolomite (fig. 37). Some of these beds contain gypsum and salt; materials which have a tendency to increase the mineral content of water. As a result, water from wells penetrating the water-bearing zones in bedrock is often hard, high in chlorides, and poorly suited for domestic use. For example, water from 2 wells penetrating bedrock have dissolved-solids contents of 1,560 mg/l (milligrams per liter) (table 5)--much higher than that recommended for most uses. In developing a water supply, it should be recognized also that water from bedrock may migrate into the overlying glacial deposits and produce a higher than normal mineral concentration, especially in the lower parts of these deposits.



After Martin, H. M., 1957

FIGURE 37.--The nature of the bedrock.

Of economic interest in some parts of the basin and surrounding area is the fact that the bedrock formations have been arched upward to form domelike structures. Oil has accumulated in some of these structures and many holes have been drilled to tap this resource (fig. 38).

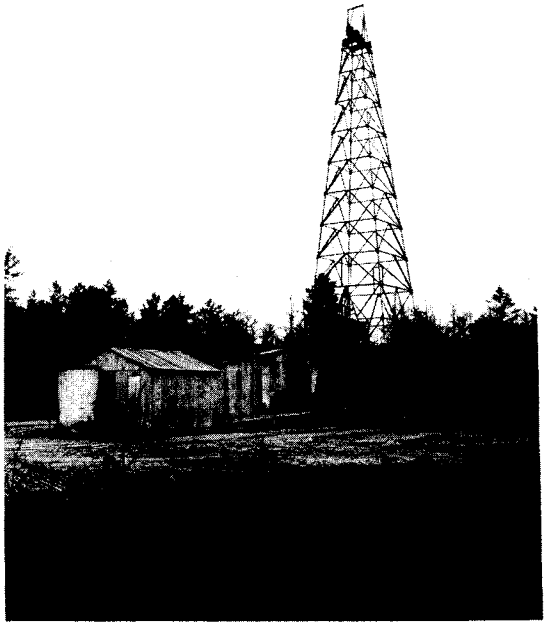


FIGURE 38.--A sign of oil.

HOW GROUND WATER MOVES

The movement of ground water is little different than the movement of surface water. The path that ground water takes may be somewhat more circuitous. Yet, in the final analysis, it, like surface water, is generally seeking a lower altitude. Water in the higher areas along the northern and western parts of the Rifle basin is moving downward to the low-lying areas to the south and east. Let us look at the path it takes.

AN AREA OF HIGH RECHARGE

North and east of Rose City, at altitudes above 1,200 feet, is an area that has excellent ground-water recharge capabilities. Precipitation falling on this area has two primary avenues of escape--it either returns to the atmosphere through evapotranspiration or it seeps into the ground to recharge the ground-water reservoirs. Little or none of the water goes directly to streams as overland runoff. No single feature of the area promotes this condition. Rather, it appears to be brought about by the inter-working of three features--topography, soils, and glacial deposits.

The topography that permits the capture of precipitation is of two types. One type predominates principally in the area north of Rose City--an area that contains numerous bowl-shaped land features termed here as *topographically closed depressions*. These depressions, several of which are more than 100 feet deep (figs. 39 and 40), serve to capture pre-

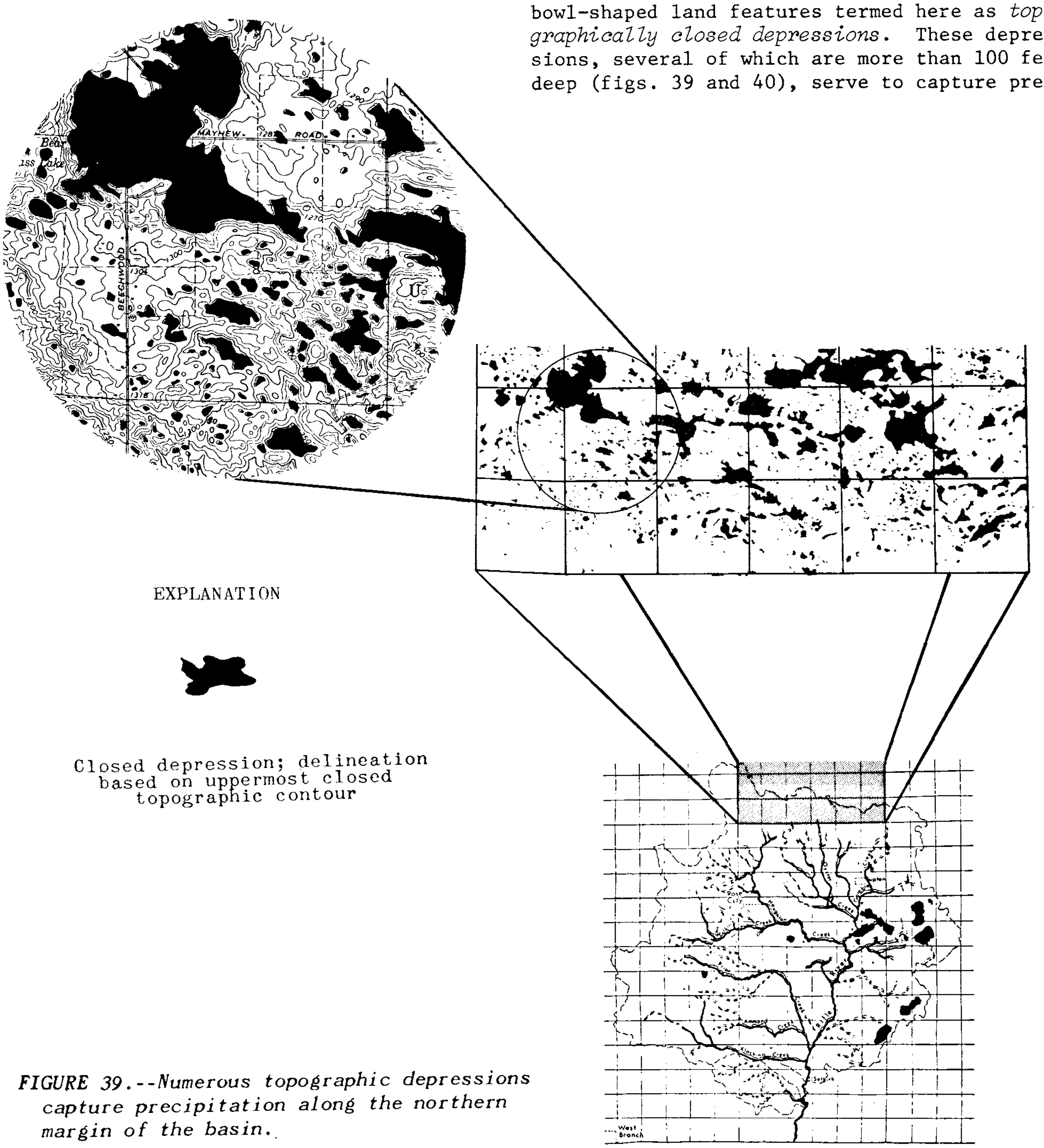


FIGURE 39.--Numerous topographic depressions capture precipitation along the northern margin of the basin.

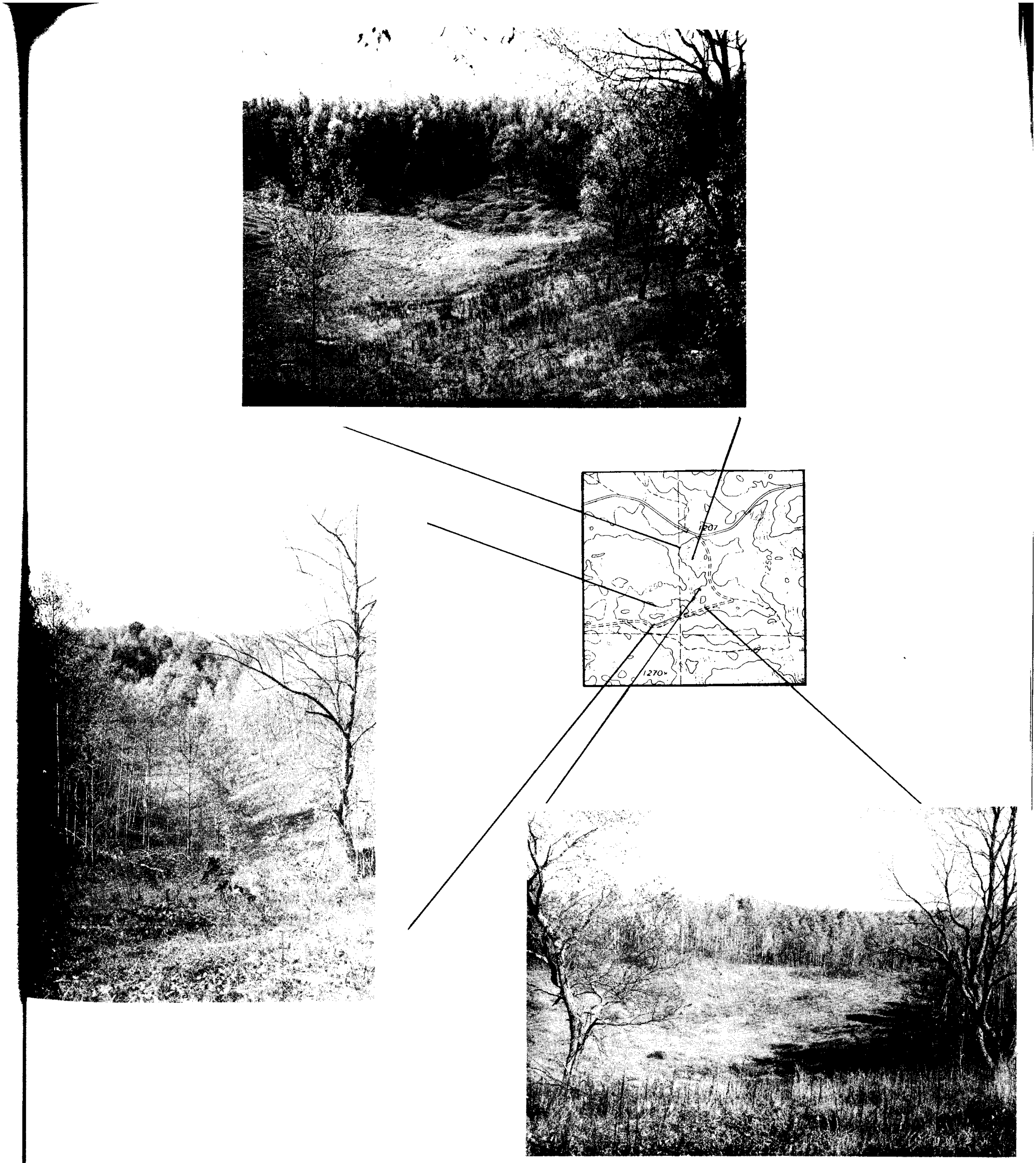


FIGURE 40.--A look at several topographic depressions.

cipitation that falls into them and water that drains into them from the surrounding hillsides. Most of the captured water is then available for recharging the ground-water reservoirs. Only a few depressions, such as that at Bear Lake (fig. 41) have impermeable bottoms, retain the captured water, and are less important as recharge areas.

The second type of topographic feature that permits capture of precipitation is the broad, flat areas in the highlands beyond the basin divide west of Rose City (fig. 42). These areas, because of their flatness, slow down overland flow and provide opportunity for precipitation to infiltrate into the soil. This water subsequently migrates into the Rifle River basin, as will be shown later in the report. But, flat land surfaces and areas having closed depressions do not, by themselves, guarantee high recharge. To allow high recharge, the soils must be capable of absorbing water. Fortunately, most areas west and north of Rose City are covered with sandy soil (fig. 43) that readily absorbs water falling on them. Thus, the nature of the topography and the soils in the high areas assures the capture of water from precipitation. Subsequent movement to the ground-water reservoirs depends on the nature of the glacial deposits.

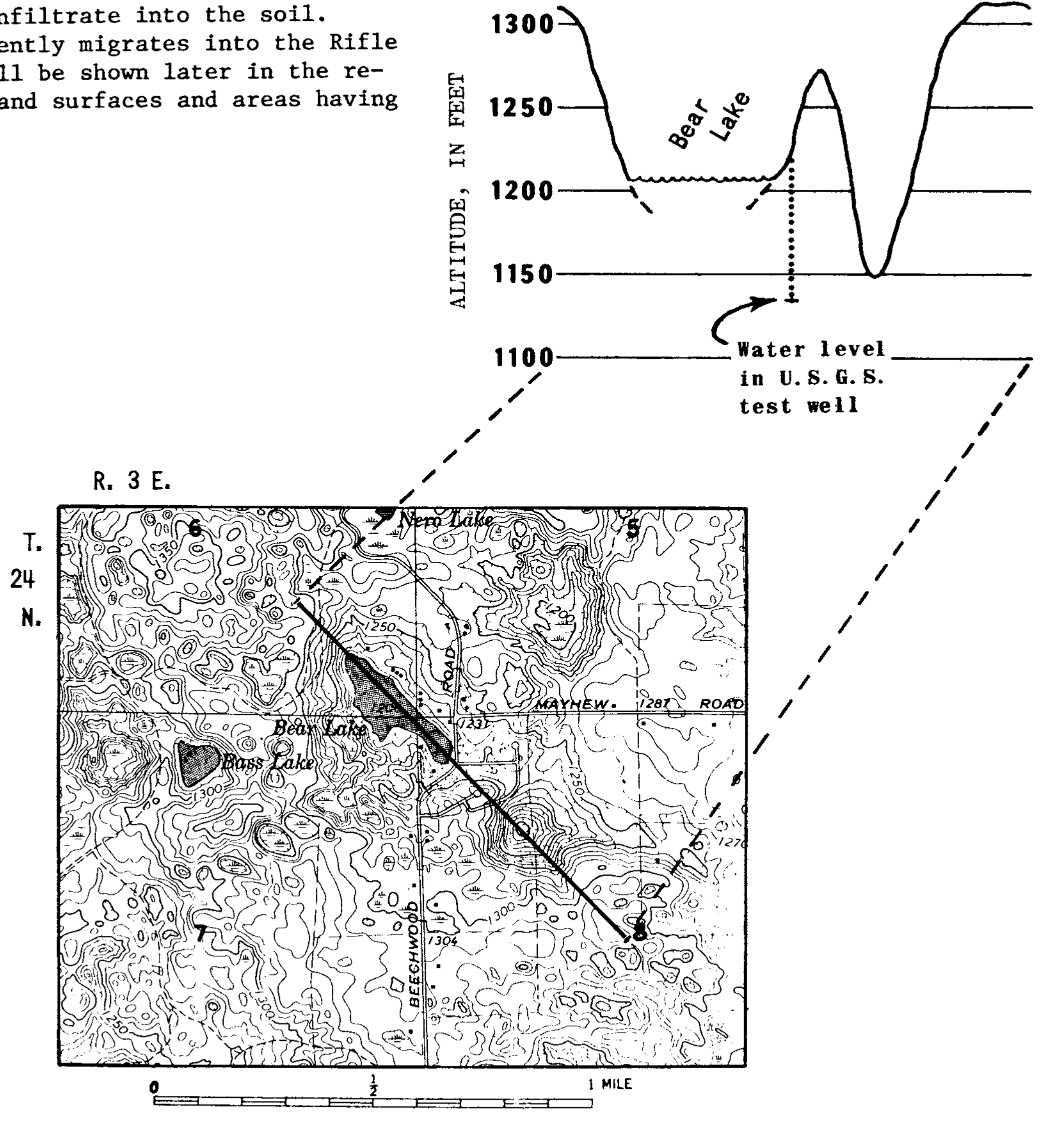
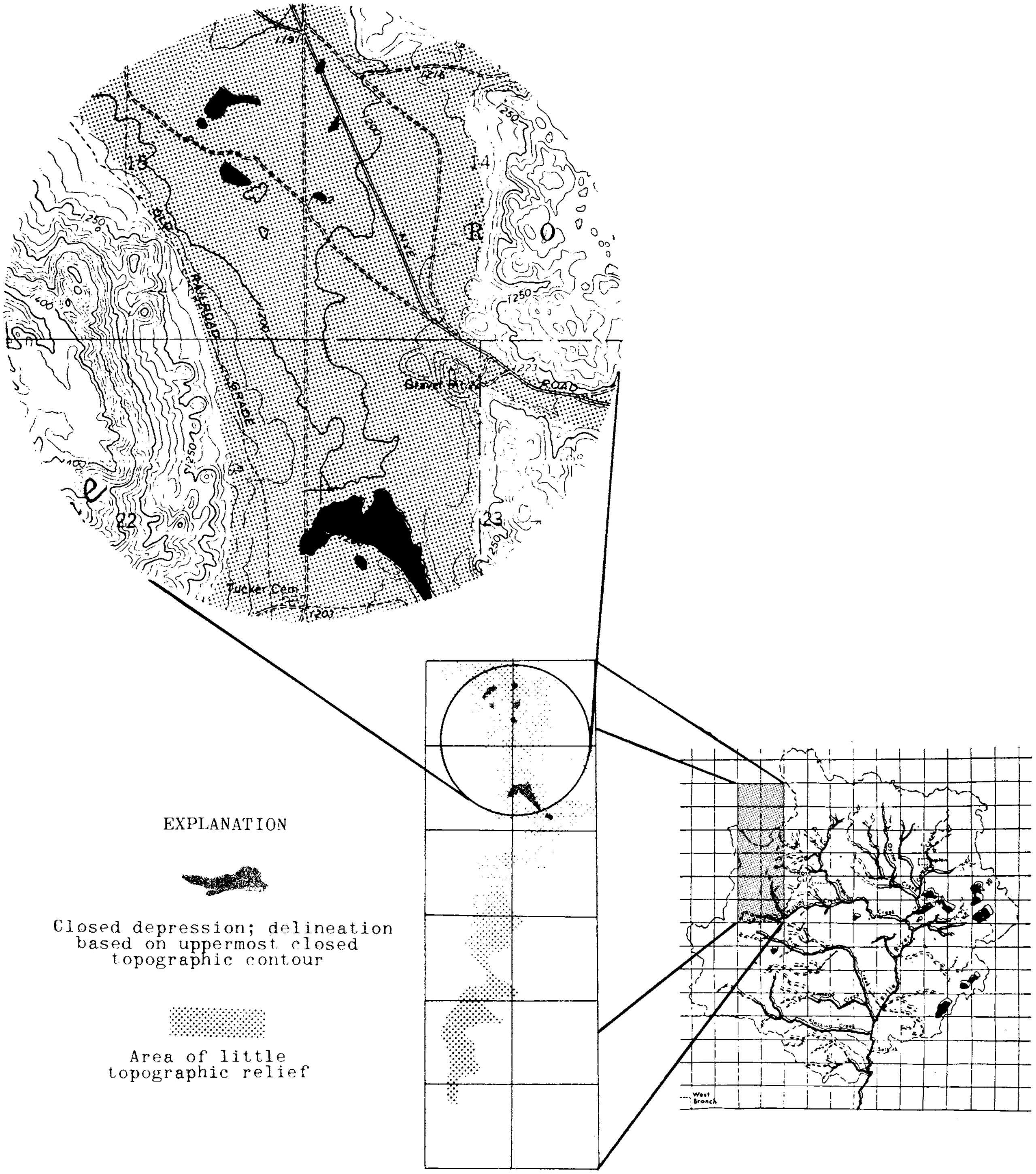


FIGURE 41.--*Two adjacent 'closed depressions'; one contains water whereas the other remains dry.*



EXPLANATION

● Closed depression; delineation based on uppermost closed topographic contour

▨ Area of little topographic relief

FIGURE 42.--Broad flat areas along the west margin of the basin greatly reduce the velocities of overland flow providing opportunity for infiltration of precipitation.

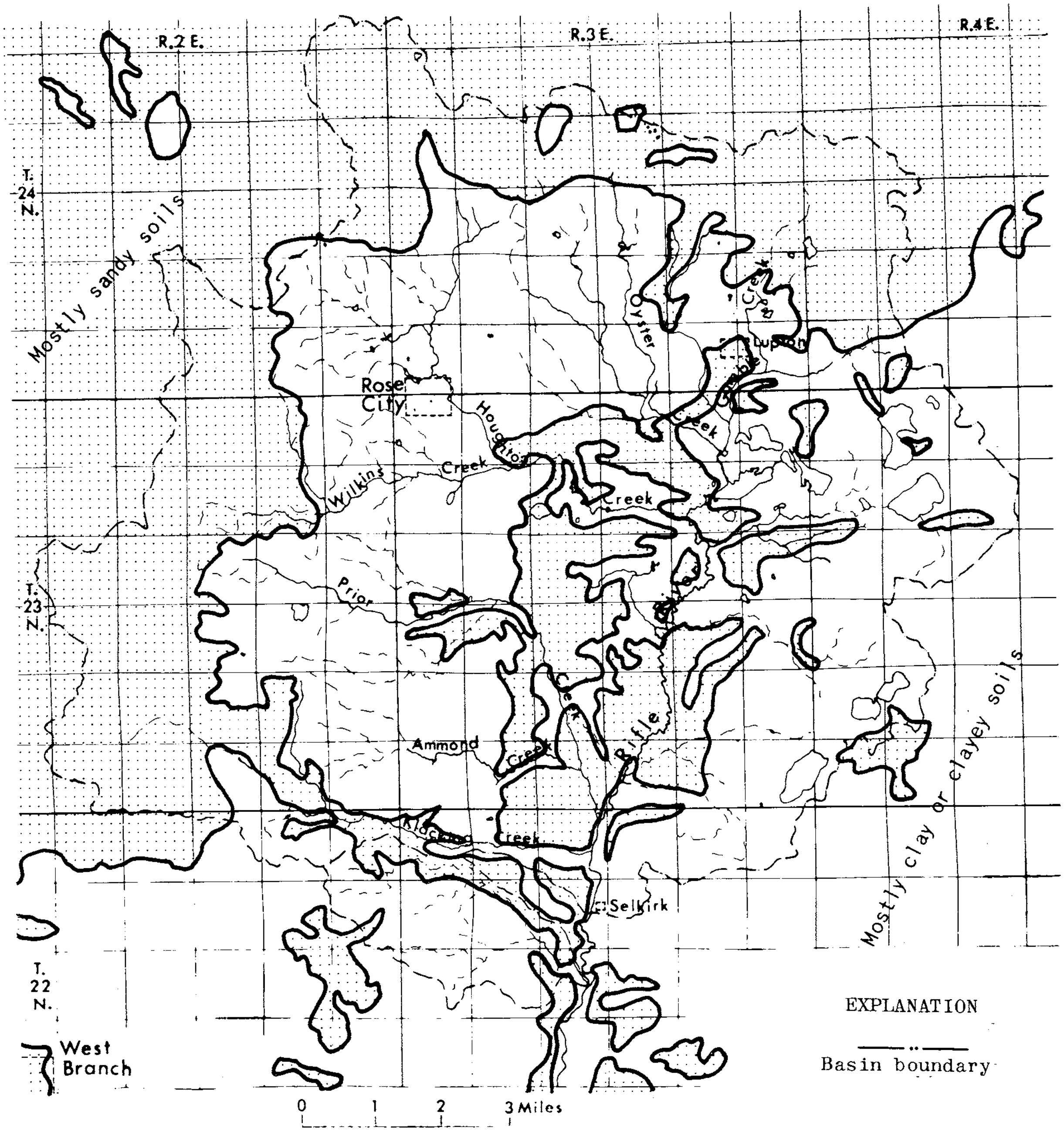


FIGURE 43.--Movement of precipitation to ground-water reservoirs is influenced by the nature of the soils.

SAND AND GRAVEL INFLUENCES WATER MOVEMENT

To allow the water captured in the higher areas to percolate downward to the ground-water reservoirs, the glacial deposits need to be composed of permeable materials--materials such as sand and gravel. The upland areas of the Rifle River basin meet this requirement, as shown in figures 34 and 35. The glacial materials here greatly facilitate water's downward movement. Thus, it is the combined workings of three features--topography, soils, and glacial deposits--that produce an area ideally suited for recharge.

The permeability of the glacial deposits below the water table is also important because it influences the movement of water within the ground-water reservoir. Most water entering the reservoir moves to the south and east through lenses of sand and gravel (fig. 44). As it moves out of the recharge areas,

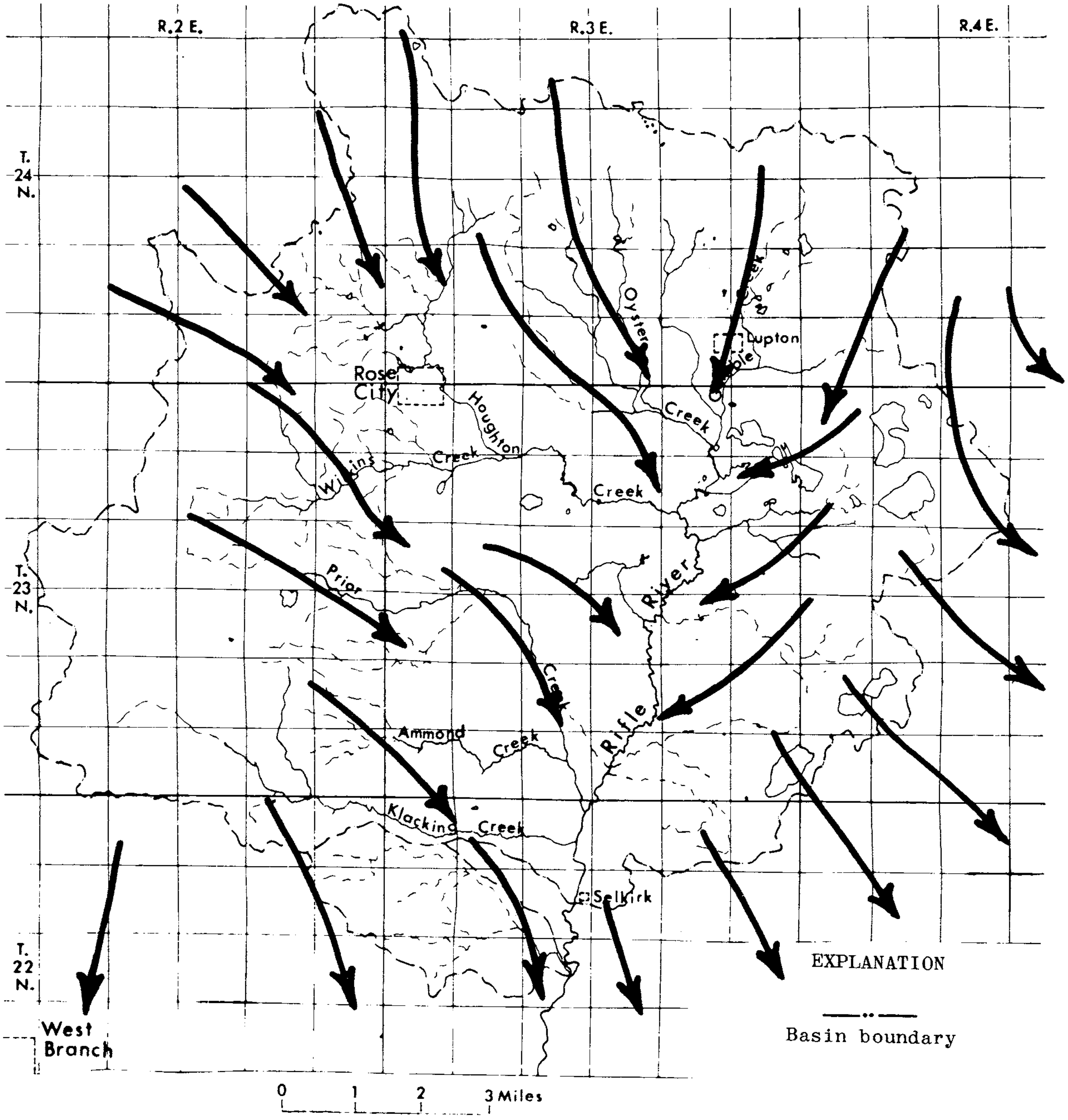


FIGURE 44.--South and east--the general direction of ground-water movement.

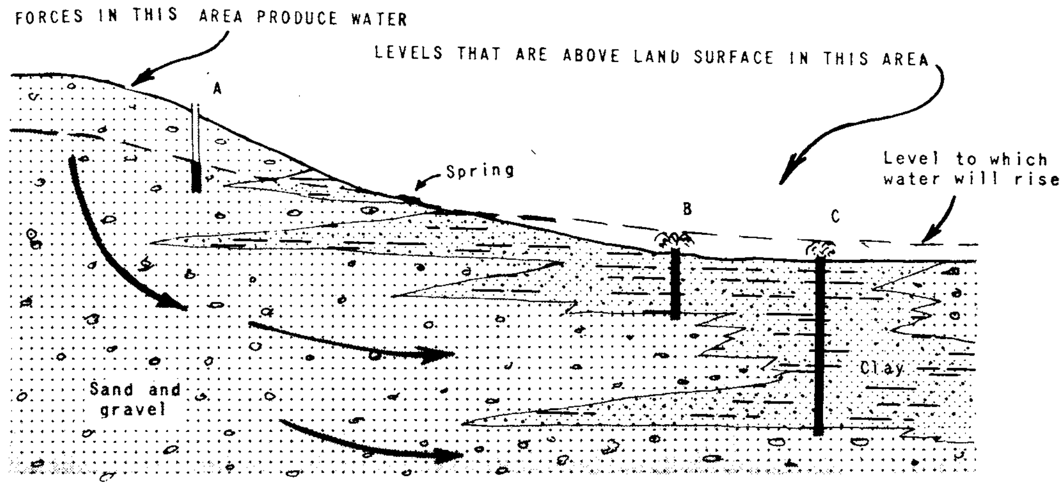


FIGURE 45.--Diagrammatic view of a flowing-well system.

it often becomes confined under layers of clay. This confinement produces a pressurized system. Such a system often causes water to rise in wells above the point where it was first encountered. In some wells (fig. 45, well A) the water will rise only within the well casing; in other wells, both shallow and deep (fig. 45, wells B and C), the water rises and flows above the land surface. Both occurrences are common in the Rifle basin. In some areas, the water level and the water-bearing material intersect at the earth's surface and produce springs. Areas where flowing wells and springs are most numerous are shown on figure 46.

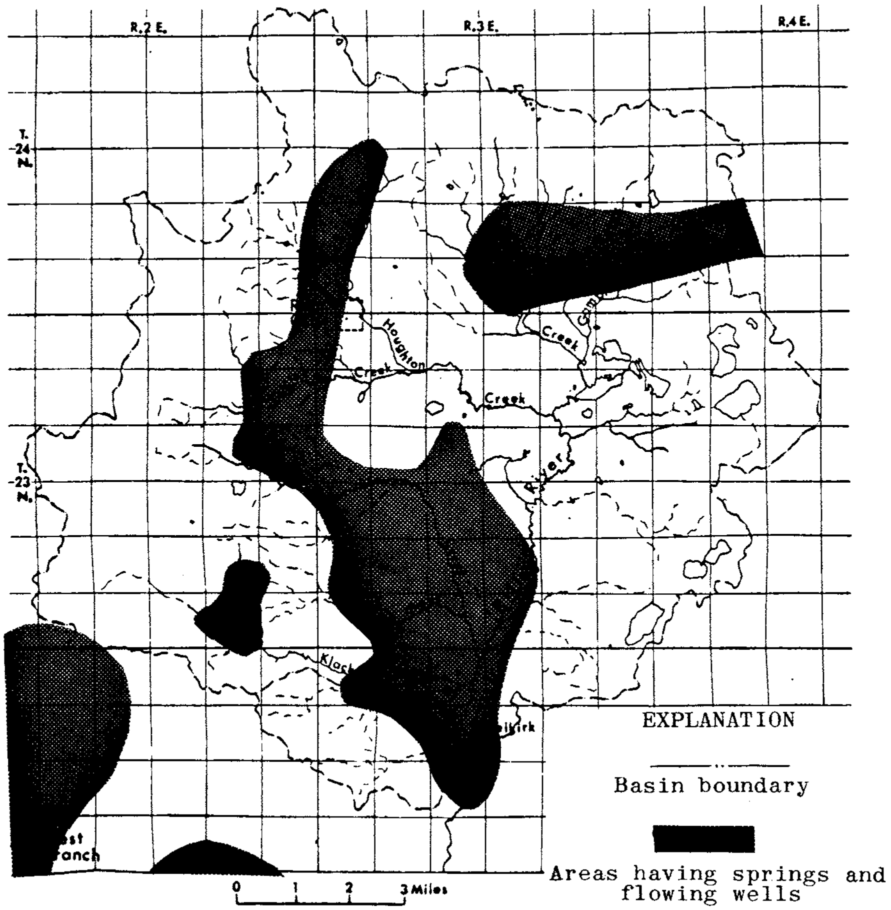


FIGURE 46.--Areas where flowing wells and springs are most abundant.

MORE WATER THAN EXPECTED

As discussed in an earlier section of this report, recharge to the upper Rifle River basin does not occur entirely within the basin's surficial boundary. Evidence that the effective ground-water recharge area extends beyond the surface boundary can be provided through assessment of hydrologic data. Average input to the basin from precipitation is about 29 inches per year or about 250 cfs. Output from the basin includes 140 cfs as streamflow, as measured at the gaging station at Selkirk, and 150 to 175 cfs as evapotranspiration. Evapotranspiration is computed as being 60 to 70 percent of precipitation, based on rates common to Michigan. Equating input and output, we find output to be from 40 to 65 cfs higher than input. This difference is probably due to the basin receiving water as underflow from beyond its surface divide. However, the possibility exists that evapotranspiration rates used in the above assessment might be erroneous. Evapotranspiration rates for the Rifle basin might be considerably lower than those typical for other parts of Michigan. To check this possibility, a regional analysis of annual runoff was made for a number of river basins in the upper part of Michigan's Lower Peninsula--basins that appear to have gross hydrologic environments similar to those in the upper Rifle River basin. From this analysis, the average annual runoff for these basins was found to be 0.8 cfsm (cubic feet per second per square mile). Relating this to the Rifle basin, a probable mean annual discharge of 94 cfs (0.8 cfsm x 117 sq. mi.) is indicated for Rifle River at Selkirk--this is 46 cfs lower than that actually measured at the station. When this 46 cfs is related to the regional average runoff of 0.8 cfsm, it is found that the actual ground-water drainage area of the upper Rifle River basin should be expanded by at least 58 square miles. This is based on the assumption that there is no surface runoff from the extended basin. This may not be entirely true, as surface runoff may occur under certain conditions. However, as shown earlier, topographic features here restrict overland flow, capture most precipitation, and promote ground-water recharge. Consequently, surface runoff is not significant and 58 square miles appears to be reasonable for the extended basin. Precipitation over the Rifle and extended basins is equivalent to 374 cfs, 140 cfs of which leaves the basin as streamflow, and the remainder, 234 cfs, is lost through evapotranspiration. As a matter of interest, evapotranspiration losses are then 63 percent of precipitation; a rate typical to Michigan.

Other hydrologic information that helps to confirm an extended ground-water basin are data on ground-water levels. These data were used to define a map of ground-water levels as shown in figure 47. Data to the north and west are scanty; however, the general trend of the ground-water surface can be defined sufficiently to give a plausible indication as to the location of the ground-water divide for the basin. The probable location of the divide is shown on figure 48. On the basis of this delineation, the size of the basin is increased by about 55 square miles--to about 172 square miles. This compares favorably with the assessment given above and in an earlier section of this report. On the basis of these analyses, an effective drainage area of 175 square miles was established for the ground-water basin.

HOW MUCH GROUND WATER IS AVAILABLE FOR USE

How much water is available in the basin is the question that is foremost in the minds of those concerned with water supply. The answer is not always easy because it depends largely on the adequacy of data available from measurements of streamflow and from wells. In the upper Rifle River basin, measurements of streamflow are adequate for most purposes. However, data from wells are less adequate. Although there are many wells in the basin, their areal coverage is restricted and only a few penetrate the entire thickness of water-bearing material. Thus, evaluation of the available supply of ground water in the basin becomes, in part, a matter of extrapolation--using what data are available and expanding them to cover areas lacking data.

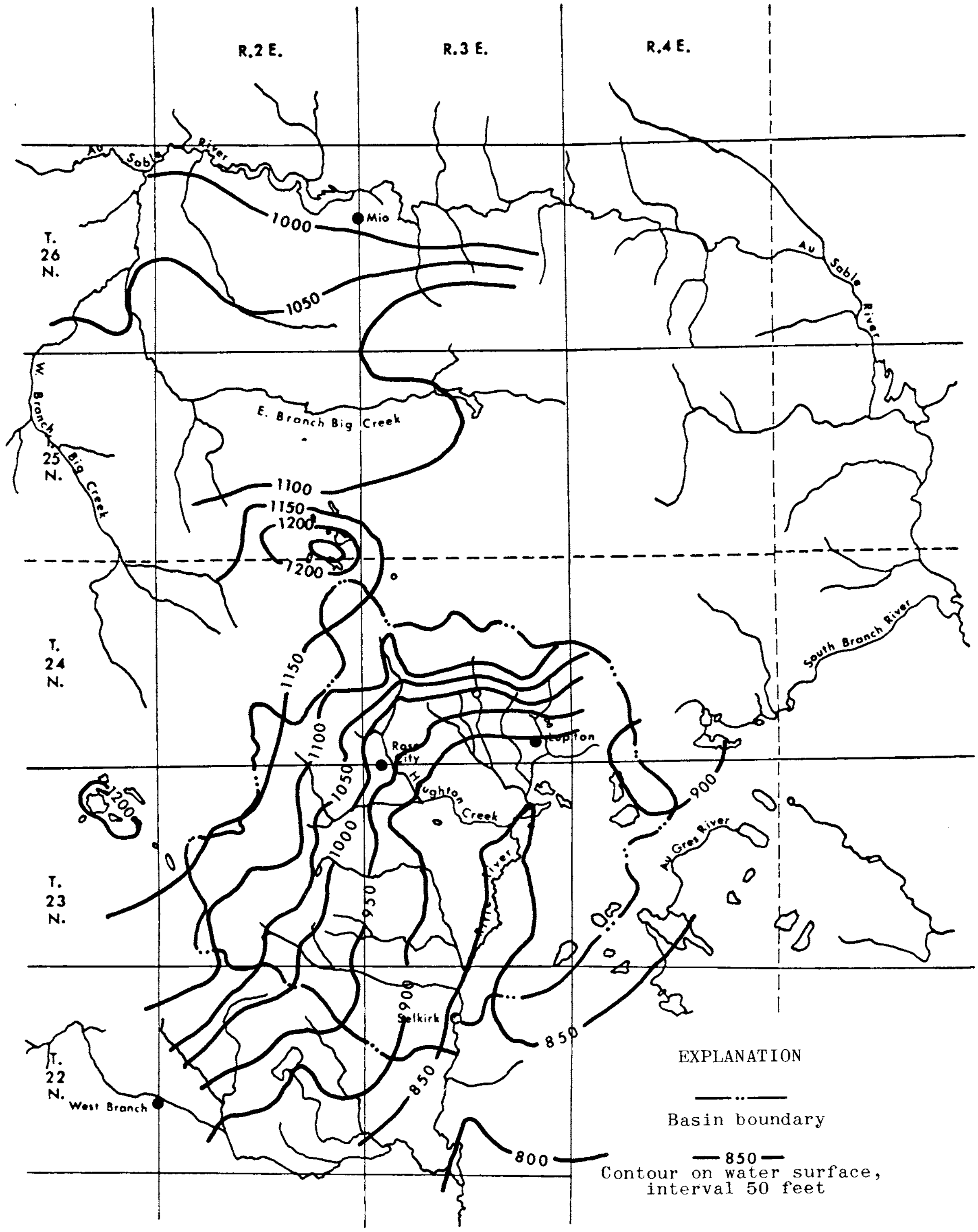


FIGURE 47.--Ground-water levels range in altitude from about 800 feet in the southern part of the basin to over 1,100 feet in the northern part.

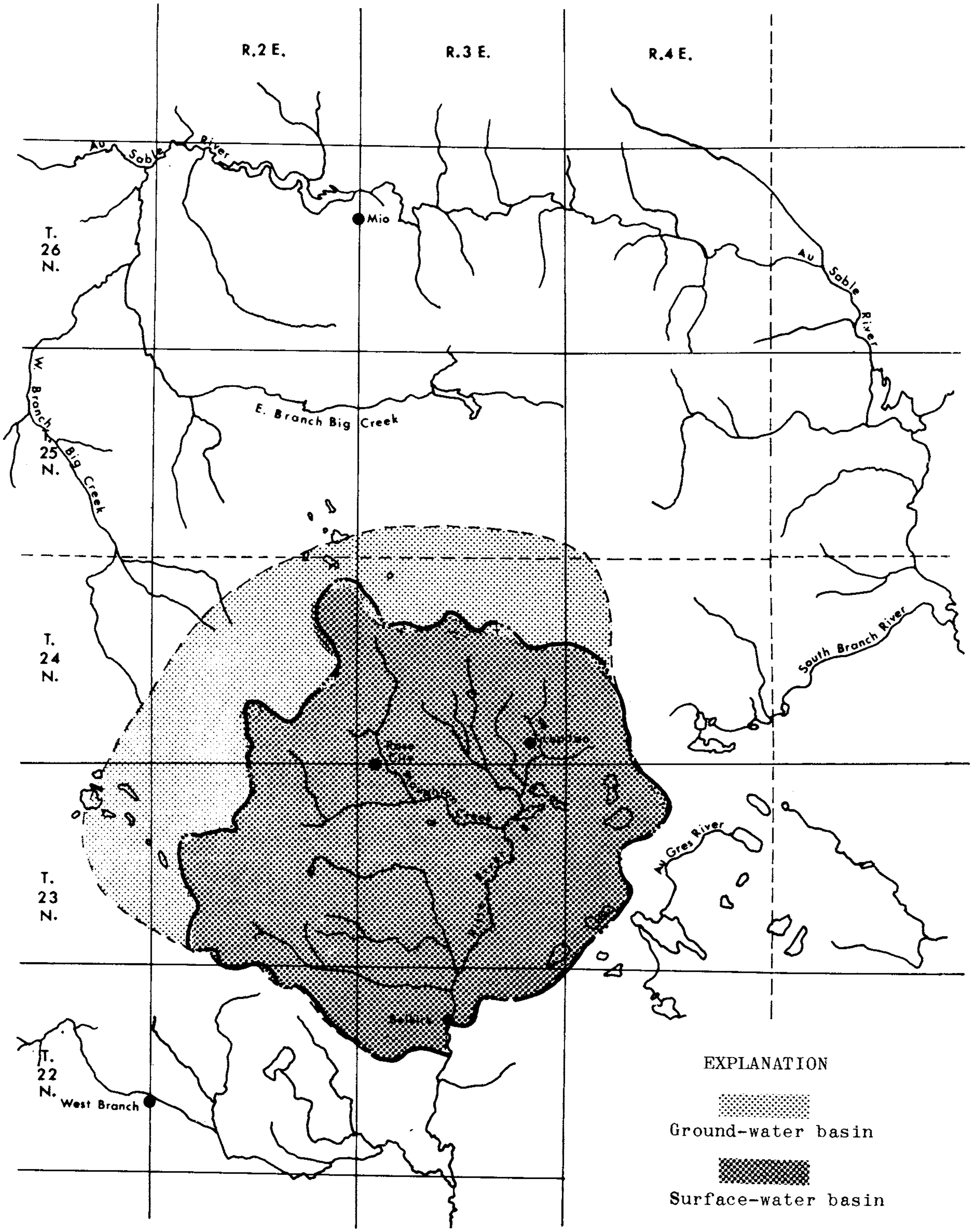


FIGURE 48.--The ground-water basin extends north and west of the surface-water basin.

Most usable ground water in the Rifle basin is stored in, moves through, and is produced from a container formed of glacial deposits. This container is limited horizontally, having an areal extent of about 175 square miles, and vertically, having a saturated thickness ranging from about 100 feet to about 400 feet (fig. 49). The volume represented by these figures is indeed large; however, not all of this volume is available for storage of water. The space available for storage within the container is restricted to the openings between particles of glacial materials--openings which commonly comprise only about 35 percent of the total volume of rock. Also, not all water in the container is available to wells. Some glacial deposits readily yield almost all the water that they hold in storage; other deposits yield little or none. An evaluation of these factors provide the basis for answering the question "How much ground water is available?"

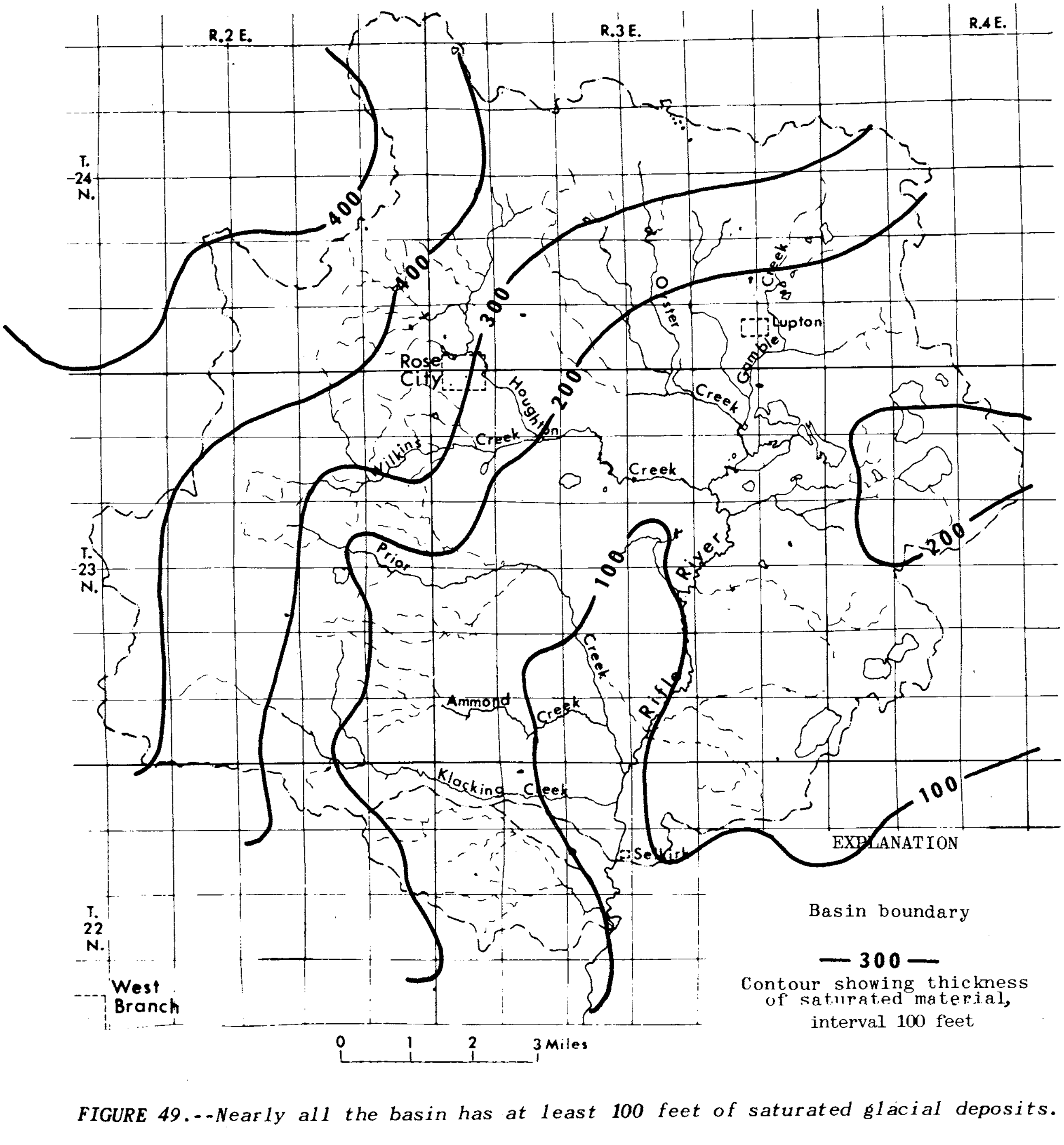


FIGURE 49.--Nearly all the basin has at least 100 feet of saturated glacial deposits.

WATER FROM OVERFLOW

At present, the ground-water container in the Rifle basin is full of water. In fact, with water added each year by recharge from precipitation, the container is overflowing. The quantity of overflow is an important consideration in evaluating the available supply of ground water in the basin.

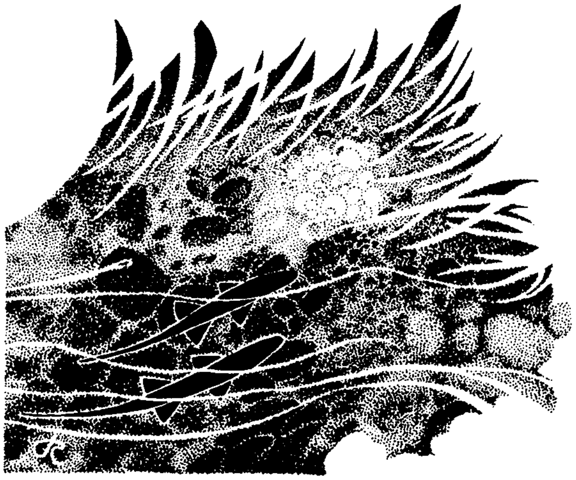
As shown previously, the base flow of streams--the overflow from the ground-water container--averages 103 cfs. This is about 46,000 gallons of water per minute or about 24 billion gallons per year--enough water to supply over 500,000 persons with at least 100 gallons of water per person per day. Much of the overflow could be captured by wells drilled in the lowland area of the basin. Such wells would capture ground water that normally discharges to streams and may induce infiltration of water from streams to ground-water reservoirs. In either event, pumping will cause a depletion of streamflow, particularly where pumped water is not returned to the streams.

WATER FROM STORAGE

A second consideration, one which increases in importance as more and more water from overflow is captured, is the water that can be produced from storage. The amount available from storage can be estimated on the basis of the *specific yield* of the glacial deposits in the area. Specific yield, which varies for different earth materials, is the ratio of the volume of water that a saturated rock will yield by gravity to the total volume of the rock. For fine-grained materials, such as clay and silt, the specific yield usually is less than 10 percent. For coarser material, such as sand and gravel, the specific yield commonly ranges between 20 and 30 percent. For the 3 classified areas shown on figure 34, the following values were assigned: clay, 2 percent; lenses of sand, gravel, and clay, 10 percent; and, sand and gravel, 20 percent. Based on these values of specific yield, and under water-table conditions, the amount of water available in storage per foot of drawdown is shown in the following table.

Area	Yield per sq.mi. per ft. drawdown in million gallons	Size area in sq.mi.	Total yield per foot drawdown in gal.
Clay	4	5	20 million
Lenses of sand, gravel and clay	20	70	1.4 billion
Sand and gravel	40	100	4.0 billion

Thus, about 5.5 billion gallons of water would be available by lowering the water table one foot throughout the entire ground-water basin. If this quantity were pumped over a 1-year period, it would supply 150,000 people with 100 gallons of water per person per day. As can be seen in figure 49, there is more than 100 feet of saturated glacial material in most of the basin totaling more than 500 billion gallons of water in storage. Although it may not be practicable to lower the water levels by 100 feet, it is significant to point out that large amounts of water are available from storage.



THE BIG PICTURE

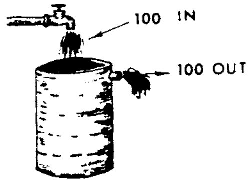
Looking at the big picture, water from overflow and from storage is sufficient to supply many people for a long time. On the basis of present population projections, it appears that no major water-supply problems will occur within the next several decades. Wise management on a basin-wide basis will assure continued high ground-water levels and flows for most wells. However, where withdrawal of ground water affects a limited area, this picture could change. This may occur in areas of heavy pumping, generally the population and industrial centers. In the upper Rifle River basin it is expected that these centers will be in the Rose City-Lupton area. If so, this is the area that probably will be the first to experience reduced flows and declining water levels. Significant reduction in flows or lowering water levels could occur in these centers without any great effect on water supplies in other parts of the basin.

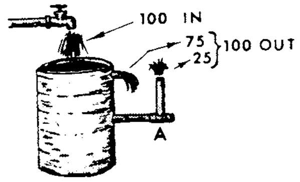
Minor changes in the water picture may occur locally because of the variable nature of the glacial materials. For example, in the Rose City area, the thick clay unit (fig. 34) may produce a problem. In this area, some wells must penetrate nearly 200 feet of clay before reaching a water-bearing formation that will produce a flow. The head, or level to which water will rise in wells, for this deep aquifer is not great, and flows often are small. If more wells are drilled in this aquifer, or if pumps are used to obtain greater volumes of water, the head will be reduced. If so, the flow from wells penetrating the aquifer will be lowered and water may cease to flow from some wells. However, pumping from this aquifer probably will not have a significant effect for any great distances laterally or on wells in shallower aquifers.

A similar situation may occur in areas comprised of lenses of sand, gravel, and clay. Here, shallow aquifers that could yield sufficient water to supply a few households may be too thin or too limited in areal extent, to yield the quantity of water necessary to supply larger developments. When too many wells penetrate an aquifer, a situation resembling that in figure 50 may occur. Wells in the shallower part of the aquifer will be affected first. Eventually all wells draining the aquifer will be affected--water levels will drop and flows will be greatly reduced or may cease.

You'll never miss the water until the well runs dry.

A BUCKET FULL OF WATER

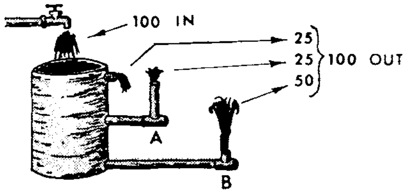




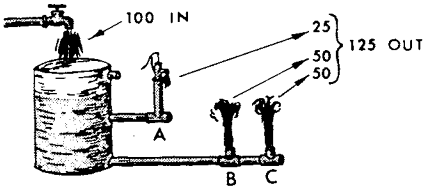
Let's look at it this way. Before development the bucket is full of water. Every month 100 units of water are added from precipitation and every month 100 units flow out as overflow. Upon development, outlet A is added to the bucket--every month this outlet utilizes 25 units of water. The quantity of overflow is reduced as shown. Subsequently outlet B is added--50 units of water flow from this outlet. Again a reduction in the quantity of water discharging as overflow. Eventually outlet C, which also discharges 50 units every month, is added. This is the turning point in the system.

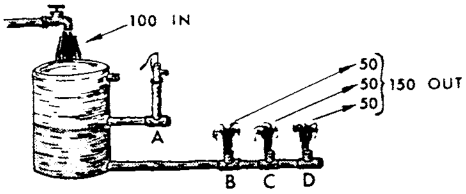
CAN BECOME

Water no longer overflows outlet A. To obtain the desired quantity of water from outlet A, water has to be pumped from storage. Soon the water level in the bucket begins to decline.



Although a predictable shadow is being cast over the system, things are normal at outlets B and C--the water flows on. Now outlet D is added. This outlet initially discharges 50 units. The combined flow from the three outlets is 150 units every month; 50 more units than are being added. The water level in the bucket drops rapidly. In a short time, outlet A can get no water by pumping and the pressures and flow at the other outlets begin to decline.





AN EMPTY BUCKET

Finally the flow from outlets B, C, and D is only about 33 units. Pumps are installed at outlets B and C to obtain the 50 units needed to operate efficiently. This stops the flow of outlet D so a pump is added here also. However, water is not available to supply all 3 outlets with 50 units each. The predictable shadow has spread over the entire system. There is no flow and water is difficult to obtain even by pumping.

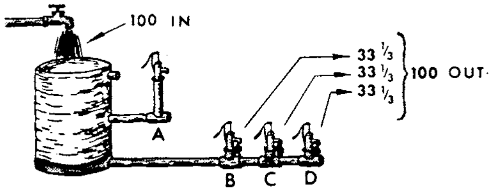


FIGURE 50.--Overdevelopment of an aquifer will result in a reduction in water levels and in the available supply of water.

WATER--ITS CHEMICAL AND PHYSICAL PROPERTIES

Water, as shown in the preceding sections, is a dynamic resource, a resource always on the move--sometimes quiet and comforting, at other times restless and troublesome. However, these are not its only features. Water is also at work in another way. As a chemically active liquid--one able to dissolve more substances than any other liquid--water reacts with nearly everything in which it comes in contact. Falling through the atmosphere water reacts with gases, dust, and other particles. On land and beneath the land, water dissolves minerals from the earth (fig. 51). The nature and amount of minerals dissolved through these contacts dictate the water's chemical quality. An understanding of the chemical quality of water along with its physical properties provides answers to questions regarding water's suitability for an intended use.

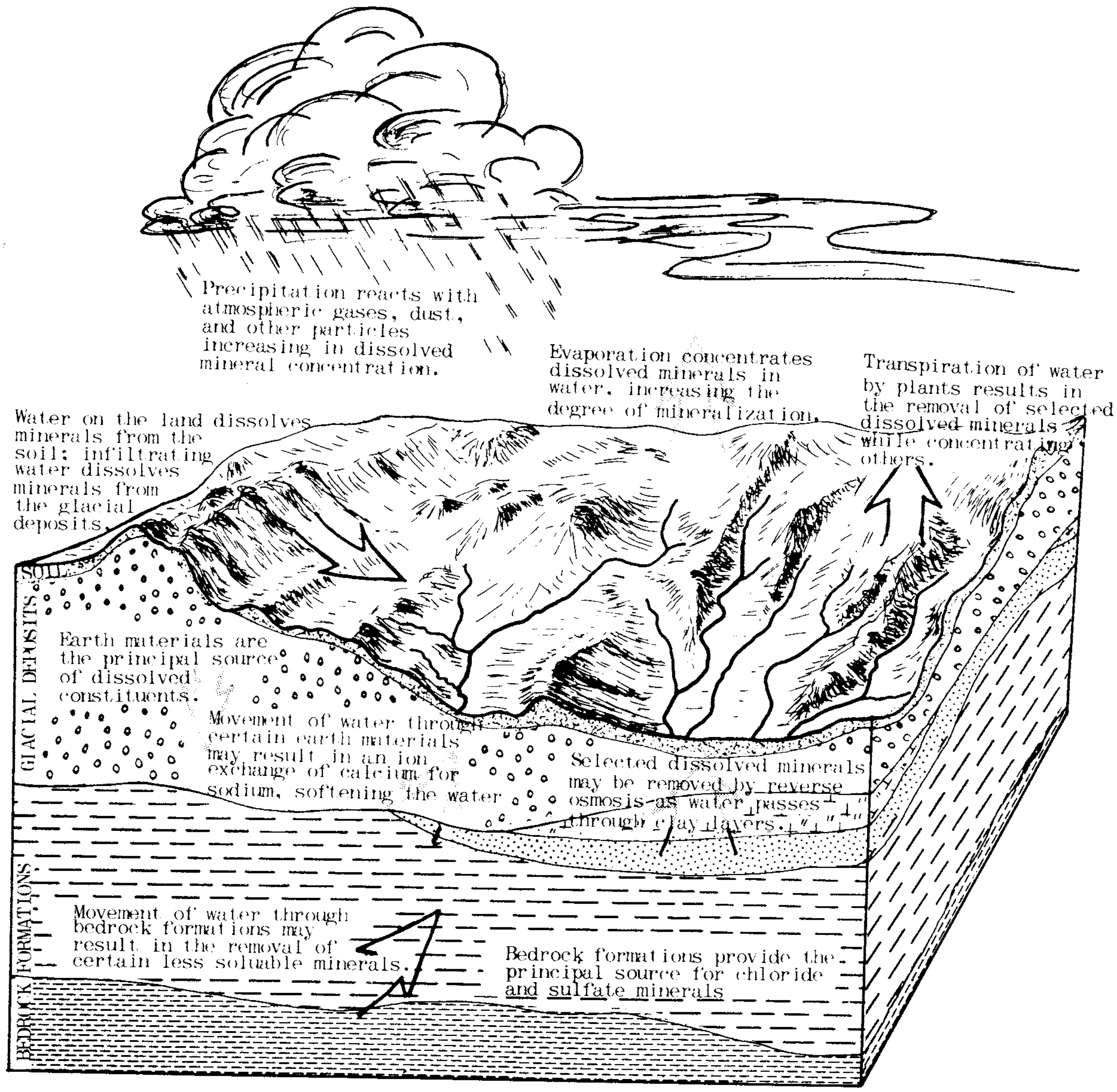


FIGURE 51.--The chemical quality of water from wells, streams, or lakes is the result of many chemical processes.

TABLE 5.--Representative analyses of dissolved constituents in ground water.

Aquifer sampled: Qgd, Quaternary glacial drift; Mm, Marshall Formation of Mississippian age. Analyses by field methods, chemical constituents in milligrams per liter. See figure 52 for location of wells.

Well No.	Aquifer	Depth (ft)	Date Sampled	Iron	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hardness as $CaCO_3$ carbonate	Hardness as $CaCO_3$ noncarbonate	Specific conductance (micromhos at 25°C)	Dissolved solids (calculated)	pH	Temperature (°C)
1	Qgd	108	10-16-69	0.00	241	8	0.5	0.3	196	0	365	237	7.8	--
2	Qgd	48	6-20-69	.05	229	41	1.2	.1	213	25	390	252	7.8	--
3	--	--	5- 1-69	.05	217	550	10	.0	744	566	1280	833	7.3	8.0
4	Qgd	42	5- 1-69	.30	246	12	.5	.1	202	0	390	254	7.7	5.0
5*	Qgd	--	5- 1-69	.32	226	11	.5	.4	178	0	345	225	7.8	8.5
6	Qgd	219	6-19-69	.20	200	13	3.0	2.4	188	14	346	224	8.4	--
7	Mm	--	9- 9-68	.81	166	1460	52	--	1672	1536	2400	1560	7.3	--
8	Qgd	176	9- 9-68	.20	196	10	9.0	--	156	0	325	210	8.0	--
9	Mm	170	6-20-69	2.2	217	1350	7.5	2.9	1664	1486	2400	1560	7.3	--
10	Qgd	84	10-15-69	1.0	428	7	1.0	1.1	322	0	600	390	7.8	--
11	Qgd	27	10-15-69	.00	83	14	20	37	128	60	300	195	8.2	--
12	Qgd	40	10-16-69	.00	351	48	31	5.3	396	108	745	484	8.0	--
13	Qgd	45	6-20-69	.05	300	30	2.3	.1	266	21	470	306	7.9	--
14	Qgd	53	6-20-69	.05	372	16	.8	.2	302	0	520	338	7.6	--
15	Qgd	--	9-29-69	--	188	9	.5	.2	160	6	310	201	8.2	--
16	Qgd	105	6-19-69	.50	238	13	1.0	.1	246	202	384	246	7.9	--
17	Qgd	182	6-18-69	--	192	12	.0	.3	178	10	323	214	8.5	--
18	Qgd	90	5- 1-69	.50	222	110	3.0	.0	260	80	570	370	7.6	8.0

* Geroy Springs

TABLE 6.--Representative analyses of dissolved constituents in surface water.

Samples collected October 31, 1968, analyses by field methods, concentrations in milligrams per liter except as noted. See figure 52 for location of stream.

Station number	Stream	Location	Drainage area (sq. mi.)	Dis-charge (cfs)	Bicar-bonate (HCO_3)	Carbon-ate (CO_3)	Sul-fate (SO_4)	Chlo-ride (Cl)	Nitr-ate (NO_3)	Phos-phate (PO_4)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	Dissolved solids (calculated)	pH	Temper-ature (°C)	Color (Hazen units)	Tur-bity
											carbon-ate	noncar-bonate						
Base - flow conditions, streams at low flow																		
1386.00	Gamble Creek	SW¼ sec.36, T.24 N., R.3 E.	9.74	9.36	265	0	14	3.0	0.8	0.06	266	9	440	286	8.1	5.0	8	0
1386.10	Vaughn Creek	SW¼ sec.35, T.24 N., R.3 E.	3.55	6.61	260	0	16	3.0	1.0	.09	224	11	430	280	8.2	4.0	15	0
1386.20	Oyster Creek	SW¼ sec.27, T.24 N., R.3 E.	3.10	2.30	258	0	11	2.0	.5	.04	216	4	420	273	8.1	4.5	10	1
1386.55	Gamble Creek	NE¼ sec.11, T.23 N., R.3 E.	--	24.9	263	0	28	3.0	1.2	.02	235	19	450	293	8.2	4.0	15	5
1386.90	Houghton Creek	NE¼ sec.31, T.24 N., R.3 E.	8.74	7.82	240	0	9.0	3.0	.4	.04	200	3	380	247	8.2	4.0	0	0
1388.10	Houghton Creek	NE¼ sec.6, T.23 N., R.3 E.	14.1	20.1	224	0	7.0	4.0	1.4	.09	189	5	365	238	8.2	5.5	0	0
1389.30	Wilkins Creek	NW¼ sec.8, T.23 N., R.3 E.	11.1	17.9	229	0	7.0	8.0	.9	.03	190	2	380	247	8.2	5.5	20	10
1390.00	Houghton Creek	SE¼ sec.10, T.23 N., R.3 E.	29.7	40.6	232	0	17	6.0	.3	.03	201	11	400	260	8.2	4.0	20	0
1395.00	Rifle River	SW¼ sec.11, T.23 N., R.3 E.	56.8	72.4	246	0	23	5.0	.9	.07	218	16	425	276	8.2	3.9	20	0
1395.10	Skunk Creek	NE¼ sec.14, T.23 N., R.3 E.	8.31	.74	226	0	4.0	3.0	1.5	.04	190	5	375	244	7.8	5.0	55	5
1396.00	Rifle River	SE¼ sec.27, T.23 N., R.3 E.	76.7	76.5	242	4	25	5.0	1.0	.06	216	18	415	270	8.4	4.0	20	0
1396.70	Prior Creek	NW¼ sec.24, T.23 N., R.2 E.	3.51	4.25	227	0	3.0	2.0	.2	.06	186	0	365	237	8.0	7.0	10	0
1398.70	Bailer Creek	NW¼ sec.20, T.23 N., R.3 E.	5.55	.52	214	0	11	10	2.4	.03	188	12	385	250	8.1	6.0	80	10
1398.80	Prior Creek	SW¼ sec.21, T.23 N., R.2 E.	14.9	7.06	254	0	6.0	5.0	.8	.06	210	2	400	260	8.2	7.0	15	0
1399.00	Ammond Creek	NW¼ sec.32, T.23 N., R.3 E.	3.10	1.96	282	0	8.0	5.0	.8	.04	232	1	445	290	8.2	6.0	25	0
1400.00	Prior Creek	SE¼ sec.33, T.23 N., R.3 E.	21.4	9.69	264	0	19	7.0	1.3	.04	228	12	460	295	8.2	6.0	15	0
1404.00	Klacking Creek	SE¼ sec.4, T.22 N., R.3 E.	9.95	14.0	243	0	48	2.5	.4	.07	237	38	460	295	8.2	4.0	0	0
1405.00	Rifle River	NE¼ sec.9, T.22 N., R.3 E.	117	98.9	241	0	30	5.0	1.6	.06	220	22	440	286	8.2	4.4	35	2
Streams at high flow																		
		Date of Collection																
1390.00	Houghton Creek	April 17, 1967	29.7	169	149	2	24	4.0	--	--	150	24	289	188	8.3	8.3	--	--
1395.00	Rifle River	April 17, 1967	56.8	282	158	0	32	2.0	--	--	162	32	308	200	7.7	8.3	--	--
1400.00	Prior Creek	March 29, 1967	21.4	169	106	0	32	4.0	--	--	118	31	248	161	7.6	.6	--	--
1405.00	Rifle River	March 29, 1967	117	773	140	0	29	5.0	--	--	141	26	285	185	8.0	2.2	--	--

CHEMICAL PROPERTIES

The single phrase which best describes the chemical character of water in the upper Rifle River basin is that "the water is good." It is good for drinking and cooking; watering of crops; swimming, fishing, and boating; washing clothes and cars; most industrial and commercial needs; and many other uses. However, the term good does not indicate the water's chemical makeup and consequently does not define the water's suitability for a particular use. Answers to this type of problem can be attained only by defining the amount and type of chemical constituents in water.

The chemical constituents in water from wells and streams are given in tables 5 and 6, respectively. Locations of the sampling sites are shown on figure 52. Under natural conditions, the chemical properties of ground water remain fairly uniform through time. The quality of water in streams, however, varies somewhat depending upon whether the water is derived principally from ground-water sources or from overland runoff. In general, concentrations of dissolved constituents are higher during periods of base flow (predominately ground-water runoff) than during periods of high flow (predominately surface runoff). This difference reflects the fact that the ground water has been in contact with soluble earth materials for longer periods of time. Also, that it has taken different paths and has come into contact with a variety of chemical environments. Therefore, most samples obtained from streams for quality analysis were collected during a base-flow period. The resultant analyses indicate the upper range of dissolved constituents and define the chemical properties of streams at their more critical quality level.

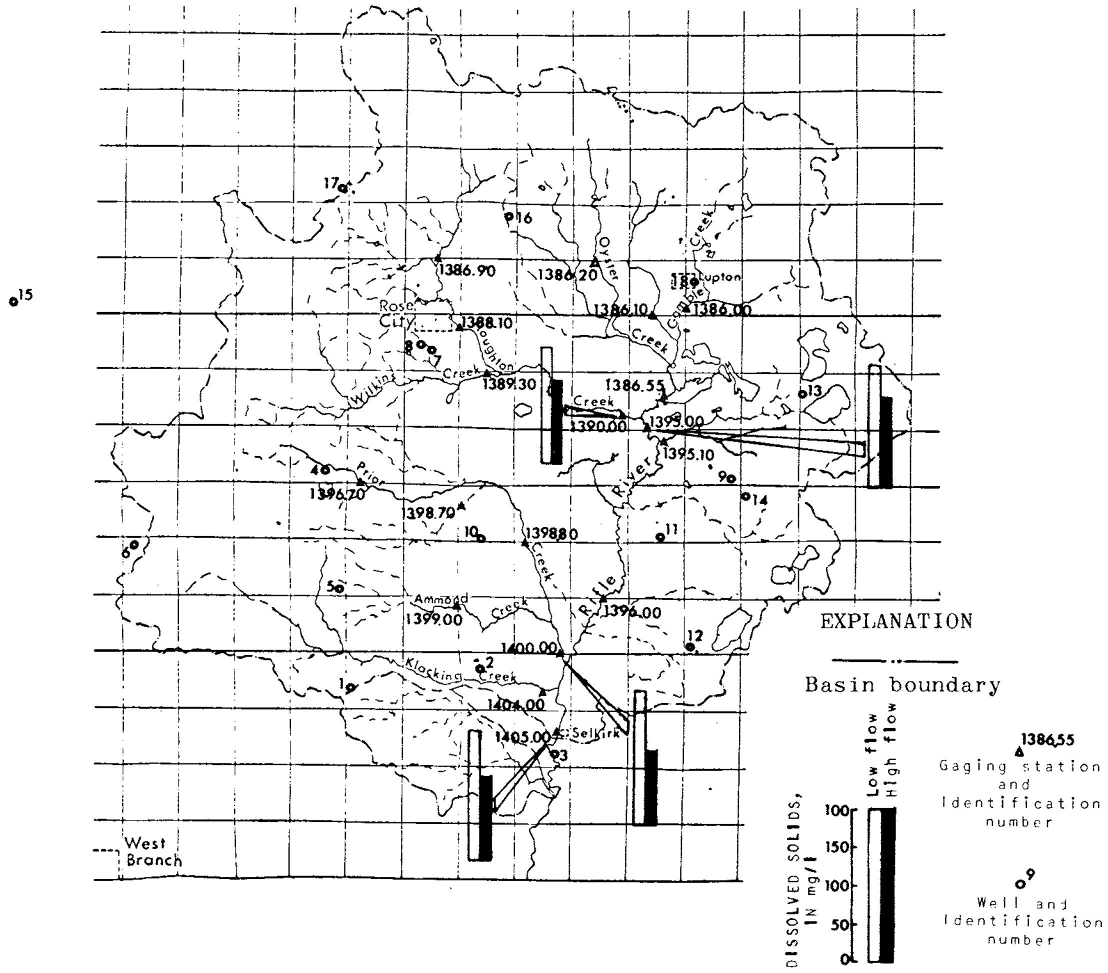


FIGURE 52.--Streams at low flow have higher concentrations of dissolved constituents than at high flow.

Some samples from streams (analyses shown in table 6 and in figure 52) were collected during a period of high flow to compare quality during different discharges. As shown, the concentration of most dissolved constituents is lower during periods of high flow.

Evaluating the concentration of the various chemical constituents in surface and ground water provides an understanding of the quality of water and water movement. Figures 53 and 54 show total concentrations of dissolved solids and give an overall picture of water quality in the basin. As can be seen, water from streams and glacial deposits has a lower dissolved-solids concentration in the western part of the basin than in the eastern part. This pattern is produced by several factors, factors such as thickness and composition of the glacial deposits, configuration of the bedrock surface, location of recharge areas relative to sampling sites, length of time water has been in ground, and composition of the bedrock. Of these, the composition of the glacial deposits and bedrock probably is the most influential because these materials are the source of most dissolved solids. Sand and gravel in glacial deposits, such as those on the western side of the basin (fig. 34), do

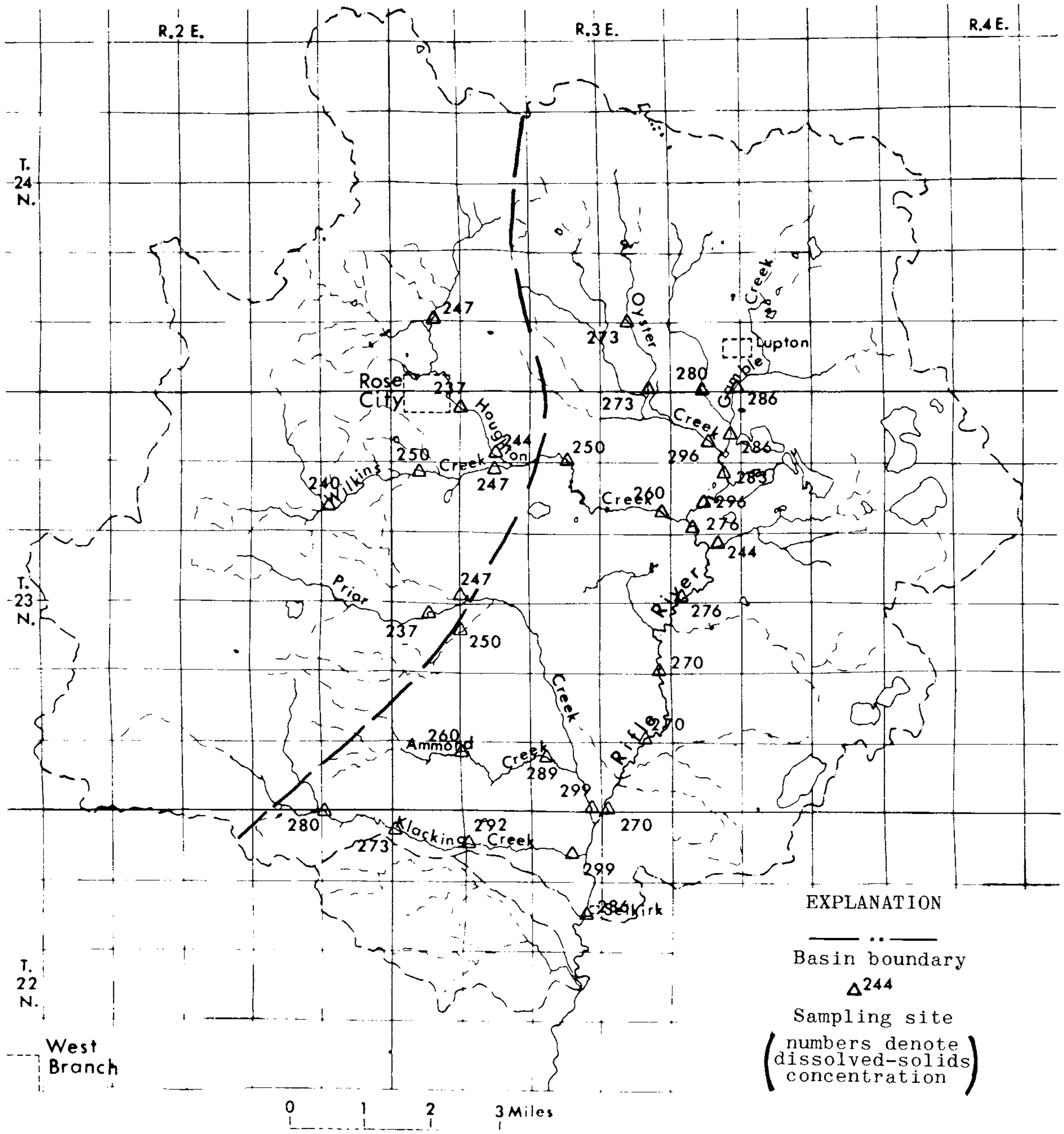


FIGURE 53.--Water from streams in the western part of the basin is generally lower in dissolved-solids concentration than in the eastern part.

not readily yield to solution. Water moving through these deposits dissolves only small quantities of solids. However, clay lenses in the central and eastern parts of the basin contain minerals that can be taken into solution rather easily. Therefore, water that has come in contact with these lenses often contains larger quantities of dissolved solids. Partly because of this factor, water in the central and eastern parts of the basin has the higher dissolved-solids concentration.

In addition to changes that occur as water moves through glacial deposits, there are the changes produced by materials in bedrock. In general, water in bedrock has a high dissolved-solids concentration, often higher than 1500 mg/l (table 5). Some of this water moves from the bedrock into the overlying glacial deposits, mixes with the water in these deposits, and is diluted. Because of mixing and dilution, wells in glacial deposits that capture water from shallow depths will yield water lower in dissolved solids than a deeper well at the same site. Because glacial deposits are relatively thin in the central and eastern parts of the basin, water from wells here generally have a higher dissolved-solids

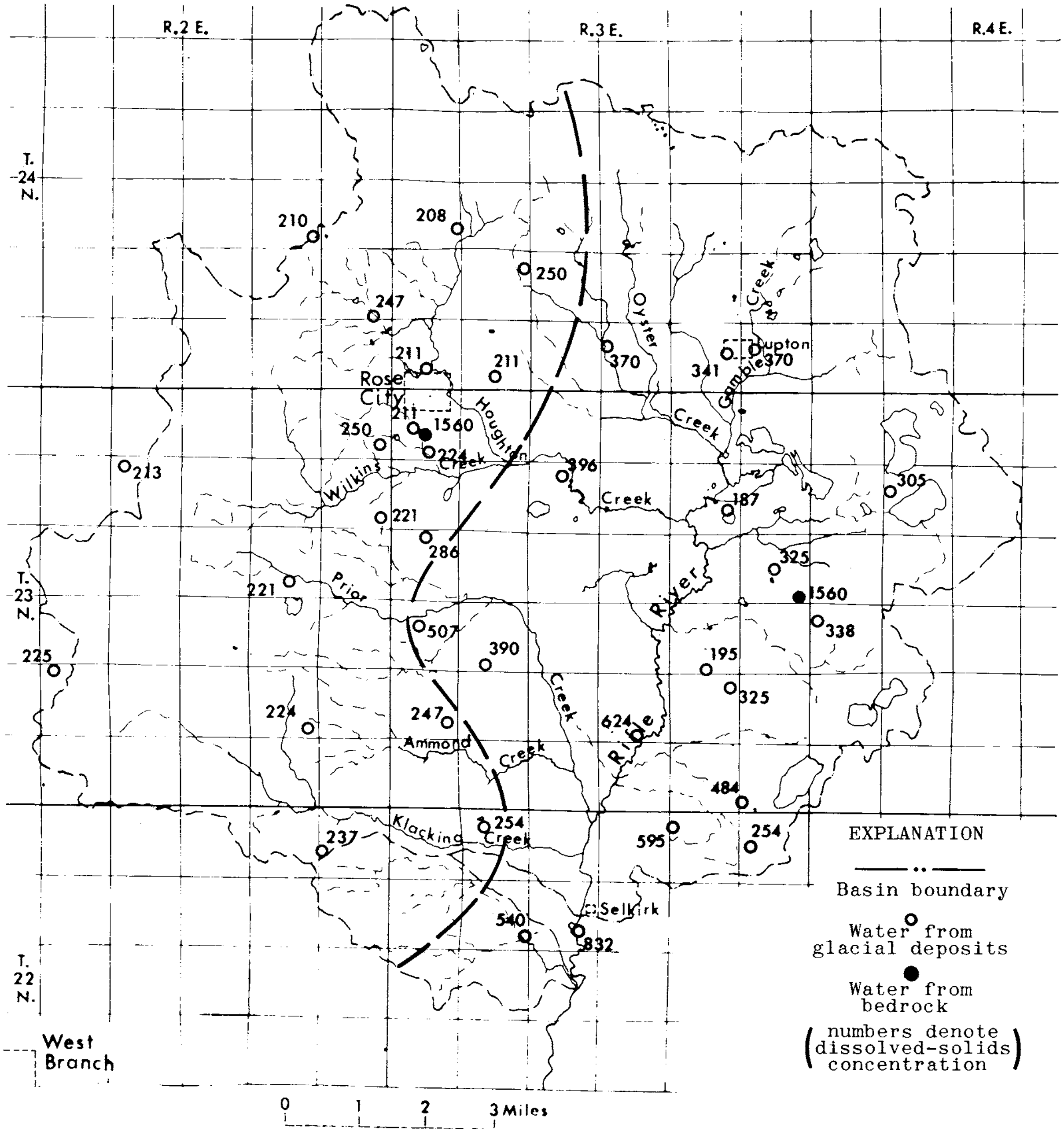


FIGURE 54.--Water from wells in glacial deposits in the western part of the basin is generally lower in dissolved-solids concentration than in the eastern part.

content than water from wells of similar depth in the northern and western parts. The thickness of glacial deposits also affects the dissolved-solids content of water in streams; however, the relationship is generally more subdued.

An effect of bedrock on the quality of water in streams in the Rifle basin is demonstrated by the distribution of chloride and sulfate ions. Streams in the central part of the basin generally have a higher chloride content (fig. 55) whereas, streams in the southern and eastern parts have a higher sulfate content (fig. 56). These differences reflect the nature of the bedrock (fig. 57). Shales containing soluble chloride minerals predominate in the west-central part of the basin; whereas, limestone and sandstone containing soluble sulfate minerals predominate in the southern and eastern parts. Although differences in concentrations are not great, the influence of the bedrock formations can be recognized.

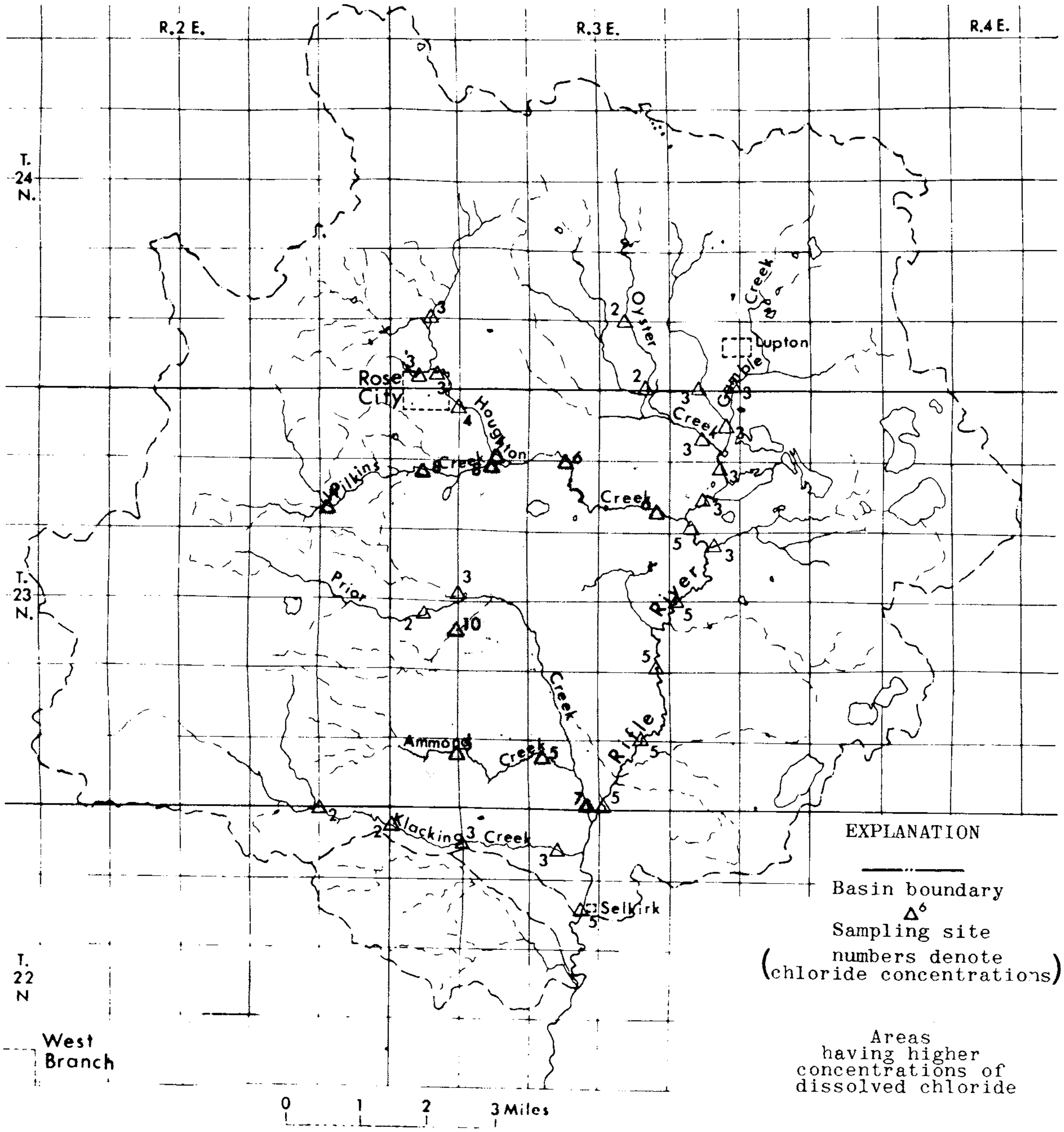


FIGURE 55.--Streams in the central part of the basin have higher concentrations of chloride, reflecting the effect of shales in the bedrock formations of this area.

It should be pointed out that the above relationships are generalizations and that there are anomalies or exceptions to the general patterns. Some of these anomalies reflect changes in the shape of the bedrock surface, the influence of one stream upon another, deflections in ground-water flow paths due to lenses of impermeable material, and numerous other causes. Some causes can be explained reasonably well with present data; others require additional data. Explaining each anamoly would not add significantly to an understanding of the basin's overall water-resources picture and thus, is considered to be beyond the scope of this report.

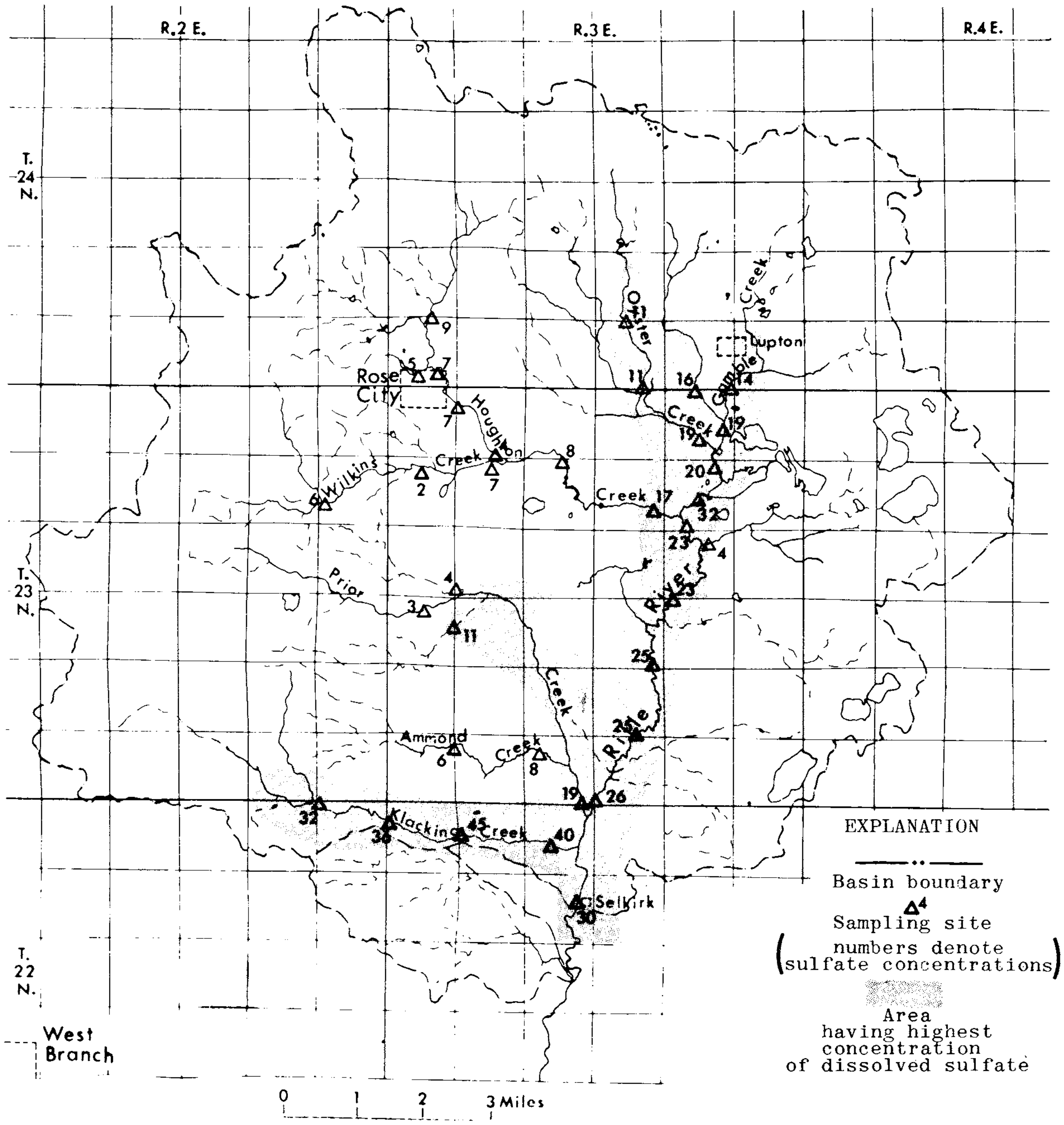


FIGURE 56.--Streams in the south and eastern parts of the basin have higher concentrations of sulfate reflecting the effect of limestone and gypsum in the bedrock formations of these areas.

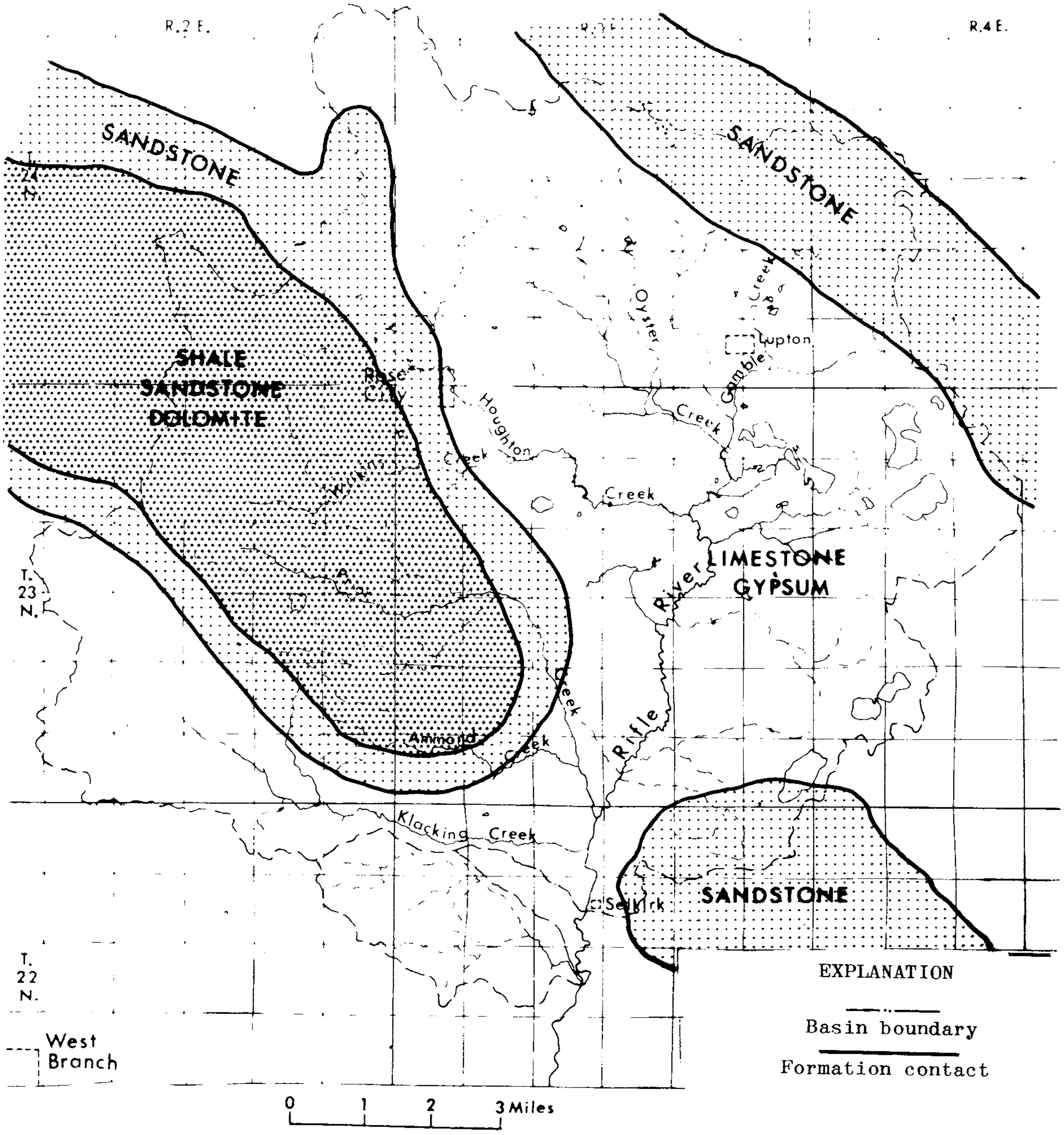


FIGURE 57.--The distribution of the chemical constituents depicted in figures 55 and 56 is a reflection of the nature of the bedrock.

PHYSICAL PROPERTIES

The physical properties of water that are of greatest concern are color, taste, odor, suspended solids, and temperature. These properties are readily perceptible. Everyone can tell if water is clear or dirty, whether or not it has a taste or odor, and if it is hot or cold. Those familiar with the water in the upper Rifle River basin know that natural waters, both ground and surface waters, generally are of good quality. Because these waters are of good quality, temperature was the only physical property measured as part of this study. This was done to determine the relationship between base-flow discharge of streams and stream temperature, to demonstrate the interrelationship between ground water and surface water, and to determine whether stream and watershed improvement work done in the early 1950's by the Michigan Department of Natural Resources had affected stream temperatures. To accomplish this, continuous records of temperature were obtained at 4 stations (figure 52, stations 1390.00, 1395.00, 1400.00, and 1405.00) and periodic measurements were made at numerous other sites.

Temperature characteristics of lakes and streams are recognized by most fisherman, swimmers, campers, and others who enjoy these water resources. Fishermen often seek out cold reaches of a stream knowing that fish may congregate here during hot weather; swimmers react to sudden changes in water temperature and seek out those spots that are most comfortable; and campers and others often utilize a spring or a reach of stream as cooling media. Each use or response reflects the influence of ground-water inflow on stream temperature. That is, if there are substantial avenues of ground water escape to streams, base-flow discharge of streams will be high and, because ground-water temperatures are comparatively cool during the summer time, stream temperatures also will be cool.

A relationship between streamflow and stream temperature for the Rifle basin is shown in figure 58. Although the data show some scatter caused by the many factors which affect stream temperature, the relationship is evident. The curve delineating the relation is relatively flat indicating that most streams receive large amounts of ground water and have similar temperature characteristics. Additional evidence of ground-water inflow is found in the fact that many streams have temperatures that are approximately the same as those of ground water, about 8 to 10° Celsius (centigrade).

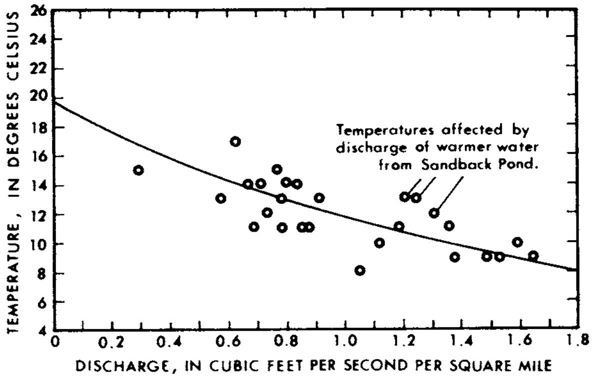
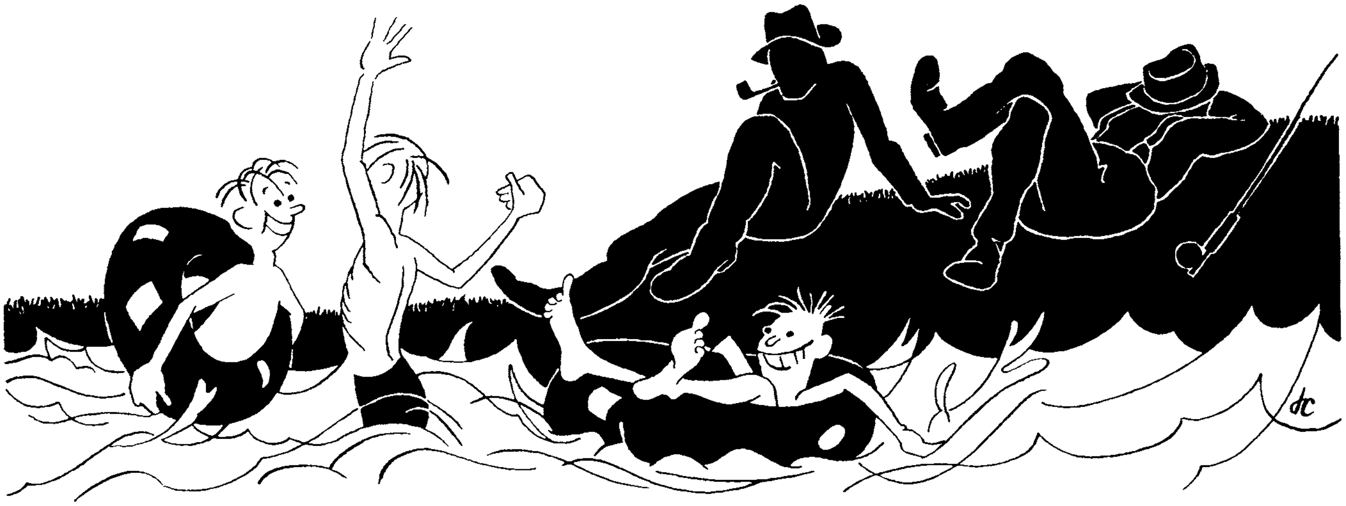


FIGURE 58.--Streams having higher base-flow discharge generally have lower summer temperatures. Relationship shown defined by measurements made during base-flow investigation of August 29, 1968.



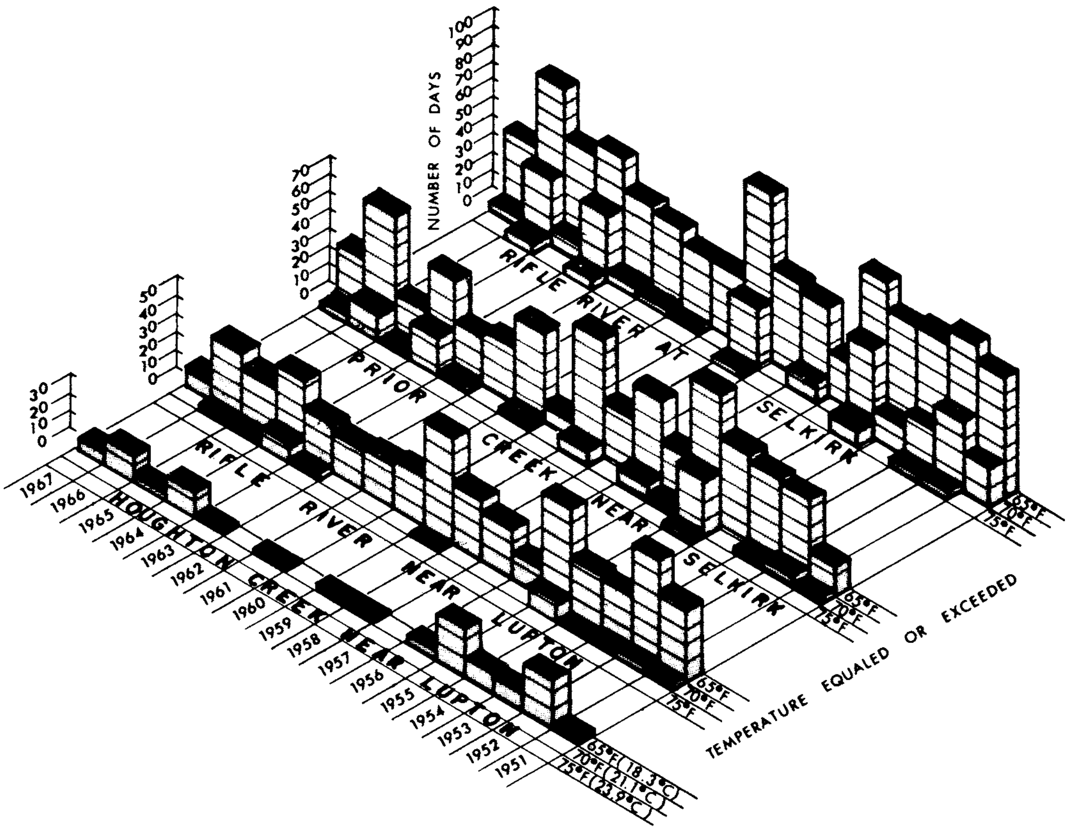


FIGURE 59.--Houghton Creek has fewer days with water temperatures exceeding 65°F (18.3°C) than Rifle River or Prior Creek.

The influence of ground-water inflow on stream temperature also is reflected in the number of days that temperatures exceed certain limits. This type of data is presented for four gaging stations in figure 59. As shown, stations on Rifle River and Prior Creek have temperatures that frequently exceed 70°F (21.1°C)--temperatures above the maximum limit recommended by the Michigan Department of Natural Resources for intolerant fish (cold-water species). Houghton Creek receives more ground water per unit area and its temperatures remain below 70°F; only occasionally do they exceed 65°F (18.3°C). Records of temperature were obtained throughout the basin during the period July 9 to Sept. 12, 1951. Maximum recorded temperatures during this period are shown on figure 60. Also shown are the areas of high base-flow discharge. As can be seen, where base discharges are high, stream temperatures often are low. This is not true in all places because other factors sometimes mask the effect of ground-water discharge. Note the effect of Sandback Creek at Rose City on Houghton Creek. Discharge of warm water from Sandback Pond increases the temperature of water in Houghton Creek.

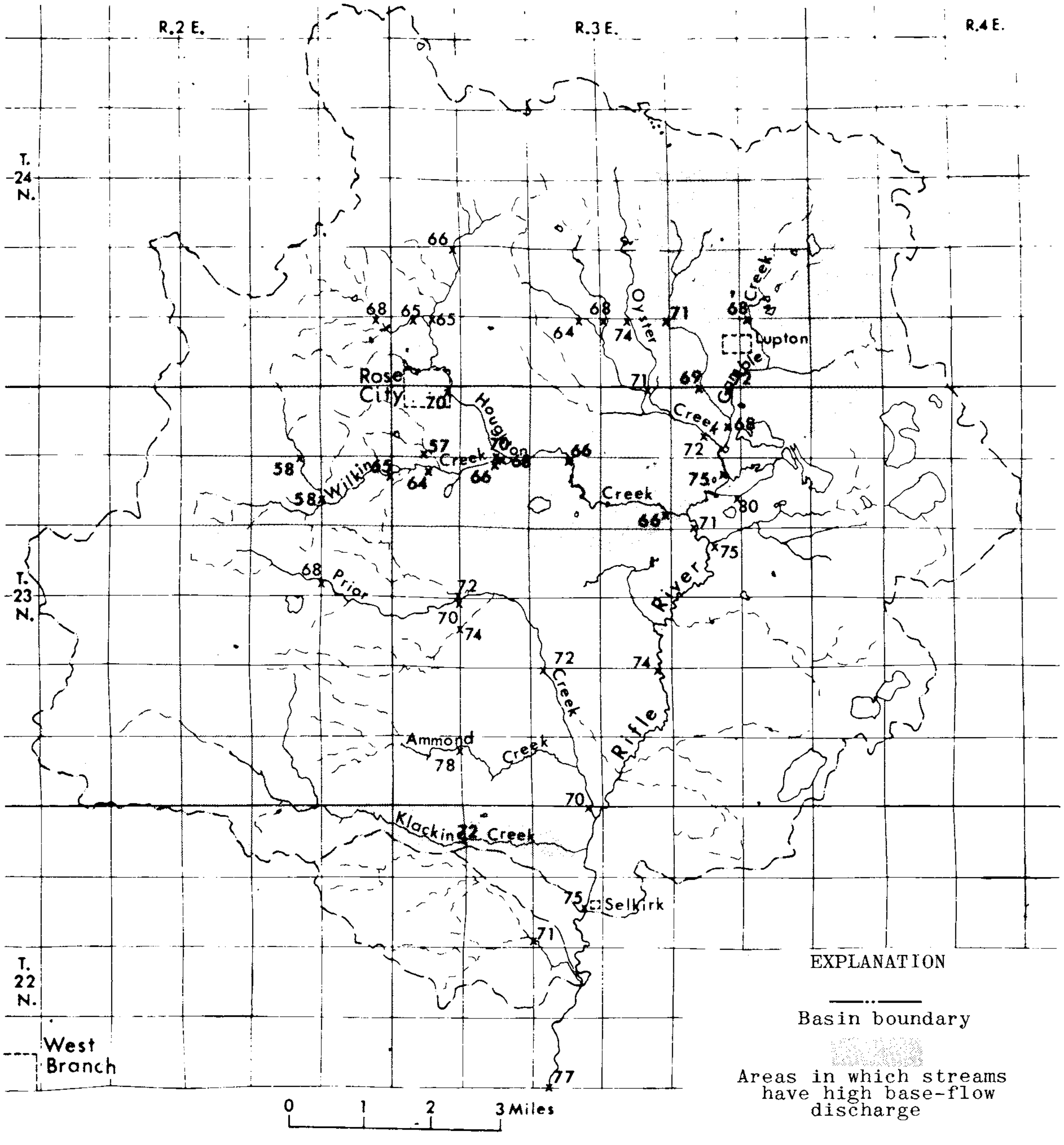


FIGURE 60.--Maximum stream temperatures during the period July 9 to September 12, 1951 ranged from 58°F (14.4°C) to 88°F (31.1°C).

Another factor commonly recognized is that some streams remain ice free during the winter, whereas, others freeze over. Those streams that remain open generally have large contributions to their discharge from ground water--water that is several degrees above freezing temperature (fig. 61). It is only after water has flowed in a stream for some time that it cools sufficiently to freeze. For example, Houghton Creek, a tributary to the Rifle River, is in an area of large ground-water inflow; hence, it contains warmer water during the winter and remains relatively free of ice. The Rifle River, however, is outside the principal area of ground-water inflow, thus, the water has an opportunity to cool and freeze.

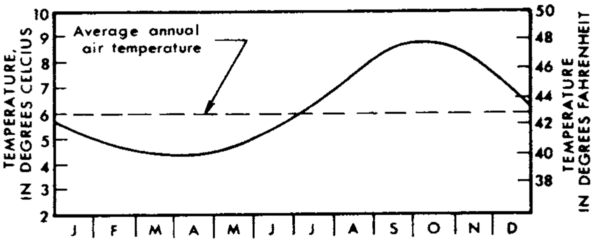


FIGURE 61.--In shallow wells, temperatures fluctuate several degrees each year. Graph shown is for well 23 miles west of Rose City (depth of well 12 feet).

In general, streams having large contributions of ground water, such as Houghton Creek, have lower summer temperatures and higher winter temperatures. Conversely, streams receiving small amounts of ground-water inflow have high summer temperatures and freeze more readily during the winter. In effect, the *ground-water stream* has a smaller range in temperature--an important consideration for many water users.

Temperatures of ground water are important also to water managers. As mentioned above, most ground-water temperatures are between 8° and 10°C and are uniform throughout the year. This is true principally for deeper wells. In shallow wells, temperatures fluctuate several degrees each year (fig. 61) and have an annual average temperature that is close to the average annual air temperature, or about 43°F (6°C). Fluctuations in temperature become less as the depth to water increases--below about 60 feet there are no fluctuations. However, based on records for other wells in Michigan, temperatures at these greater depths increase at a rate of 1.8°F (1°C) for every 100 feet of well depth. Thus, water from a well about 300 feet deep will have a temperature of about 48°F (8.9°C).

Analyses of temperature data at the four gaging stations mentioned previously indicate that reforestation, stream bank and channel stabilization, and other watershed management work has had little effect on stream temperatures. Monthly average temperatures remain essentially unaffected; however, it is possible that maximum temperatures may have been lowered somewhat. Also, it is possible that select reaches of streams may have benefited by reduced temperatures. Although stream temperatures do not appear to have been significantly affected by stream improvement practices, other benefits have been derived from these efforts.

SOURCE, SIGNIFICANCE, AND STANDARDS

The chemical and physical characteristics which define the nature of water's quality also define the purpose for which the water can be used. Clear water is necessary for drinking and bathing. Cool water is necessary for raising trout. Highly mineralized water may be an asset for certain industrial uses but will be unsuitable for domestic use. As such, quantitative expressions of dissolved constituents and temperature characteristics of water, as described in the preceding sections, are useful principally as they relate to an intended use. For a meaningful assessment of water's quality, it is therefore necessary to define the significance of the ions in solution and the limits of concentration or standards established for them.

Water dissolves and contains most of the known chemical elements of the earth, however, concentration of most elements are in trace amounts. Ions listed in tables 5 and 6 represent about 99 percent of the total dissolved constituents in water in the basin--constituents that have a practical bearing on the value of water for most purposes. Their source and significance are given in table 7. Also shown in table 7 are the maximum recommended concentrations for selected ions as established by the U. S. Public Health Service (1962).

TABLE 7.--The source and significance of the principal constituents in water in the upper Rifle River basin.

Parameter	Maximum recommended concentration[1]	Source	Significance
Iron (Fe)	0.3 mg/1	Iron bearing minerals in most formations	Adds a brownish stain to porcelain, laundered goods, etc.; imparts a bitter taste.
Bicarbonate (HCO_3) and Carbonate (CO_3)	--	Carbon dioxide and carbonate minerals such as limestone and dolomite.	Raises the alkalinity and pH of water; in combination with calcium and magnesium causes carbonate hardness and scale; releases corrosive carbon dioxide gas on heating.
Sulfate (SO_4)	250 mg/1	Shales and gypsum, oxidation of sulfides.	Commonly has a laxative effect with concentrations of 600 to 1000 mg/1, particularly when associated with magnesium or sodium; with calcium forms hard scale in boilers; causes bitter taste.
Chloride (Cl)	250 mg/1	Nearly all soils and rocks.	Imparts, a salty taste; with calcium and magnesium may increase the corrosive activity of water.
Nitrate (NO_3)	45 mg/1	Nitrate fertilizers, organic matter, and sewage.	Causes methemoglobinemia or infant cyanosis; encourages growth of algae and other organisms.
Phosphate (PO_4)	--	Detergents, phosphate fertilizers, organic wastes.	Encourages plant growth.
Hardness (as $CaCO_3$)	--	Alkaline earth minerals.	Affects the lathering ability of soap; generally objectionable for domestic use at hardness of more than 100 mg/1, but can be treated by softening.
Specific conductance	--	Dissolved mineral content of water.	Measure of waters ability to conduct an electric current, thus measures the degree of ionization.
Dissolved solids	500 mg/1	Chiefly minerals dissolved from rocks and soils; organic matter; water of crystallization.	Waters containing more than 1000 mg/1 of dissolved solids are unsuitable for many purposes.
pH	--	Acids, acid-salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, raise the pH.	A pH of 7 indicates neutrality of a solution; lower values of pH generally indicate more corrosiveness of water.
Temperature (°C)	--	Climatic conditions, pollution.	Affects usefulness of water for many purposes; important in fisheries industry.
Color	15 units	Organic matter, sewage.	Color objectionable for many domestic and industrial uses.
Turbidity	5 units	A function of concentration and size of suspended material.	Affects fish production by excluding light and interferring with plant growth.

[1] Maximum concentrations as established by the U.S. Public Health Service.

The State of Michigan also has established water-quality standards and designated their areas of use for the protection and upgrading of interstate waters. In this regard the State has established several broad water use categories and set standards "... designed to both protect the receiving waters of the State for designated use, and to provide maximum protection for the high quality Great Lakes into which they eventually empty" (Michigan Water Resources Commission, 1969). Table 8 lists the uses for which waters in the upper Rifle River basin have been protected and standards for several parameters. Standards for coliform, dissolved oxygen, toxic and deleterious substances, and radioactive material are not listed because data on these parameters is lacking.

The Michigan Water Resources Commission (1969) has designated all public waters in the upper Rifle basin as being protected for water supply; total body contact; intolerant fish, cold water species; and agriculture. Because of the multiple use classification the most restrictive parameters shall apply. Where the natural water quality is superior to the adopted standards it cannot be lowered in quality unless it can be shown that no injury shall result. As can be seen from table 6, for most parameters water in streams is well within the limits set by the Water Resources Commission. The surface waters are of excellent quality and suitable for most uses.

Quality of ground water is not covered specifically by quality regulations as that for surface water. However, sec. 6(a) of Act 245, Michigan Public Acts of 1929, as amended, makes it clear that pollution of ground water by any means that adversely affects the value of the resource is unlawful. The quality of ground water from the glacial drift is suitable for most purposes. However, it is hard and may contain objectionable amounts of iron. Water from the bedrock is likely to be very highly mineralized and very hard. In general, it is not suitable for domestic supplies. Because of potential water-quality problems, water from the bedrock should be developed only when water from the glacial deposits is unavailable.

TABLE 8.--Water-quality standards are related to an intended use.

Summary adapted from "Michigan's Intrastate Water Quality Standards" as adopted by the Michigan Water Resources Commission.

PARAMETERS WATER USES	SUSPENDED COLLOIDAL & SETTLEABLE MATERIALS	RESIDUES (Debris, material of unnatural origin, oils)	TOTAL DISSOLVED SOLIDS (mg/1)	NUTRIENTS Phosphorus, ammonia nitrates, and sugars	TASTE & ODOR PRODUCING SUBSTANCES	TEMPERATURE * °F (°C)	HYDROGEN ION (pH)
WATER SUPPLY INDUSTRIAL Such as cooling and manufacturing process.	No objectionable unnatural turbidity color, or deposits in quantities sufficient to interfere with the designated use.	Floating solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil gasoline or related materials. No globules of grease.	Total Dissolved Solids: Shall not exceed 500 as a monthly a average nor exceed 750 at any time. Chlorides: Monthly average shall not exceed 125.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growth of algae, weeds and slimes which are or may becomes injurious to the designated use.	Concentration of substances of unnatural origin shall be less than those which are or may become injurious to the designated use.	The maximum natural water temperature shall not be increased by more than 10°F (5.6°C).	Maintained within the range 6.5-8.8 with a maximum induced variation of 0.5 unit within this range.
RECREATION TOTAL BODY CONTACT Such as swimming, water-skiing and skin-diving	Same as above	Same as above	Limited to concentrations less than those which are or may become injurious to the designated use.	Same as above	Same as above	90°F (32.2°C) maximum	Same as above
PARTIAL BODY CONTACT Such as fishing, hunting, trapping, and boating	Same as above	Same as above	Same as above	Same as above	Same as above	Same as above	Same as above
FISH, WILDLIFE AND OTHER AQUATIC LIFE Such as growth and propagation	Same as above	Same as above	Standards to be established when information becomes available on deleterious effects.	Same as above	Same as above--the use being fish or game	Ambient 32° to nat. max. Allowable increase 10° (5.6°C) Maximum limit 70° (21.1°C)	Same as above with a maximum artifically variation of 1.0 unit. Changes in the pH outside these values must be toward neutrality (7.0).
AGRICULTURAL Such as livestock watering, irrigation and spraying.	Same as above	Same as above	Less than 700 dissolved minerals. Maximum percentage of sodium 40% as determined by the formula $\frac{(Na \times 100)}{(Na+Ca+Mg+K)}$ when the bases are expressed as milliequivalents per liter.	Same as above. Also, NO_3 concentrations shall conform to USPHS Drinking Water Standards.	Same as for industrial supply	Not applicable	pH shall not have an induced variation of more than 0.5 unit as a result of unnatural sources.

* Temperature standards are being reviewed, and may be revised.

WATER FOR FUTURE GENERATIONS

The upper Rifle River basin enjoys an auspicious setting and has a lavish supply of fresh water. Its many lakes and streams provide recreational and water supply opportunities seldom paralleled elsewhere in Michigan. Ground-water resources, too, enjoy a unique character--a resource whose abundance is evident in the volume of water flowing in streams, in the numerous springs dotting the area, and in the flowing wells located throughout much of the basin. Indeed, the water resources of the upper Rifle River basin are a real asset, perhaps its most important natural commodity. But an abundant supply of water does not necessarily assure a bright outlook for the future. This assurance comes only through wise resources planning, an awareness of potential water-resources problems, and an understanding of the basin's hydrologic system. Wise water-management practices now may serve to arrest potential problems before they arise and protect the water resources for future generations.

Much work has been done by State agencies to retain the streams in the basin in a useful state for the recreationist, and in a productive state for fish propagation. Stream banks have been stabilized by grading, mulching, seeding, sodding and rip-rapping. Jetties have been installed to deflect eroding currents (fig. 62). Willows and other trees have been planted to provide shade and cover. In addition steps have been taken through construction of farm ponds and check dams, reforestation, and land use practices to increase infiltration of water and lessen the amount of sediment being carried to streams.

FIGURE 62.--Jetties deflect eroding currents and arrest the decay of stream banks.

Just as important as retaining the physical character of streams is the importance of water-quality control. Concern, for example, should be centered on the amount of nitrates and phosphates, by-products from municipal and industrial wastes, farm fertilizers, decomposition of plant and animal life, and many other sources, as well as other chemical compounds which may enter surface waters. Concern for such compounds is due to their role as nutrients for algae and other water plants whose growth degrades surface water (fig. 63). Of particular concern is the concentration of these ions in lakes, for in plant growth lies a principal cause for lake decay. Nutrients, particularily in land-locked lakes, may be trapped and increase with time, adding increased support to plant growth and accelerated degradation of the water body.

Although critical concentrations of nutrients differ in different bodies of water, the upper limits are usually low. For example, analyses of water of 17 lakes in Wisconsin led to the suggestion that annual average concentrations of 0.015 mg/l of inorganic phosphorus and 0.3 mg/l of inorganic nitrogen were critical levels above which algal blooms could be expected (American Chemical Society, 1969). Elsewhere, excessive growth has been found at much lower levels of phosphorus and, at other places, growth has not occurred at higher levels. As such, determination of critical concentrations of nitrogen and phosphorus are complicated, however, maximum levels are not great and care must be exercised to protect surface waters from such nutrient enrichment. A good indicator of nutrient enrichment is the density of aquatic vegetation.

FIGURE 63.--Bear Lake; this and other lakes can be retained for future generations if management and development are intelligently planned (note aquatic growth in foreground).

In addition to protecting surface water resources are areas of concern regarding the ground-water resources. As shown previously, many aquifers in the upper Rifle basin are under artesian pressure. Development of wells in the basin requires a special awareness of the artesian conditions in order to protect against "run-away flowing wells"--wells which release pent-up water and cannot be easily capped once water begins to flow. Such flowing wells have been drilled in several places in the basin. However, only a few attempts have been made to seal them off. Thus, the water continues to pour forth, generally going unused. As an example, one well, put down for exploration purposes along Heath Road at Barber Creek was found to be flowing during the course of this study (fig. 64). The well had been flowing for about a year at a rate of about 200 gallons a minute. In the year's time, nearly 100 million gallons of water flowed from the ground-water reservoir through this well. Considering the large volume of

FIGURE 64.--Run-away flowing wells release millions of gallons of water each year--water generally lost to man's use.

water in storage and that added to storage each year, this is a relatively small quantity. However, with the addition of more and more such wells, the total amount of water lost could reach significant proportions. A large number of such wells would reduce artesian pressures. Thus, appropriate action should be taken requiring that all flowing wells not serving a useful purpose be sealed off. Also, future permits to drill flowing wells should be restricted to those persons who assure that all efforts will be made to manage and conserve water. Good management and conservation of ground-water reserves benefit not only the individual well owner but all other persons in the basin.

One common use of water from flowing wells is in the maintenance of trout ponds. Most often, these wells flow unrestricted, supplying water to keep the ponds full and to keep the water temperature within a range suitable for raising trout. The relatively undeveloped condition of the basin at the present time (1970) allows the installation of wells for this purpose without serious damaging effects. However, each well similar to run-away flowing wells, offers avenues of easy escape for ground water. As more wells are installed, more water can escape. Obviously, this situation cannot continue forever. Eventually, the countryside will be perforated by wells. Water levels will decline and some wells will cease to flow. Thus, the most advantageous use of ground water would be through planned and restricted installation of flowing wells. If such is not accomplished, then the obvious can be expected. Even so, there is a compensating factor or perhaps, another area of concern. As heavy withdrawals of water occur throughout the basin and as water levels decline, the ground-water divide will move further to the north and west. In so doing, the size of the ground-water basin, as well as that of the recharge area, will be expanded. What this means, in effect, is that more ground water can be obtained than is indicated by the present basin delineation. This type of expansion is satisfactory as long as it does not interfere with water supplies in the areas to the north and west. However, if large quantities of water are needed for these contiguous areas also, the actual expansion of the Rifle River ground-water basin should be restricted.

With the details of water management given above, the wise water manager must concern himself with the total water-resources picture and how the resource picture will be affected by development. A look at this picture reveals that the basin's major water-resources assets that need protection and maintenance are:

1) Streams having high base-flow discharge
2) Large quantities of ground water
3) Ground water under artesian pressure
4) Flowing wells
5) Surface and ground water of good quality.

Through good management practices, development can be diverted in directions that will assure that the water resources will be used to the best advantage of all concerned.

Glacial deposits form the principal framework for the basin's ground-water supply system and are the prime source of ground water. This water-supply system is relatively unique in character. In much of the basin ground water is confined under thick clay layers and thus is under artesian pressure. Wells often tap this pressurized system and water from the wells frequently flows above land surface. Indeed, in some areas artesian pressures are sufficient to supply household needs without the use of pumps. Because ground water is under artesian pressure, this resource has been developed to supply numerous trout ponds as well as many commercial and domestic needs.

Streams, lakes and ground-water reservoirs in the upper Rifle represent a large volume of water. But, to be useful, the water must be of good quality--a characteristic which well describes most of the basin's water. Concentrations of chemical constituents in water from lakes and streams are well within the limits established by the Michigan Water Resources Commission and the U. S. Public Health Service. Concentrations of chemical constituents in most water from the glacial deposits are also within the recommended limits. However, water from the bedrock formations is generally too highly mineralized for domestic use.

# # #

SUMMARY

The upper Rifle River basin is an area rich in water resources--a resource whose abundance is evident in the volume of water carried by streams, by the many springs that dot the area, and by the numerous flowing wells. Streams discharge annually an average of about 140 cfs, but more importantly, most streams have high sustained rates of flow. For example, discharge at Selkirk recedes below 78 cfs only five percent of the time. Also, median annual 7-day low flows of more than 1 cfsm are common, occurring in Houghton, Wilkins, and Klacking Creeks, and on the Rifle River. On other streams, median annual 7-day low flows are generally more than 0.5 cfsm; however, in the southern part of the basin such flows may be as low as 0.02 cfsm. Streams having high sustained discharge, even during extended drought periods, provide favorable sources for water supply and are excellent for fishing and other recreational uses.

Peak discharges, though troublesome at times, do not pose a serious problem. Flood plains are principally in a wilderness state and consequently flooding generally causes only minor inconveniences. However, at some sites destruction from flooding does occur occasionally. For example, a destructive flood occurred in 1959 when heavy rains caused streams to overflow their banks, washing out culverts and road fill, and causing a considerable amount of damage to other structures within the flood plains.

Of the 140 cfs that discharges from the basin annually, about 103 cfs is from ground-water sources and 37 cfs reaches the streams as overland or surface runoff. The ratio of ground-water discharge to surface-water discharge is vastly different from that in most other areas in Michigan. This difference reflects the contribution of water to the basin from areas north and west of the topographic divide--areas that total about 58 square miles in size. An estimated 46 cfs enters the basin as ground-water flow from these areas.

There are about 40 lakes and ponds in the basin. Most are small and have little development around them. Lakes have been important primarily for their recreation and esthetic values. It is expected that they will continue to serve in that capacity rather than for water supply.

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