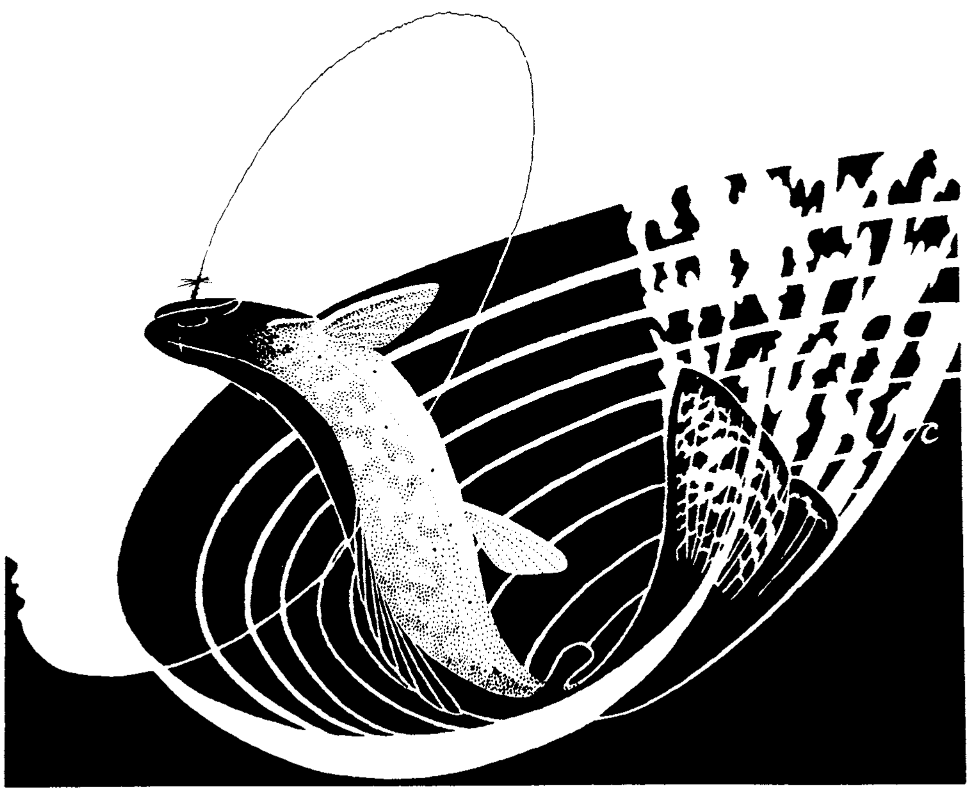
WATER INFORMATION SERIES REPORT 3

HYDROLOGY AND RECREATION ON THE COLD-WATER RIVERS OF MICHIGAN'S SOUTHERN PENINSULA



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

1972

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HYDROLOGY AND RECREATION ON THE COLD-WATER RIVERS OF MICHIGAN'S SOUTHERN PENINSULA

by G. E. Hendrickson
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U. S. Geological Survey

artwork by Jim Campbell

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HYDROLOGY AND RECREATION ON THE COLD-WATER RIVERS OF MICHIGAN'S SOUTHERN PENINSULA

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ABSTRACT

Michigan's cold-water rivers provide recreation to thousands of trout fishermen, boaters, campers, and cabin-dwellers. The recreational values of these rivers are dependent on their streamflow characteristics, water-quality, and character of channel, bed, and banks. Recreational values are generally benefited by a relatively uniform streamflow and a high sustained flow even during drought periods. Other valued qualities are clear water free from objectionable contaminants and river banks that are protected from erosion. A correlation of hydrologic parameters and trout populations showed a general negative relationship between mean annual maximum water temperatures and trout populations. A positive relationship between the ratio of the 90-precent and 10-percent duration discharges and trout populations also is suggested. Other hydrologic parameters investigated also suggested correlation to various degrees but such relationships are not conclusive.

Preservation and improvement of recreational values of cold-water rivers will require continued assurance of high drought flows, maintenance or lowering of maximum water temperatures, control of waste disposal, and prevention of erosion of stream bed and banks. Maintenance of high flow during drought periods may involve management of ground-water pumpage, placing limitations on surface-water diversions, and management of the river basin to maintain or improve ground-water recharge. Maintenance or lowering of maximum water temperatures can be accomplished by preserving streamside vegetation, maintaining high drought flows, and controlling disposal of heated water to streams. Control of impoundments in the watershed may also be necessary to avoid possible warming of water or change in streamflow patterns. Prevention of streambank erosion can be accomplished by "greenbelt" zoning--zoning ordinances that restrict removal of streamside vegetation and restrict grading and filling on the river banks. Rip-rap or other structures for erosion control may be needed in places.

Cold-water rivers are a fragile resource that can be preserved for enjoyment of future generations only by continuing effort. Management practices must be based on an understanding of hydrologic factors as they relate to recreational values. Effective management will require continuing records of streamflow, ground-water levels, and water quality.

INTRODUCTION

The special qualities of recreation afforded by Michigan's cold water rivers--trout-fishing, semi-wilderness canoeing, and camping--are an important asset to the State. Although these recreational values are important and irreplaceable, they provide for only one segment of the possible uses of the streams. Recreational uses must compete with all other uses. In order to manage our water resources for the maximum benefit to mankind, the water requirements of all uses must be understood. The purpose of this report is to analyze the hydrologic conditions favorable to recreational values on cold-water streams of Michigan's Southern Peninsula so that recreational values can be considered with other uses in water-management decisions. Such an analysis should be useful in three ways:

1. To make possible an estimate of the recreational potential of a stream by inventorying its hydrologic characteristics.

2. To determine what water-management practices, if any, can be used to improve the recreational values of the streams. Or, if improvement is not possible, to determine what measures can be taken to prevent or minimize changes in hydrologic characteristics that result in deterioration of recreational values.

3. To determine to what extent other uses of water can be made compatible with recreational uses.

The report is intended for use chiefly by recreational planners, park managers, and fisheries' biologists. It should be of interest also to all persons who wish to preserve the recreational resources of streams. The report will be of value only if it results in action--informed and intelligent action--in management of water resources.

Scope

The study describes the hydrology of most cold-water rivers in the northern part of Michigan's Southern Peninsula.

The hydrologic characteristics that directly influence recreational values--streamflow and water quality, river channels, and bed and banks--are the major subject of this study. However, to describe these characteristics it is essential to understand the physical character of the entire river basin--the topography, geology, soil and vegetation. Accordingly, brief descriptions of these features are included in an early section of this report.

The areas of study include the watersheds of most cold-water rivers in the northern part of Michigan's Southern Peninsula (fig. 1). However, the intensity of study in the different basins varied widely.

Method of Study

The first step in the study was to analyze and interpret records of streamflow, water quality, and ground-water levels in selected river basins, and relate them to geology and topography of the watersheds. Next, field studies were made on the Pere Marquette, Manistee, Sturgeon, Pigeon, Black, Au Sable, North Branch Au Sable, and Rifle Rivers. Information was obtained on water quality, low-flow characteristics, and character of river channel, bed, and banks. The third step was to sample segments of several additional streams to obtain wider coverage. Next, specific information was obtained on the recreational use and potential of the streams under study. The Michigan Department of Natural Resources was the chief source of this information. Other sources were field observation, local Chambers of Commerce, managers of canoe liveries, resort owners, realtors, fishing guides, and recreationists of all kinds--fishermen, boaters, campers, and cabin dwellers. Some of the information of this kind was quantitative and objective--such as park-attendance survey, price of river frontage, fish-population surveys, creel-census data, and data on canoe rentals. Other information--such as attractiveness of the river scene--was qualitative and subjective. Finally, an analysis was made of the relationship of hydrologic factors to recreational use and potential of the rivers.

Acknowledgments

Advice and assistance in this study were provided by authorities in several disciplines in the Michigan Department of Natural Resources. Special thanks for initiating the study go to Gerald E. Eddy, formerly State Geologist and Chief, Geological Survey Division, Authur E. Slaughter, Mr. Eddy's successor, and the late John G. Rulison, former head of the Water Section of the Division. David S. Shetter and Gaylord Alexander, of the Hunt Creek Fisheries Research Station, provided fish-population data and prepared a section of the report dealing with trout habitat. Leonard N. Allison, Fish Pathologist-in-charge, Grayling Research Station, provided continuing advice and encouragement. Gerald F. Myers, Pigeon River Fisheries Research Station, contributed much useful information from his first-hand knowledge of the Sturgeon, Pigeon, and Black Rivers.

Assistance in the study and review of the report were also obtained from colleagues of the U.S. Geological Survey. Streamflow and specific conductance were measured for the study by Dale Pettengill, Robert W. Larson, Horace L. Failing, Thomas E. Robertson, and James C. Failing, of the Grayling subdistrict office. Mr. Robert L. Knutilla advised the authors on correlation techniques and processed data for computer analysis.

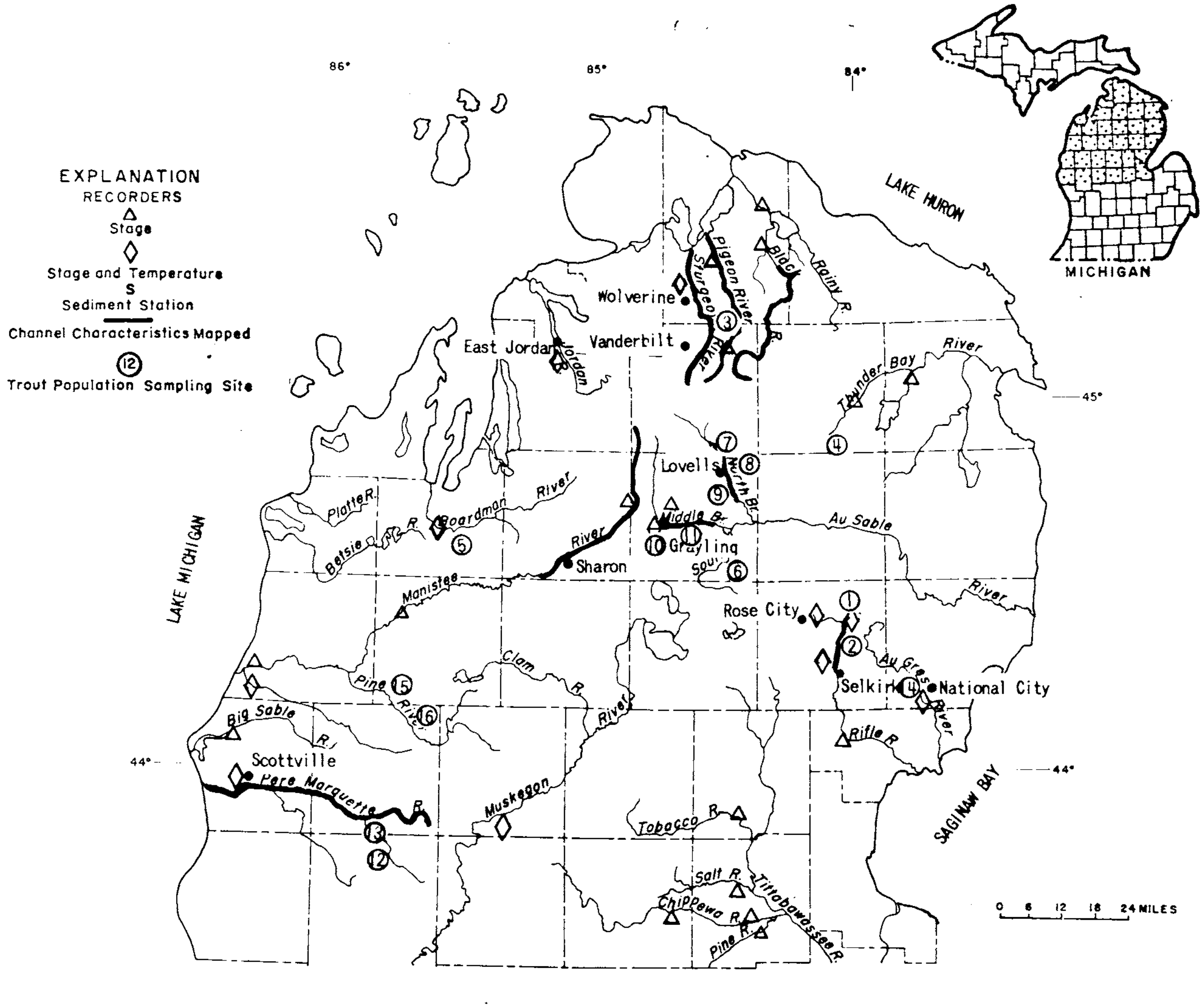


Figure 1. Area of study includes watersheds of most cold-water rivers in the northern part of Michigan's Southern Peninsula.

GENERAL HYDROLOGY

The relatively thick deposits of permeable glacial drift and the cool climate, and abundant rainfall in most of the northern part of Michigan's Southern Peninsula provide the environment needed for rivers to have a high sustained flow of cool water. The influence of the environment on streamflow, temperature, and quality of water in the streams is best understood by considering the movement of water from the atmosphere to the earth and back to the atmosphere again--the water cycle. Water falling on the watershed travels three different routes. Part runs over the surface of the land to the stream; part is held in soil and on plants to be lost by evaporation and transpiration; and part seeps down to the "zone of saturation" below the water table, then moves laterally as ground water to discharge into springs, streams, and swamps. In general, the greater the amount of water that follows this subsurface route, the greater the drought flow of the stream.

Precipitation

Atmospheric water condenses and falls to earth as rain or snow. A small amount condenses at the earth's surface as dew. Precipitation in the study area ranges from 26 to 32 inches a year, but is near 30 inches over most of the area (fig. 2). The differenc^ in the amounts of water received annually from precipitation in the various river basins are quite small, and differences in streamflow characteristics between basins do not appear to relate chiefly to precipitation.

Precipitation at most stations ranges from 1 to 2 inches per month during the winter months and from 2 to 4 inches per month the rest of the year. Most winter precipitation is in the form of snow, and much of this remains on the ground until the spring thaws. Typical responses of ground-water levels and streamflow to increments of rainfall and snowmelt are illustrated by the hydrographs in figure 3.

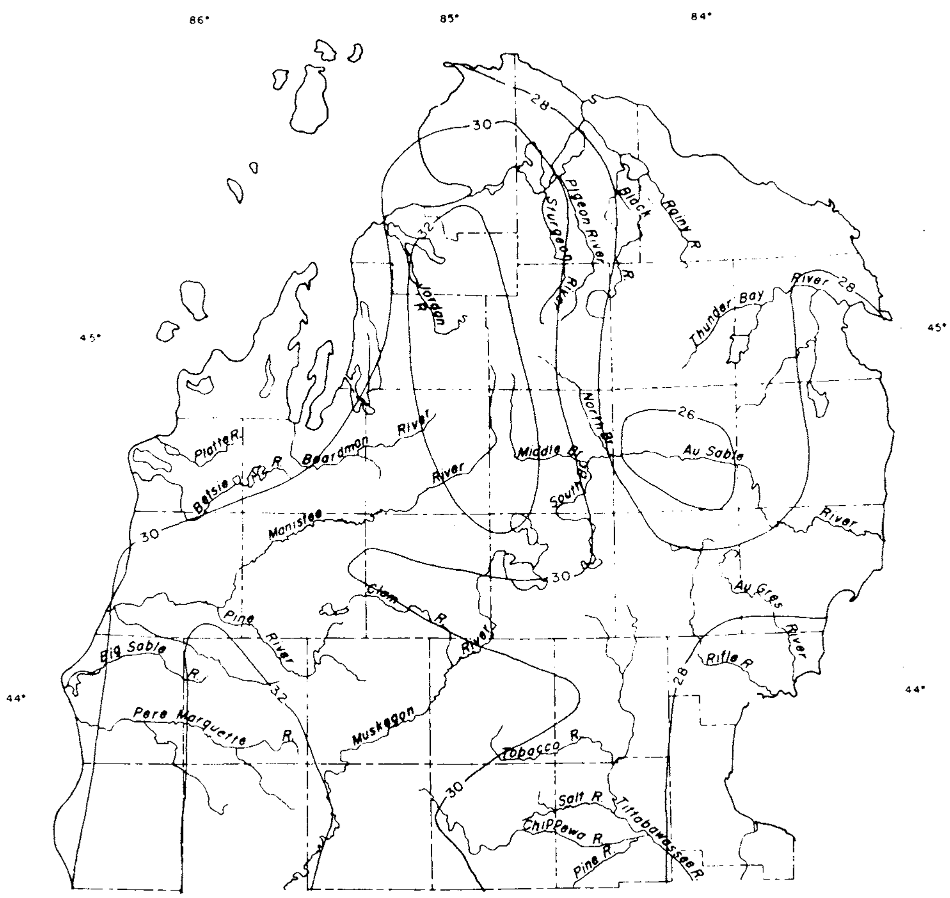


Figure 2. Precipitation in the study area ranges from about 26 to 32 inches a year.

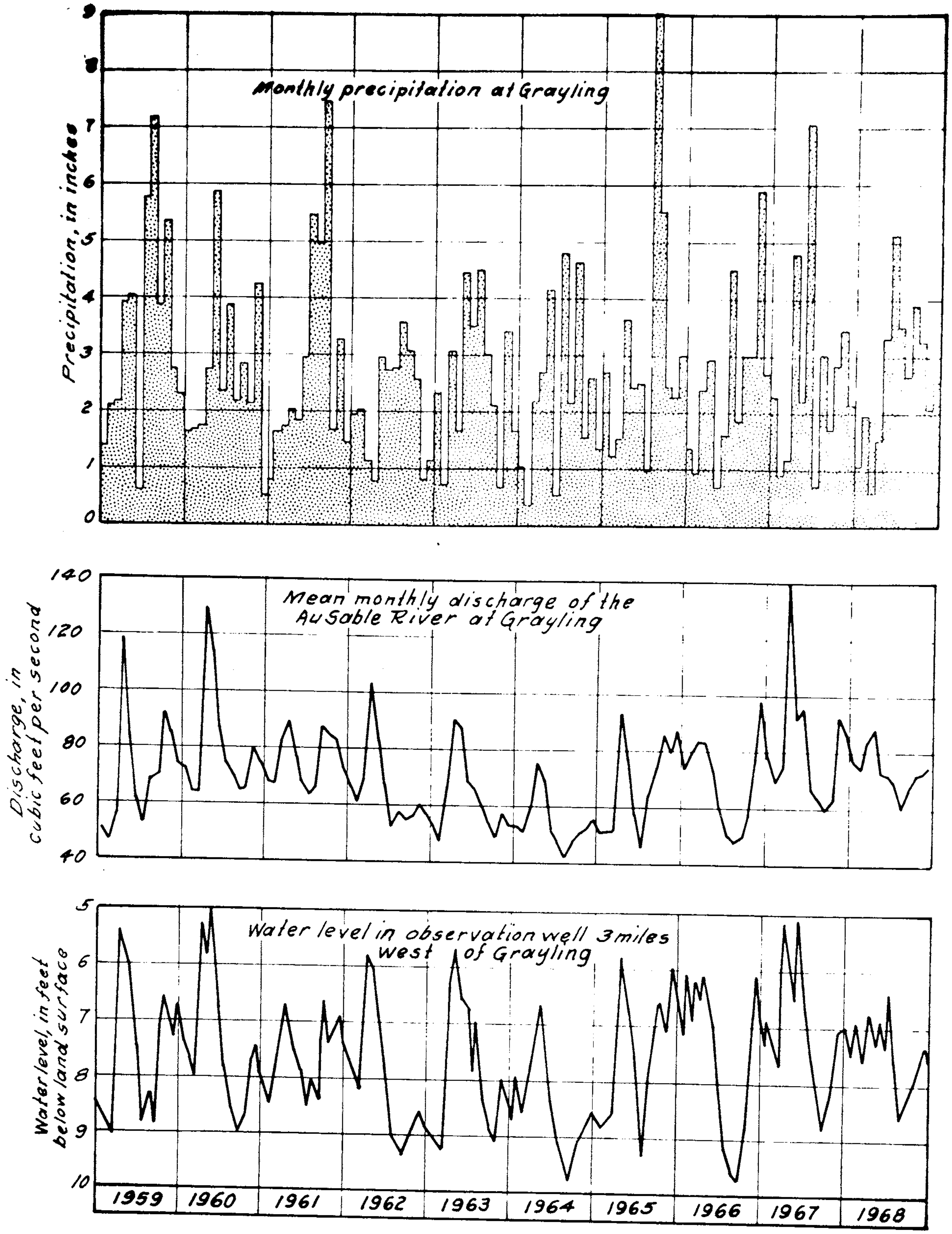


Figure 3, Ground-water levels rise and streamflow increases in response to spring snowmelt and heavy rains. The influence of rainfall is relatively small during the growing season.

Evaporation and Transpiration

Evapotranspiration (evaporation and transpiration) in the study area ranges from about 14 to 20 inches a year (fig. 4). Figure 4 was prepared by subtracting the average annual runoff from the average annual precipitation. Although air temperature directly influences the rate of evaporation and transpiration, it appears that other factors also exert strong influence. The higher rates of evapotranspiration generally are in areas with relatively impermeable soils and glacial drift that characterize the lake deposits along most of the Lake Huron shoreline (figs. 6, 8). The tighter soils hold greater amounts of moisture by capillary action than do the more porous sandy soils, and consequently more water is available for evaporation and transpiration. The relatively high rate of evapotranspiration in the headwaters of the Muskegon River probably can be attributed to the large area of lakes and wetlands here.

Runoff

The average annual runoff in the study area ranges from about 8 to 16 inches (fig. 5). Values higher than 18 inches are recorded in some small areas not shown on the map, but these are invariably the result of movement of ground water from one basin to another. The differences in runoff are greater than differences in precipitation. Also, the higher values of runoff do not correlate precisely with the higher values of precipitation. Differences in runoff are chiefly the result of differences in the physiography of the basins--the topographic situation and especially the character and thickness of the glacial deposits.

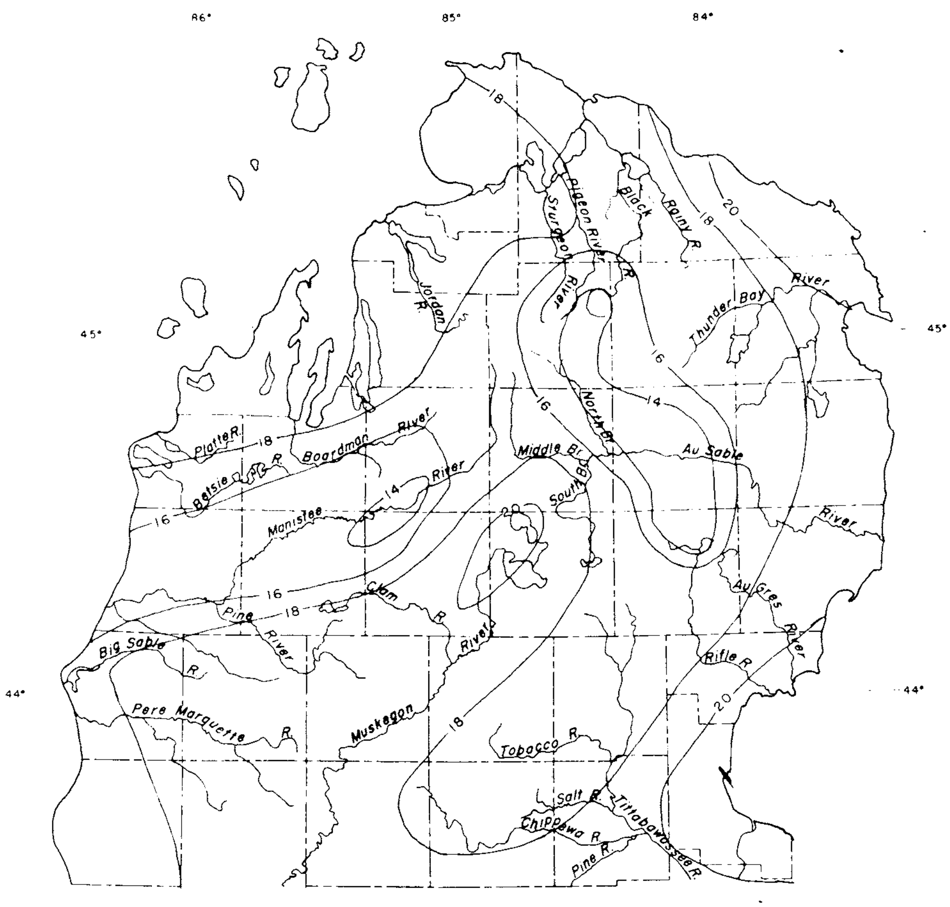


Figure 4. Evaporation and transpiration range from about 14 to 20 inches a year.

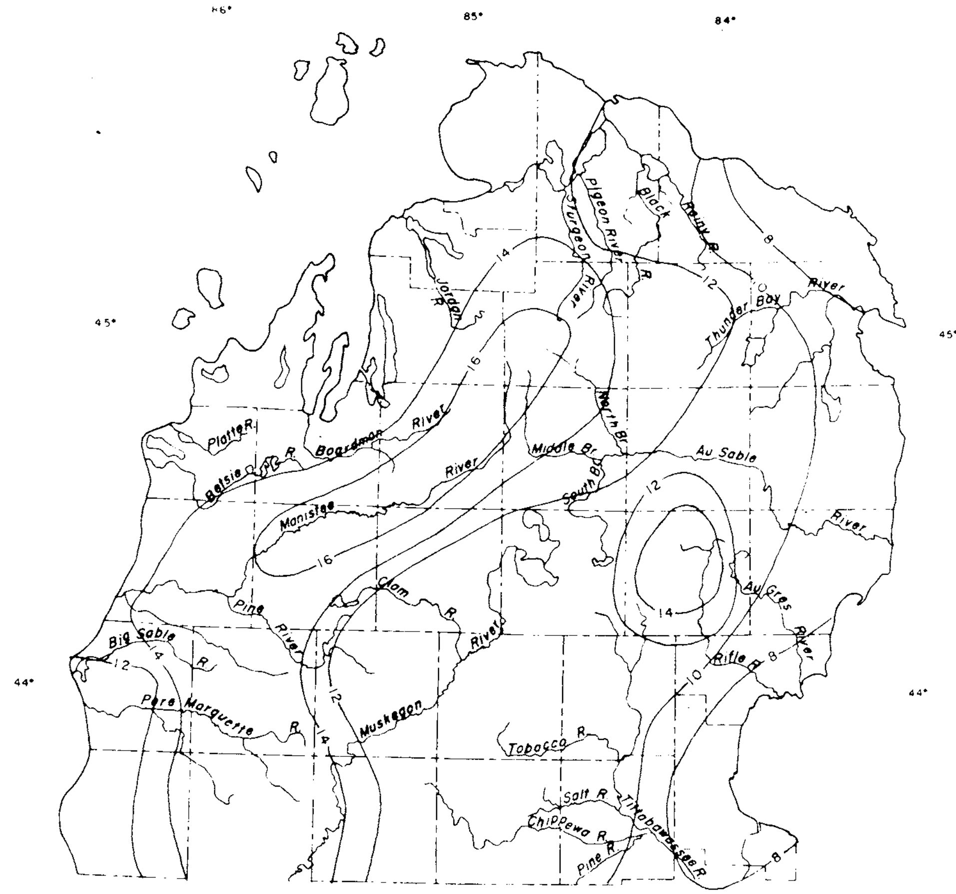


Figure 5. Runoff ranges from about 8 to 16 inches a year.

PHYSIOGRAPHY

The rivers we deal with here are alike in one respect--all are in glaciated terrains where the influence of underlying bedrock is relatively small. The glacial features themselves, however, differ widely within each basin, as well as from basin to basin, and the rivers reflect these differences.

Glacial Deposits

The generalized surficial geology map of the northern part of the Southern Peninsula (Martin, 1955, fig. 6) shows a series of moraines which mark temporary halts in the retreat of the Pleistocene glaciers. Forward movement of the ice was matched by melting, and materials carried by the ice accumulated at the ice front. These materials were, for the most part, dropped from the melting ice with little movement or sorting by running water. Consequently, these materials, called till, are a mixture of sand, silt, clay, and stones in various proportions, depending upon the character of the materials over which the ice had moved while accumulating its load. The pattern of the more prominent moraines generally conform to the outlines of the ancestral glacial lake basins from which the various lobes of ice advanced. The older moraines are farther inland; the younger moraines are nearer the present shoreline of the Great Lakes.

Meltwaters from the halted ice carried water-sorted materials beyond the moraine to be deposited as outwash. The outwash materials are chiefly stratified sand and gravel, but also include some silt and clay.

When the ice stagnated, or the rate of ice melting became greater than the rate of forward thrust of ice, the ice front retreated, and materials dropped from the wasting ice. This material, also called till, formed the ground moraine or till plains behind the end moraines. Some of the ground moraine may also have been deposited under the ice during the ice advance. Ground moraine differs from end moraine chiefly in that the resultant topography is of low relief, and lacks the transverse linear pattern characteristic of end moraine.

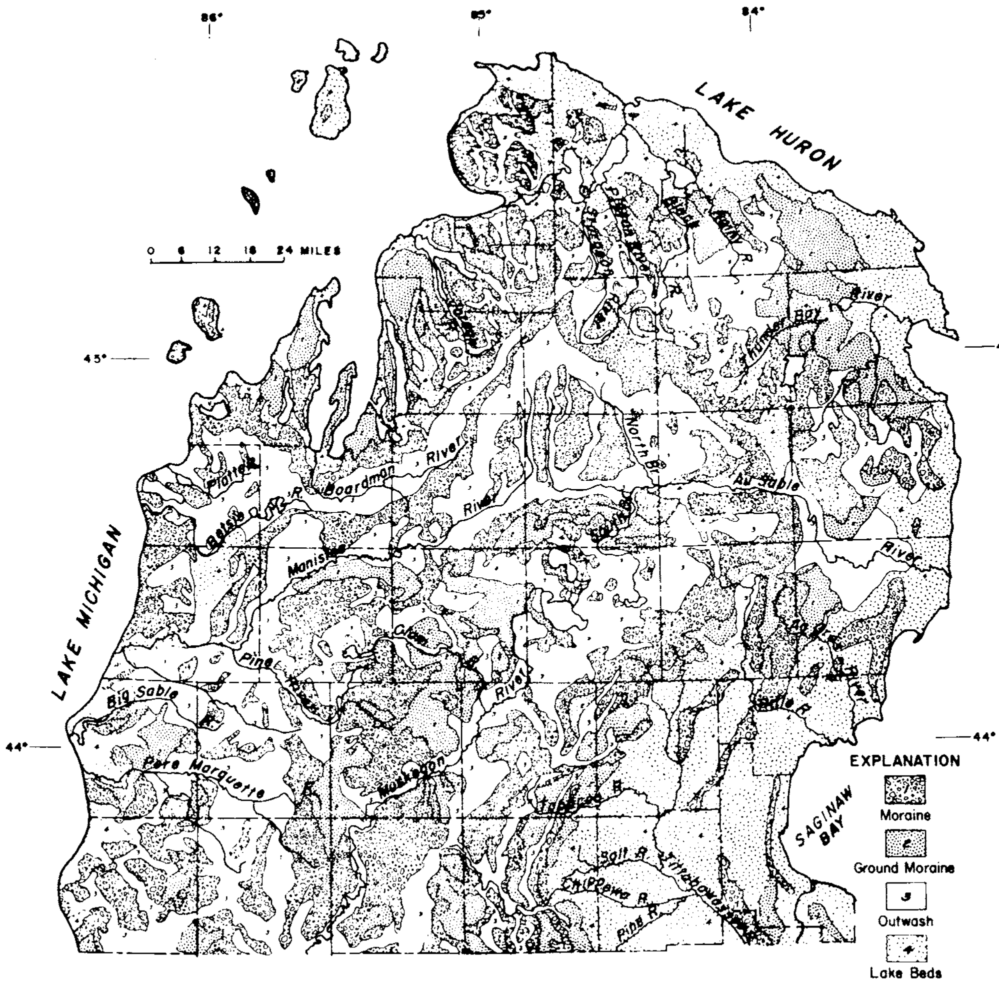


Figure 6. Permeable outwash deposits in the northcentral and western part of the study area contribute to stable streamflow and cool summer water temperatures. The relatively impermeable lake clays along Lake Huron and Saginaw Bay are characterized by low drought flows and warm summer water temperatures (Geology after Martin, 1955).

As the ice retreated, meltwaters accumulated in low areas between the ice front and adjacent highlands, and sediments carried into these ponded waters were deposited as stratified sand, silt, and clay, called lake beds.

The importance of these glacial deposits to a river system is threefold: they are a major factor in determining the topography of the river basin; they strongly influence the rate of infiltration of precipitation, surface runoff, and groundwater discharge to the streams; and they influence the quality of the water in the streams.

End moraines are conspicuous topographic feature, typically forming ridges of considerable relief which, in places, are boundaries between adjacent watersheds. The outer slope of the end moraines (in the direction of ice advance) may be buried in places by outwash deposits so that the ridge-like character is inconspicuous, and the moraines and adjacent outwash plains form a series of steps descending from older to younger moraines in the direction of ice retreat. The topography of the outwash deposits is relatively flat, but the outwash plain may be dissected by streams and pitted by kettle holes formed by melting of buried blocks of ice. Some of the kettle holes are occupied by lakes. Areas of ground moraine are gently rolling with greater local relief than the outwash plains but generally less than the end moraines. Lake beds, characterized by generally flat topography, are the surface materials bordering Lake Huron in a belt ranging in width from a few miles to as much as 40 miles. Lake beds also occur in relatively small patches near Lake Michigan and in scattered areas inland.

Rates of infiltration, surface runoff, and ground-water discharge are related to the permeability as well as the topography of the glacial deposits. Because outwash plains are relatively flat and highly permeable, rate of infiltration and ground-water discharge is high and surface runoff is low. The steeper slopes and lower permeability of end moraines and ground moraines result in lower rates of infiltration and ground-water discharge and higher rates of surface runoff. The permeability of the lake beds is moderate where the lake beds are composed chiefly of sand, and very low where the lake beds are composed chiefly of clay or silt.

The gross characteristics of streamflow can generally be predicted by reference to the predominant glacial materials in the basin. For example, the basin of the Au Gres River above National City is chiefly end moraine and ground moraine. As will be shown later, streamflow in this basin is characterized by high surface runoff and low ground-water runoff. In contrast, the Manistee River basin above Grayling is chiefly outwash plain. Surface runoff on the Manistee is very low, and ground-water runoff is high. Rivers with basins underlain by clayey lake beds, such as the North Branch Kawkawlin River, have extremely high surface runoff and extremely low ground-water runoff.

Bedrock

Although the influence of bedrock on hydrologic characteristics is insignificant in most of the areas of study, in those areas where the glacial drift is thin or absent the bedrock affects topography, streamflow characteristics, and water quality. Figure 7 shows the approximate thickness of glacial drift in the study area. Bedrock is at or near the surface in the northwestern, northeastern, and southeastern fringes of the study area. In general the bedrock is likely to be less permeable than the overlying glacial drift, so the areas of bedrock outcrop or thin drift are likely to be areas of high surface runoff and low ground-water discharge.

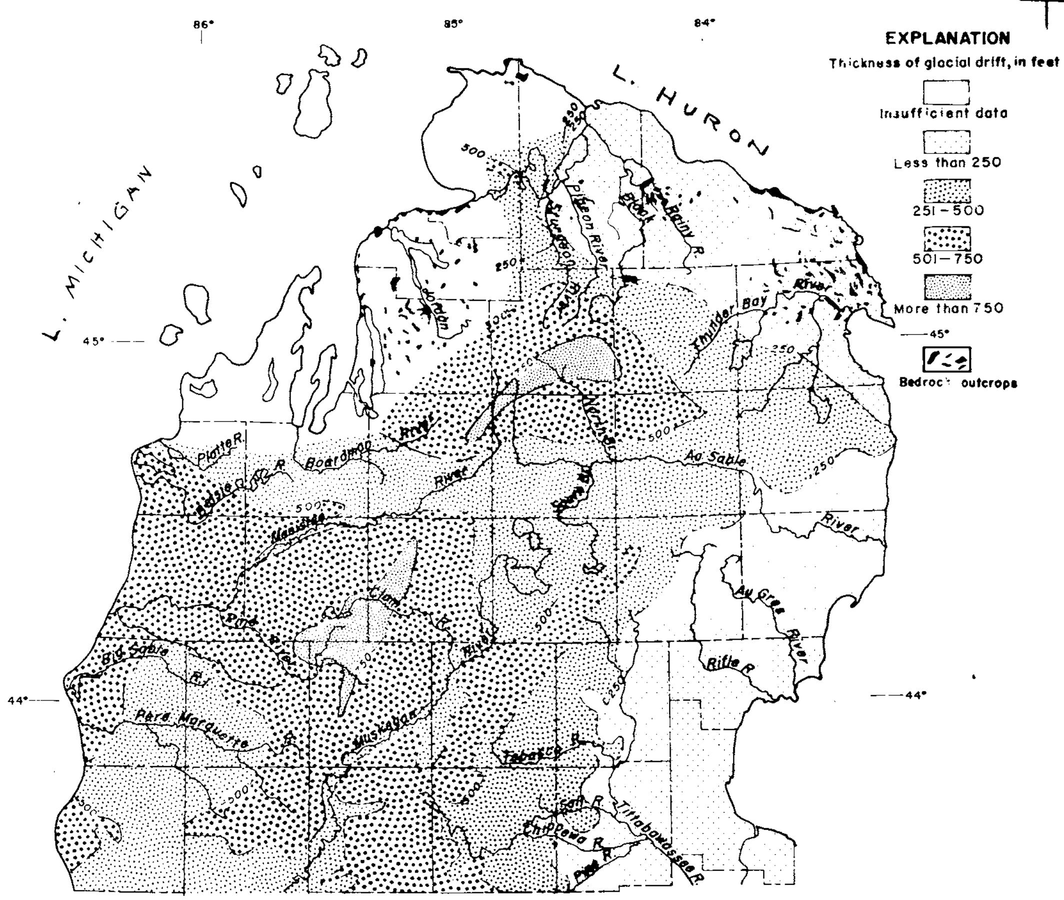


Figure 7. Glacial drift is several hundred feet thick in most of the study area, but is thin or absent in places near the Great Lakes shorelines.

Topography and Drainage

The topography of the study area, as indicated above, is largely controlled by the moraines and intervening outwash plains deposited by the Pleistocene glaciers. Some of the hills on the interior morainal ridges are more than 1500 feet above mean sea level. The outwash plains are more than 1300 feet above sea level near Gaylord, stepping down to about 600 feet in places near Lake Michigan. Lake beds range in altitude from about 1000 feet to the level of Lakes Michigan and Huron (approximately 580 feet).

The rivers of the study area generally drain to the west, north and east from the interior highlands to Lake Michigan and Lake Huron. Most of the larger rivers flow on outwash plains that are parallel to morainal ridges. Because of the step-like character of the moraines and outwash, adjacent basins may differ greatly in altitude. Where this occurs the lower basin may capture some of the ground-water discharge from the higher basin. For example, the Sturgeon and Pigeon Rivers north of Gaylord capture some of the ground-water flow from the Au Sable River basin to the south. The captured water contributes to the high base flow and low summer water temperatures of the upper Sturgeon and Pigeon. Other rivers favorably located to capture ground water from adjacent basins are the Jordan in Antrim County, and the Rifle in Ogemaw County.

Soils

The soils of glaciated regions are derived from the underlying glacial deposits, and, since the period of weathering has been relatively short (in geologic terms) the soils resemble their parent material more closely than do soils derived from older bedrock. Soils overlying outwash deposits usually are sandy, sometimes stoney, and quite permeable. Soils overlying till deposits (end moraine and ground moraine) usually contain more silt and clay and are less permeable than those over outwash deposits. However, some morainal deposits, such as those in central Crawford County, are mostly sand and are overlain by sandy, permeable soils. Soils overlying clayey lake beds are the least permeable of all Michigan soils. Infiltration rates for soils in the northern part of the Southern Peninsula are shown on figure 8. (Schneider and Erickson, 1966). In general, the higher the infiltration rate the greater the ground-water discharge and the smaller the surface runoff.

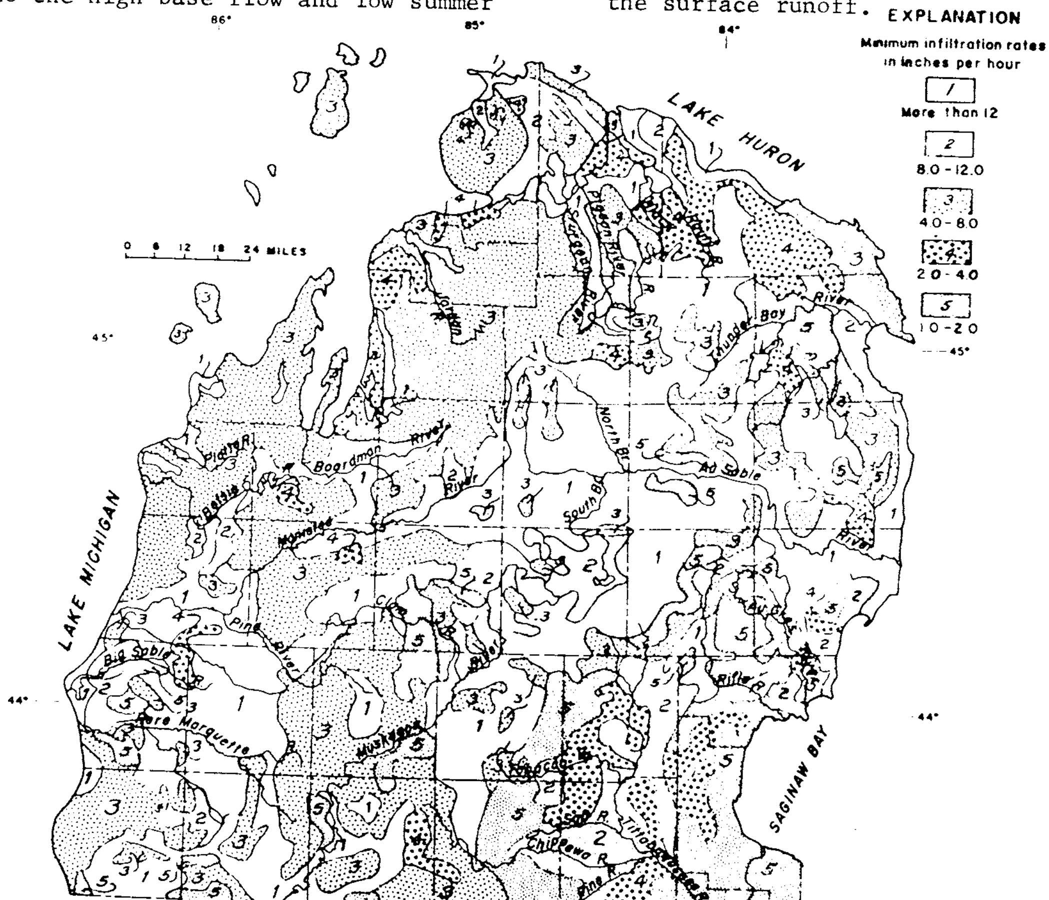


Figure 8. Minimum infiltration rates of soils range from about 1 to 12 inches per hour. Infiltration rates generally are high in the northcentral and western parts of the study area where outwash deposits are abundant and moraines are relatively sandy (from Schneider and Erickson, 1966).

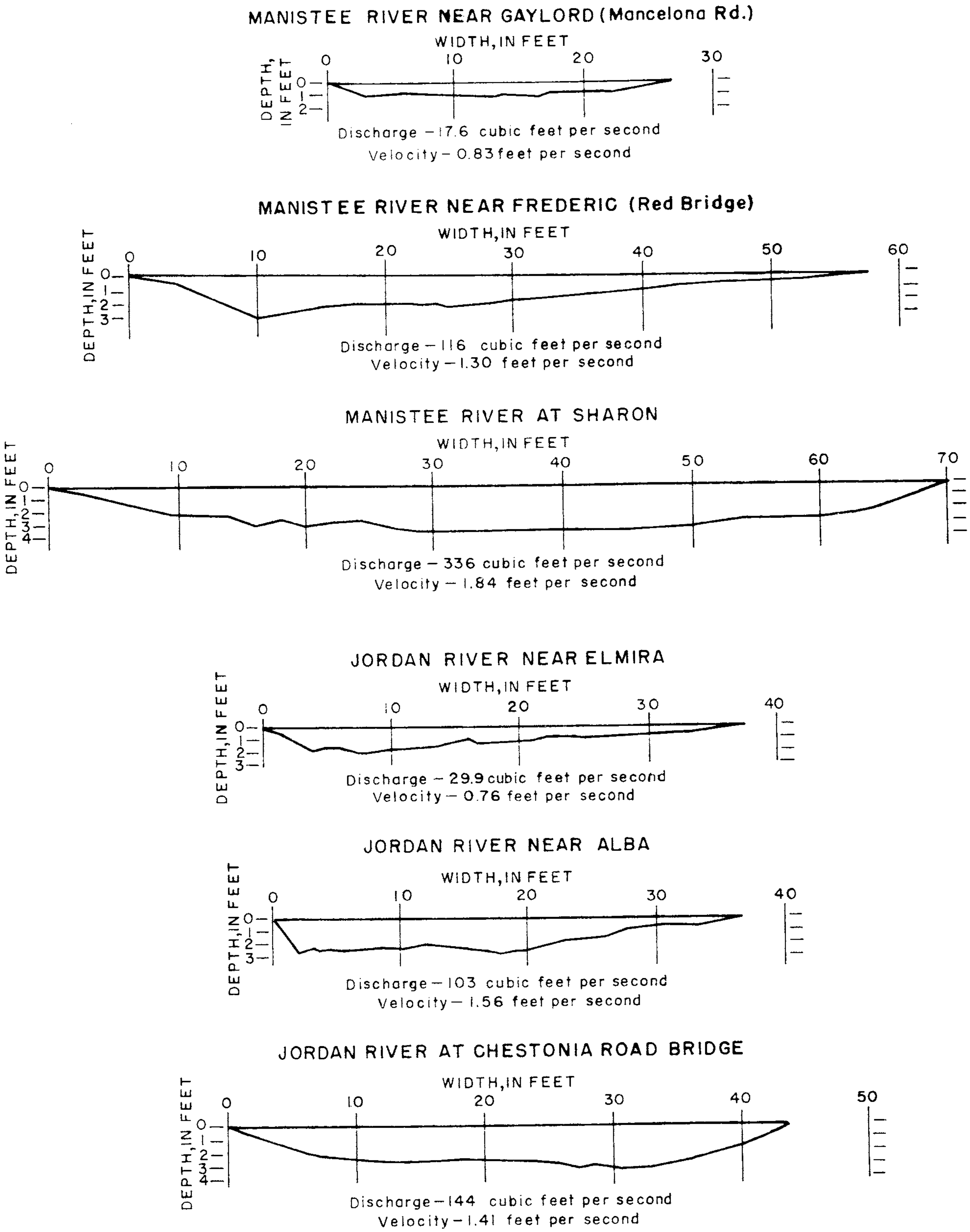


Figure 9. Cross-sectional areas of streams generally increase downstream with increasing discharge.

RIVER CHANNEL, BED, AND BANKS

Although the river channel, bed and banks are essential features of all rivers, they are not generally mapped or measured as systematically as are the characteristics of streamflow and water quality. The river channel, bed, and banks of six rivers (fig. 1) were mapped in the present study (Hendrickson and Doonan, 1970, 1971). These maps are the principal source of information for the following discussion.

Width and Depth of Channel

The width and depth of channel determine the cross-sectional area of the river and affect the velocity of flow. The discharge of a stream is the amount (volume) of water moving past a given cross section in the stream in a unit time. If discharge remains constant a decrease in cross-sectional area is compensated by an increase in velocity; conversely, an increase in cross-sectional area results in a slower velocity. The proverb "still water runs deep" is an observation of this fact.

Stream segments included in this study range from small brooks less than 10 feet wide and a foot deep to rivers more than 200 feet wide and 10 feet deep. Typical cross-sections are shown in figure 9, and width and depth maps are shown in figure 10. Cross-sections of rivers in straight reaches tend to be trapezoidal in shape (Leopold, and others, 1964, p. 202). At bends in the river the outside of the bend usually is deeper than the inside. The cross-sectional area of streams generally increase in a downstream direction, but the increase is by no means uniform.

Controls of the shape of a cross section in any reach of stream are complex and not fully understood. According to Leopold, and others (1964, p. 202) the width of a stream generally increases downstream faster than the depth. The ratio of width to depth of some of the rivers measured increased downstream; width to depth ratios of others remained about the same or decreased (fig. 9).

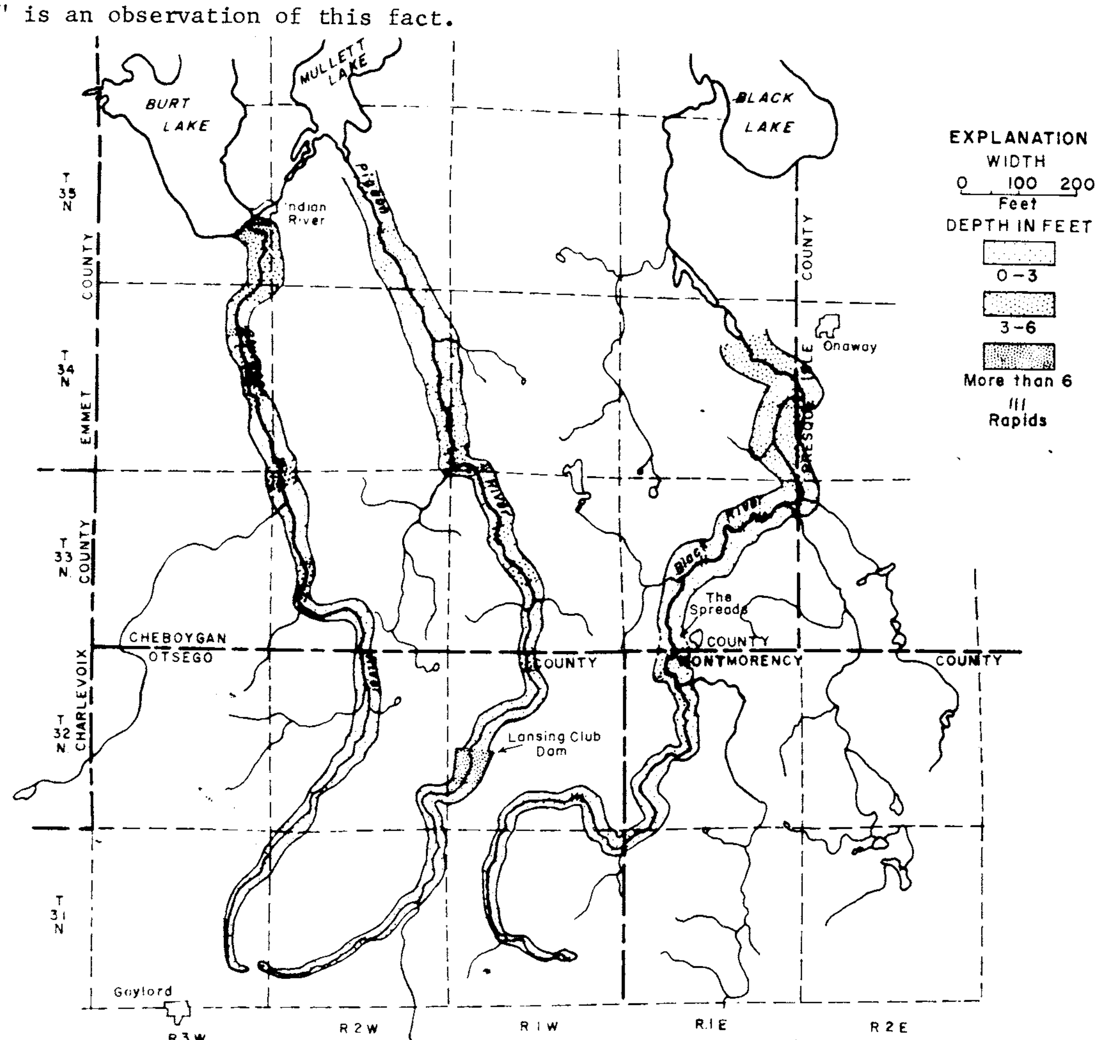


Figure 10. Stream widths vary, but generally increase in the downstream direction. Upper reaches of streams in study area are shallow; shoals and deeps alternate in lower reaches.

Width to depth ratios also are influenced by the character of bed and bank materials. If the bank materials are cohesive silt and clay and bed materials are sand, the width of the river will be smaller in relation to depth than if both bed and banks are composed of sand (Leopold, and others 1964, p. 201). The relatively narrow and deep channel of Houghton Creek east of Rose City may be attributed to the silty banks and sandy stream bed here.

Alternating increases and decreases in cross-sectional area is common to all the streams studied and is caused by both deepening and shoaling and by widening and narrowing of the channel. Leopold, and others (1964, p. 203) noted that the repeating intervals of pools and riffles in American streams characteristically are spaced at 5 to 7 times the stream width, where bottom materials are larger than coarse sand. Thus, in a river 100 feet wide, the distance from the beginning of one riffle to the beginning of the next would be about 500 to 700 feet. Repeating distances of pools and riffles were not systematically measured in the present study, but some riffles on the Black River and some pools on the Au Sable River are many times longer than 5 to 7 river widths. Some riffles in the study area are obviously related to resistant moraines and rock outcrops, but most do not appear to be so controlled. Where rivers flow through broad, flat, marshy areas the channel may branch out into several smaller braided channels (fig. 11). These braided channels, usually in sand or fine gravel, presumably were formed when deposition of sediment was equal to, or greater than, downcutting. The braided streams often are difficult or impossible to traverse by boat.

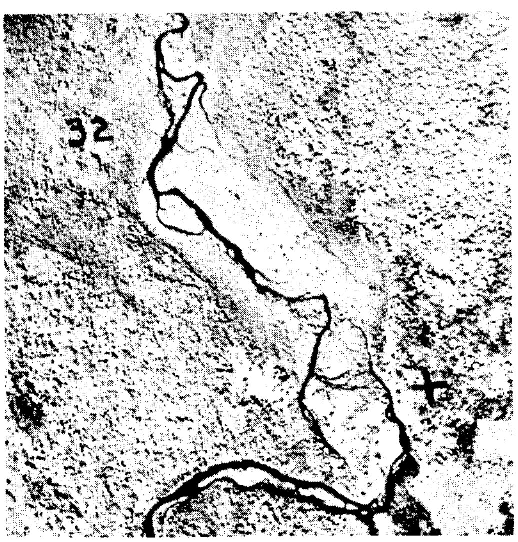


Figure 11. The Black River divides into several small channels at "the spreads" which makes canoeing difficult to impossible.

Width and depth of a river at a given site also varies with time, as discharge increases or decreases, or as erosion and deposition of sediment alter the cross section. An example of a stream that changes cross section drastically with discharge is the Rainy River near Ocqueoc. The cross sectional area increased from 9 square feet on August 14, 1968, to about 75 square feet on August 23, 1968 (fig. 12). The discharge at the same times increased from about 2.5 cfs (cubic feet per second) to 231 cfs. The increase in discharge and area of cross section resulted from heavy rains in the vicinity totalling more than 4 inches during the period August 19 and 20. The area of cross-section increased about 8 times; the rate of discharge increased about 92 times. The average velocity of flow increased about 11 times.

Some of the rivers in the study area, such as the upper Au Sable and Manistee, are so uniform in flow that they never overflow their banks in any significant areas. Increase in discharge on these rivers is accompanied by a small increase in depth but little or no increase in width. Other rivers, such as the Rainy and the upper Rifle, may occasionally overflow relatively large areas, greatly increasing both width and depth of channel.

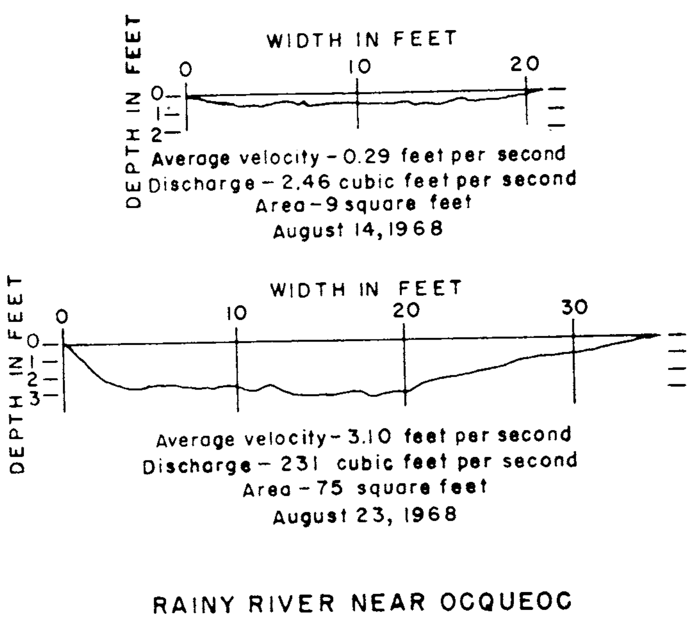


Figure 12. The cross-sectional area of the Rainy River increased about 8 times when surface runoff from heavy rains reached the stream.

Bank Height and Slope

Steep, high banks help to shade the river, especially the smaller, narrower streams, and help to keep the water cool on hot sunny days. Because higher banks usually are associated with greater depth to water table, evapotranspiration may be diminished and streamflow increased. In areas of cabin development the greater depth to water table promotes oxidation of sewage wastes from septic tanks before the wastes reach the river. Steep, high banks are vulnerable to erosion, and may contribute sand and silt to the river bed.

Height of banks of three rivers is mapped on figure 13. Most rivers in the study area alternate between high and low banks, but low banks (less than 3 feet high) generally predominate on the upper reaches. The bank on the outside of the loop of a meandering stream usually is higher than the bank on the inside. Where the outside of the loop impinges on the edge of a flood plain the differences in bank height may be very great.

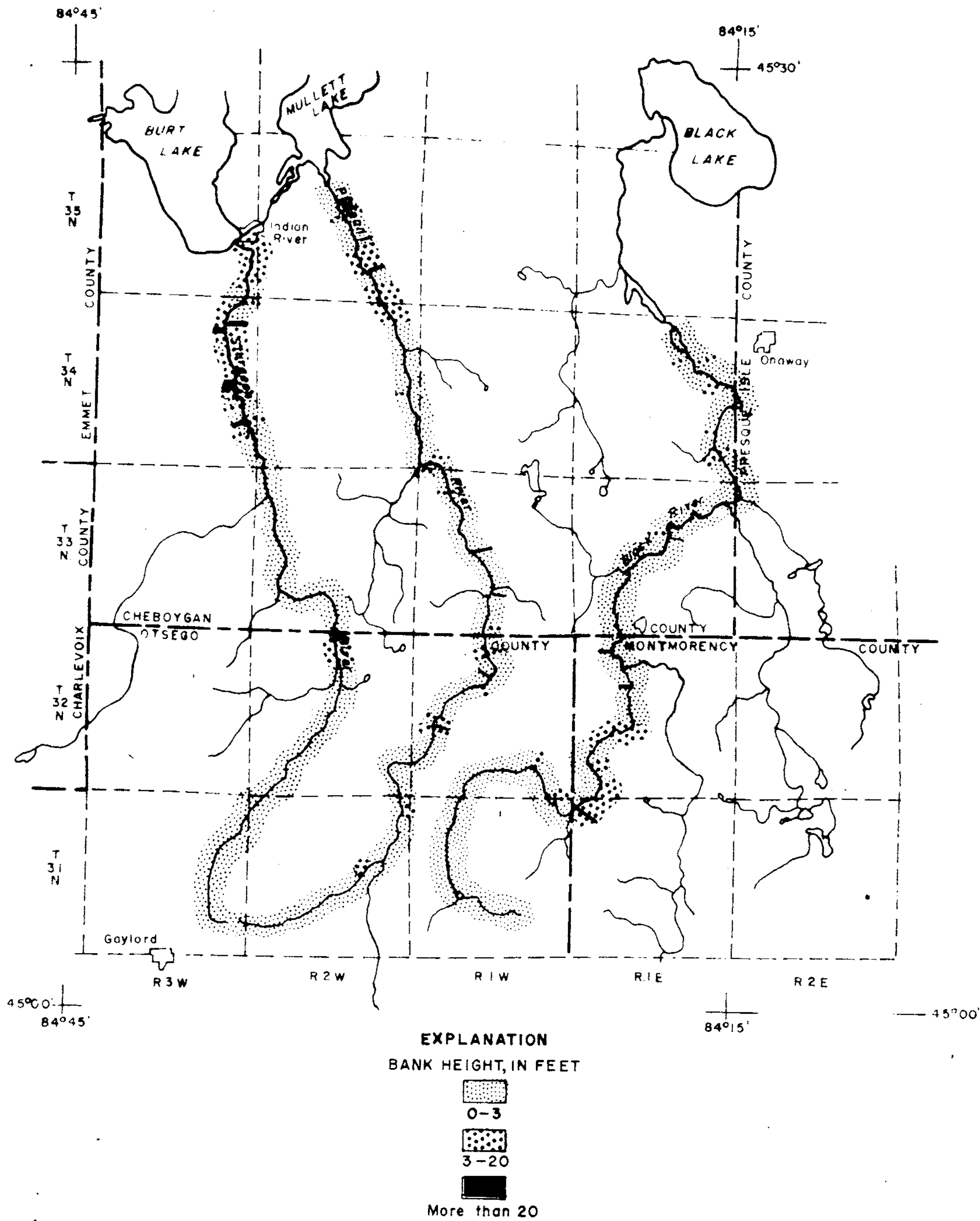


Figure 13. Low banks predominate on the upper reaches of most rivers in the study area, with alternating high and low banks in the lower reaches.

Bank Materials

Material eroded from the stream banks is a major source of the bed materials of a stream. As indicated above, high sandy banks are easily eroded and contribute sand to the stream bed. Clay banks, although more resistant to erosion, contribute to the turbidity of the stream. The clay particles, smaller and lighter than sand, may be held in suspension so that they are carried into the Great Lakes. Both sand and clay banks may contain pebbles, cobbles, and boulders which are too heavy to move at normal flows. As the banks are eroded the finer materials may be carried downstream, leaving the coarser materials on the bed of the stream.

Bank materials also influence the bankside vegetation which in turn effects the temperature and dissolved oxygen of the water. Sand banks usually support coniferous, poplar, or scrub oak trees, whereas silt and clay banks are more likely to support maple, elm, and the larger oaks. The bank materials in the study area are chiefly sand in the high ground and chiefly muck and peat in the swamps (fig. 14). Clay banks occur intermittently on most of the streams.

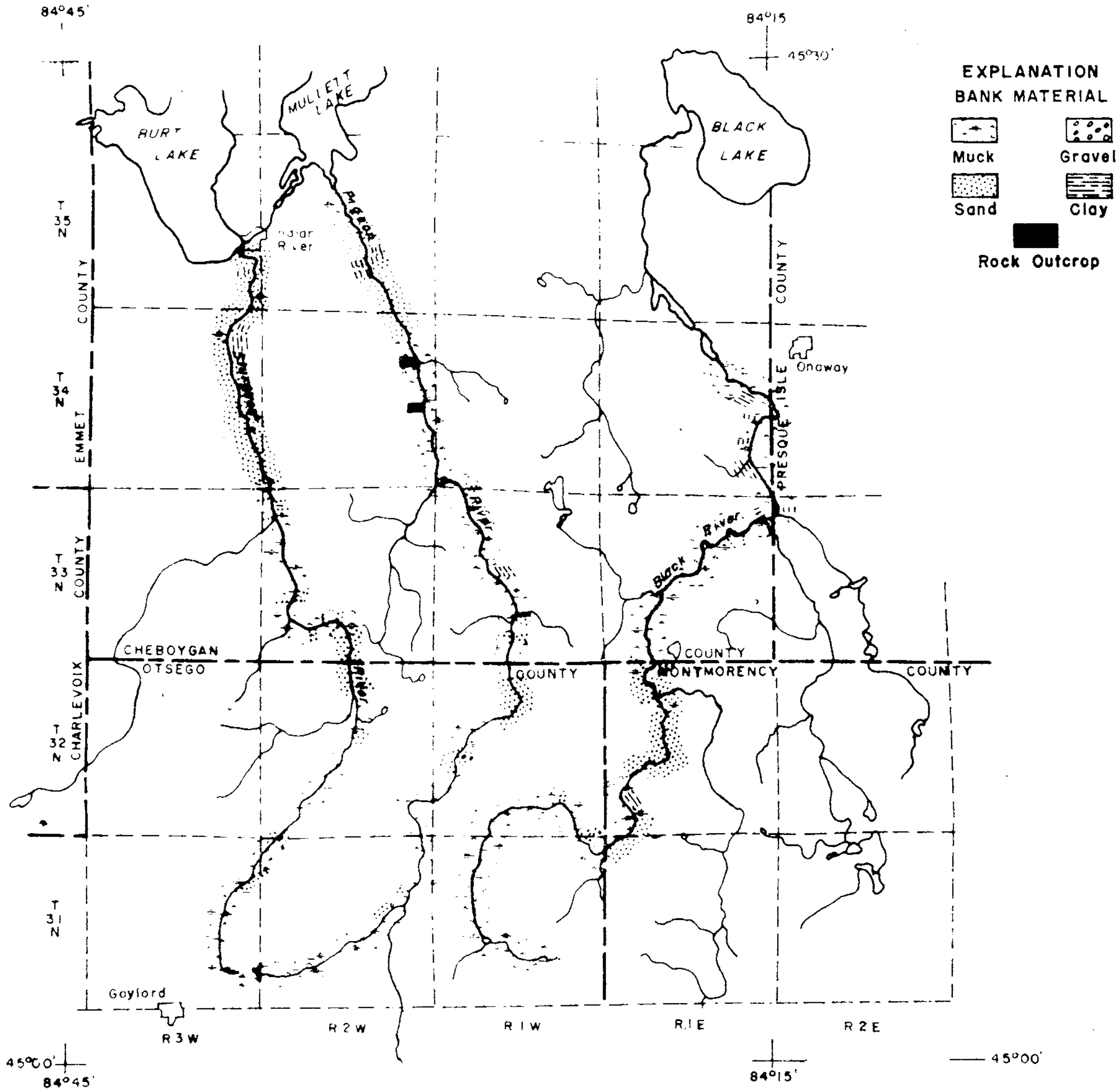


Figure 14. Low banks are chiefly muck; higher banks are predominately sand.

Bank Vegetation

The height and density of bank vegetation is a major control of stream temperature, especially on the smaller streams. A dense forest cover shades the river and keeps the water cool. Bank vegetation may help prevent bank erosion, thus reducing the turbidity of the water and the amount of sand deposited on the river bed. However, mature trees may discourage undergrowth to such an extent that erosion of silt or clay banks is accelerated. Trees that fall into the river reduce the velocity of flow near the banks, and may help to reduce bank erosion. On the other hand, fallen trees in a small stream may divert the flow toward the opposite bank and increase erosion of this bank. Open reaches of grassy banks allow sunlight to reach the water and promote growth of aquatic vegetation, resulting in warmer water and greater diurnal fluctuation in dissolved oxygen.

The rivers in the study area for the most part are lined with trees or brush (figs. 15, 16). Grass lined banks are limited chiefly to residential and agricultural areas.

Figure 16. Sturgeon River near Vanderbilt

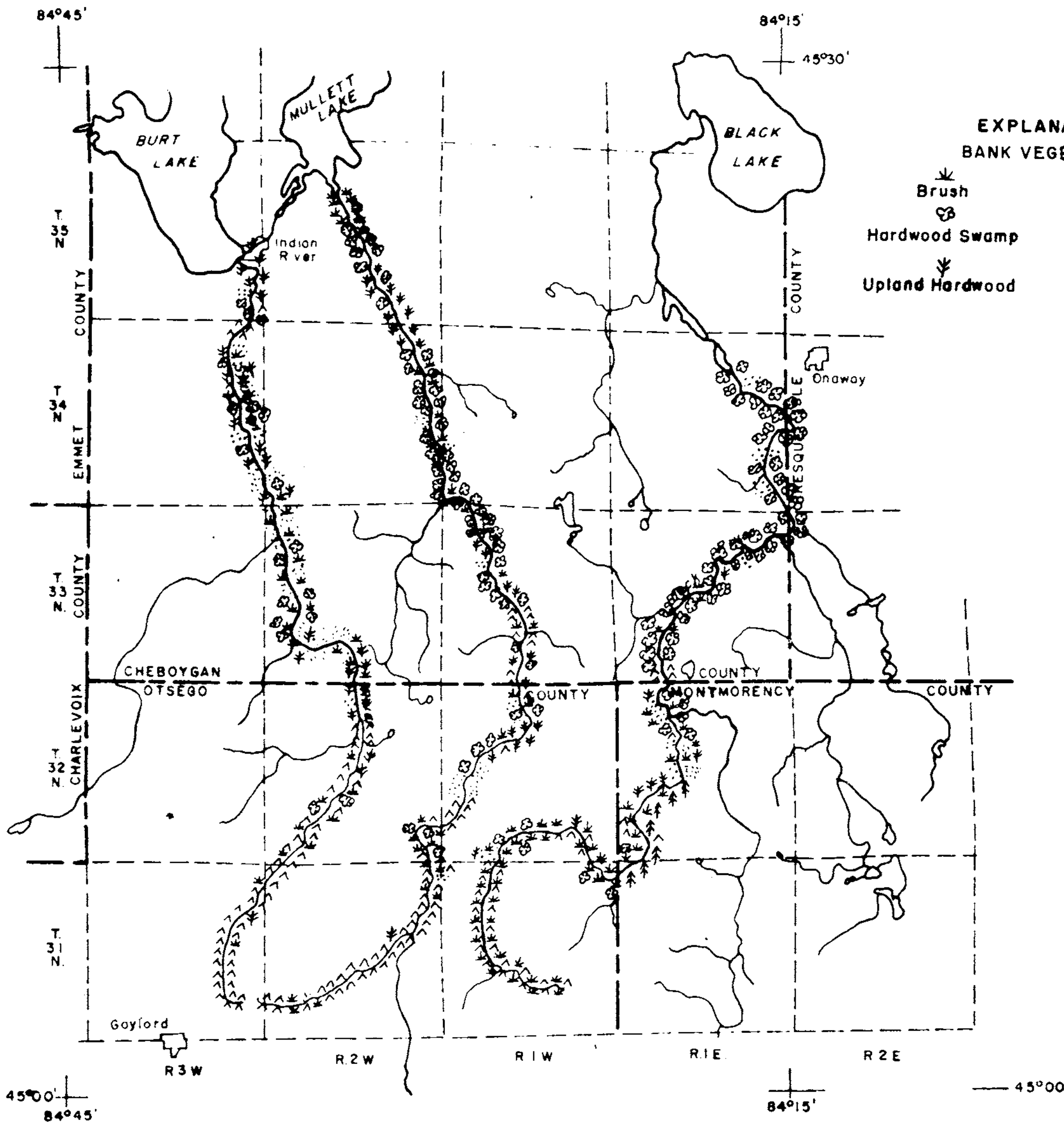


Figure 15. Bank cover is chiefly trees and brush with a few areas of open grasslands.

Aquatic Vegetation

Plants growing on the river bed strongly influence the dissolved oxygen content of the water and probably have some influence on water temperature. The diurnal variation in dissolved oxygen that occurs on all streams studied results from photosynthesis and respiration of aquatic plants. Where bottom vegetation emerges above the water surface it shades the water and reduces daytime temperatures. Dense bottom vegetation decreases the velocity of a stream and thus changes the stage-discharge relationship. Bottom vegetation also retards stream bed erosion.

The streams in the study area range greatly in density of aquatic vegetation. Some reaches of the Au Sable below Grayling are choked with vegetation in midsummer; other rivers, such as the Sturgeon, have very sparse vegetation.

River Profile or Gradient

The profile or gradient of a river refers to its fall per unit distance from source to mouth. The steepness of gradient influences recreational values chiefly by modifying the velocity of streamflow and the cross-sectional area of channel. Velocity and cross-sectional area, in turn, influence the temperature and dissolved oxygen content of the water, which also influence recreational values.

Where the gradient of a river increases the velocity of streamflow increases. If the rate of discharge remains constant the cross-sectional area of the channel must decrease. This usually results in a shallower depth of channel (fig. 17). The shallower depth combined with increased velocity frequently results in riffles or rapids.

Normally the profile of a river is relatively steep in the headwaters and relatively flat near the mouth. Locally, this general relation is modified by the geology of the river basin. The profiles in figure 18 are typical of rivers in the northern part of the Southern Peninsula. Gradient of most rivers in the study area range from 5 to 15 feet per mile, with local steepening of more than 50 feet per mile. Local steepening of gradient may occur where the rivers cut across moraines or beds of stoney outwash. Beds of dense clay in outwash deposits may also resist erosion and cause a steepening of gradient.

The relationship of bottom materials to stream gradients in the Au Sable River are shown in fig. 19. In general, bottom materials in steeply-sloping reaches are coarse gravel or clay, whereas bottom materials in the flatter reaches are chiefly sand, fine gravel, silt, and muck.

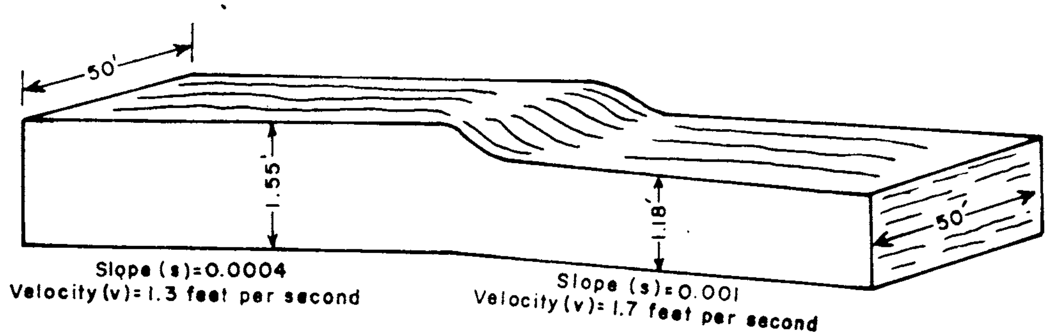


Figure 17. When the gradient of a river increases, velocity of streamflow usually increases and cross-sectional area decreases.

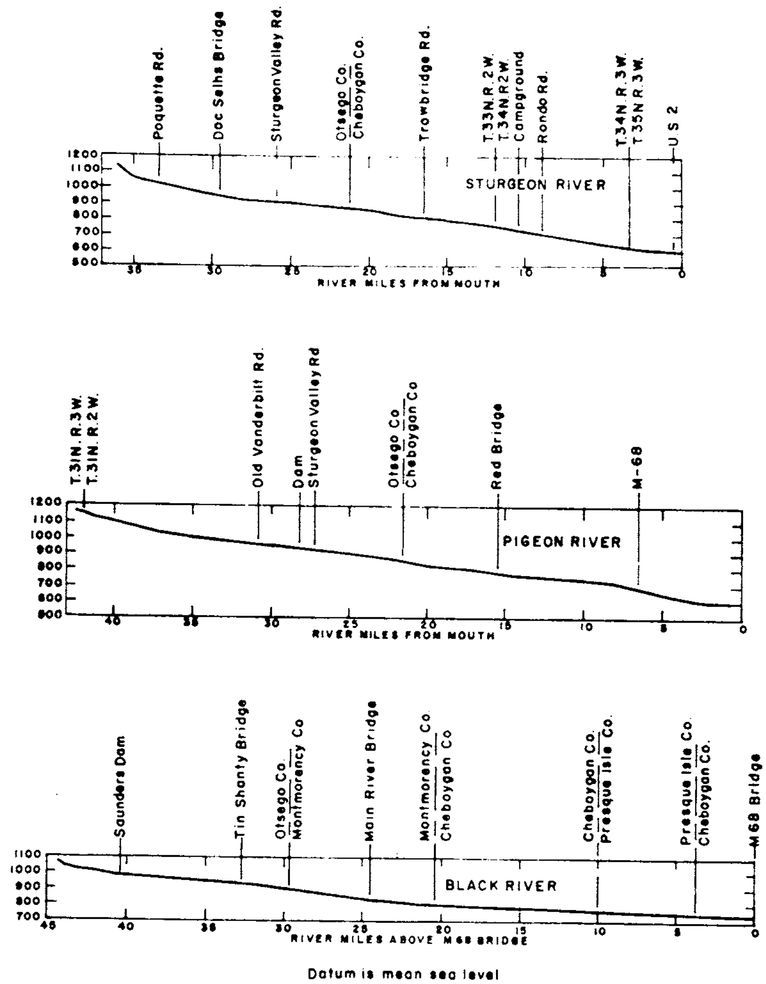


Figure 18 Profiles of the Sturgeon, Pigeon, and Black Rivers are typical of rivers in the study area.

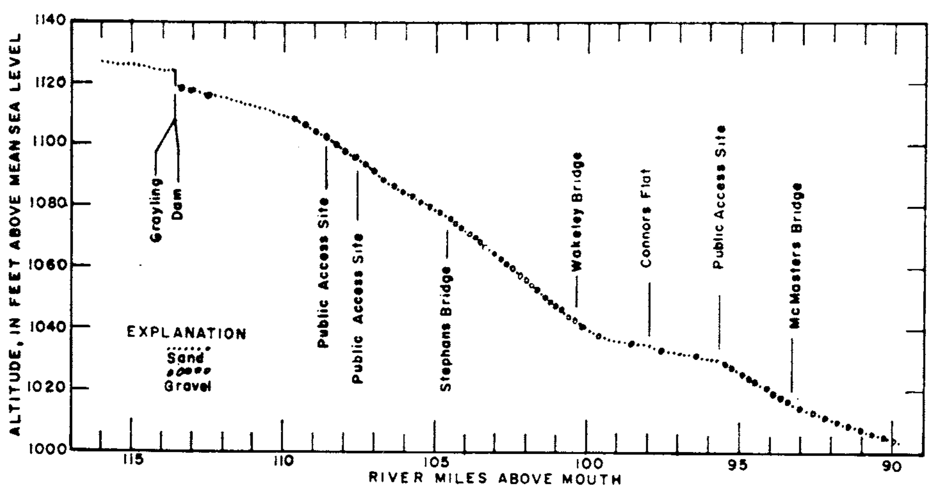


Figure 19 Bed materials in the Au Sable River are chiefly sand where gradient is gentle, chiefly gravel where gradient is steep.

Bed Materials

Bed materials influence streamflow characteristics and quality of water of a stream. Large rocks and boulders induce turbulent flow in a stream which stimulates aeration of unsaturated water. The permeability of bed materials may limit the inflow and outflow of ground water so that discharge of the stream, temperature of water, and dissolved oxygen content are affected. Bed materials influence the growth of water plants which also affect the temperature and dissolved oxygen of the water.

Bed materials of three Michigan rivers are mapped in figure 20. Materials mapped are sand, gravel, clay, and bedrock. Silt and muck, which is the bottom material in some of the deeper pools and in the still-water along most of the river banks, is not differentiated on this map because it is usually a minor component of any reach. Most rivers flow alternately on sand beds in the deeper pools and gravel beds in the riffles. Clay beds may occur in either riffles or pools, but clay makes up a very small part of the beds of most rivers in the study area.

The relationship of bed materials to stream gradient was described above and is illustrated in figure 19. The relationship of bed materials to geology of the basin is not so readily apparent, chiefly because the geologic map is not detailed enough to show all glacial features that would influence bed materials.

In some reaches a thin veneer of gravel overlies a bed of sand or sandy gravel. It appears that in cutting down through the sandy drift the larger pebbles and cobbles remain as the sand is carried away. In other reaches a thin veneer of gravel overlies a dense coherent clay. In these places it appears that the gravel was deposited over the clay as there does not appear to be gravel in the clay itself.

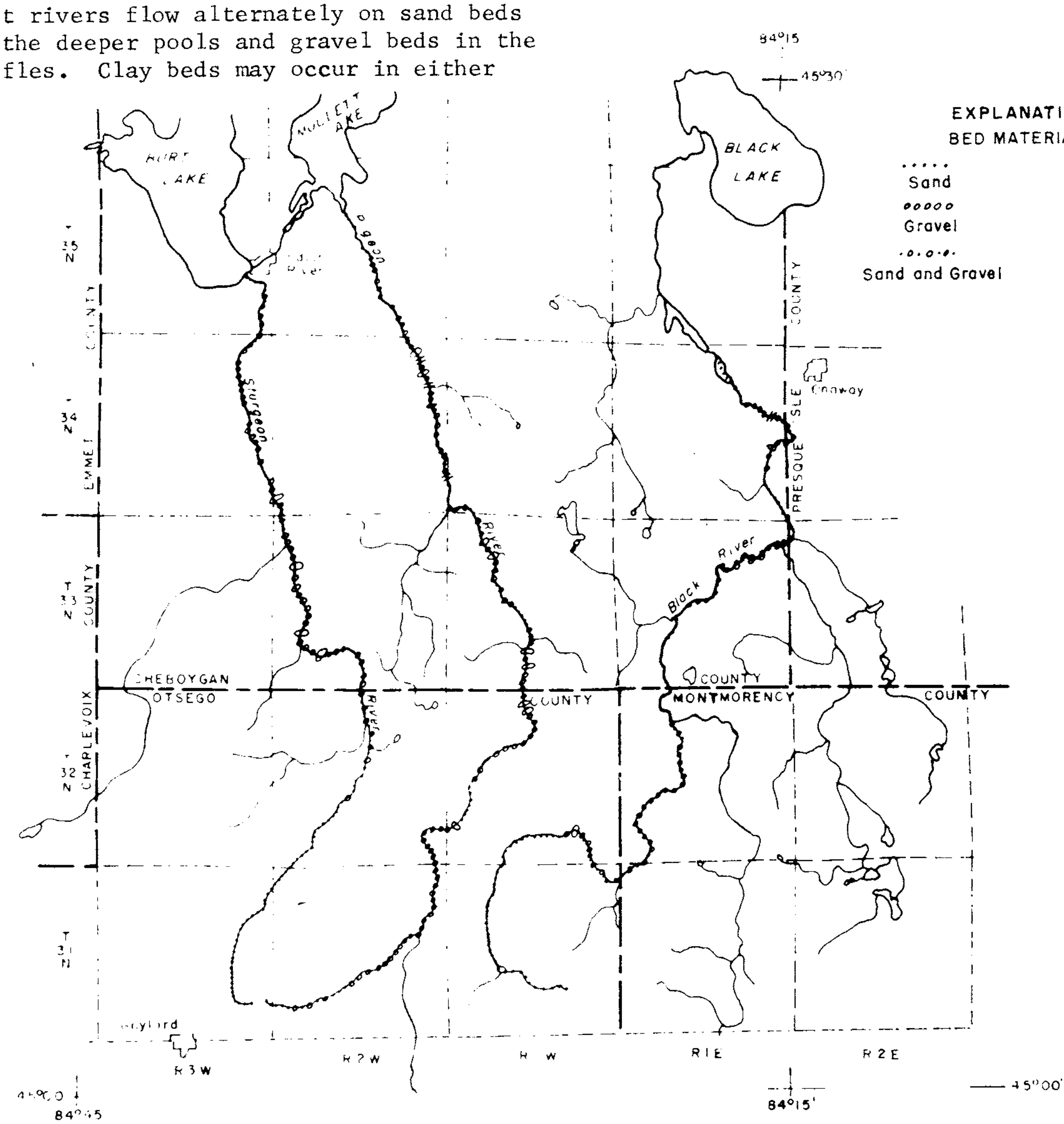


Figure 20. Sand and gravel beds alternate in varying proportions.

Recreation and the River Channel, Bed, and Banks

The physical character of a river influences streamflow and water quality, which, in turn, influence recreational values of the river. For example, a narrowing or shoaling of a stream channel, by decreasing the cross-sectional area, increases the average velocity of the stream. High or tree-covered banks shade the river and keep the water cool. The physical character of a river also directly influences recreational values. The character of bed and banks and of bank vegetation determines ease of accessibility to the river, the convenience and attractiveness of cabin and campsites, and the quality of esthetic values for all users. The earth materials making up the river bed are an important factor in the fish populations that a river can support.

For convenience of reference, each recreational use affected by the character of channel, bed, and banks is discussed below under separate heading. This arrangement makes it possible for those who are concerned chiefly with one recreational use of the rivers, such as boating, to concentrate on the sections of the report dealing with their area of interest.

Esthetic Considerations

Very likely all people who go to rivers for recreation enjoy the sights, sounds, and scents of the natural river. This enjoyment may be the chief attraction to some, only a background to others, but probably essential to all. The size and shape of the river channel, its width and depth, and the character of the river bed and banks all contribute to the attractiveness of a stream. The size of a river would not seem to be critical, as many small brooks are most attractive, whereas some large rivers are unsightly. Other qualities being equal, however, it appears that more people prefer to look at a large river than a small one. The cost per foot of water frontage perhaps reflects this preference (table 1).

The character of the river bottom is important esthetically if the river is shallow enough and clear enough that the bottom is visible. Gravel and boulders are usually considered to be most attractive, with sand, clay, and mud bottoms following in order of attractiveness. Shallow riffles, with accompanying sounds and sparkling waters, are attractive to more people than are deep quiet pools.

High banks generally give a better view of the river than low banks, but badly eroded banks are unattractive. Large trees, especially conifers, are more attractive than brush or young growth, but open park-like areas with scattered trees also are attractive. Litter of any kind on bed or banks is an obvious detraction and decreases esthetic values.

All the cold-water rivers in the study area are esthetically attractive in their natural state, although none are truly spectacular. With the ever-increasing pressure of urbanized living, the most critical need may be a natural environment with as little distraction by works of man as possible. From this standpoint the more attractive reaches of streams are those with the minimum evidence of streamside cabins, roads, bridges, cultivated fields, and other works of man. Some of the features that make rivers attractive are illustrated in figure 21. The photographs show the eye appeal, but cannot show the sounds and aroma that contribute to the attractiveness of these streams.

Table 1. -Hydrologic conditions and 1970 price of river frontage on cold water rivers in Michigan

Stream	Location	Character of channel and banks: Width (feet)	Depth (feet)	Bottom material	Bank height[1/] (feet)	Bank material[2/]	Estimated mean discharge (cfs)	Access: Dist. from freeway (miles)	Dist. from hard road (miles)	Amount of development in area	Ave. price per foot front[3/]
Little South Branch Pere Marquette	Near Baldwin	35	2	Gravel	2-3	Silt	70	55	1	Sparse	10.00
Au Sable River	North of Grayling	30	1.5	Sand	1-3	Sand	60	6	3	Sparse	30.00
Manistee River	Near Frederic	60	3	Sand	3	Sand	110	8	0	Moderate	40.00
Pere Marquette River	Near Baldwin	70	3	Gravel	3	Sand	160	60	0	Dense	50.00
Au Sable River	2 miles east of Grayling	100	3	Sand	2-3	Sand	120	3	1	Dense	60.00
Au Sable River	Wakely Bridge	100	2.5	Gravel	2-3	Sand	150	13	0	Dense	70.00
Pere Marquette River	Near Scottville	120	4	Sand	3	Sand	630	45	0	Moderate	100.00

1/ Cabin sites may be substantially higher in altitude than banks immediately adjacent to river.

2/ Muck occurs at water's edge at most sites.

3/ Averages based on estimates of local realtors and Chambers of Commerce.

Table 2.-Hydrologic Characteristics and Boating on the Au Sable River and Tributaries.

Stream segment	Location	Miles of stream	Houses: Residence	Cabins	Campgrounds	Boat Launch Access: Distance from freeway	Distance from hard road	Channel character: Mean width (ft)	Mean depth (ft)	Predominate bottom material	Shoals or obstructions[1/]	Streamflow: Approximate mean discharge (cfs)	Ratio 90%/10% discharge	Boating man-hours per mile per season: Pleasure	Loitering	Boat-fishing
Main Au Sable River upper	Grayling-Burton's Landing	5.6	16	24	1	1	0	88	3	Sand	None	114	.48	8,942	676	911
Lower	Burton's-Wakely Bridge	8.7	30	93	2	4	0.5	95	2	Gravel	None	192	.58	5,802	714	1,275
South Branch upper	Deerheart Valley Road to Downey's	7.1	3	14	-		0	60	2	Gravel	None	-	-	2,195	138	192
Lower,	Downey's to mouth	9.0	2	28	1			75	3	Gravel	None	215	.34	1,493	99	137
North Branch upper,	Dam 2 - County Line	4.2	-	3	-	8	7	70	1	Gravel	Many	80	.60	1	1	2
Middle	Co. line-Eaman's	6.9	15	45	1	17	4	108	1.5	Gravel	Some	165	.61	4	5	6
Lower,	Eaman's-Kellog Bridge	8.7	1	26	1	18	1	95	3	Gravel	None	224	.64	7	9	10

1/ Shoals causing grounding of loaded canoe.
Obstructions requiring portages.

The "Mason Grant" on the South Branch Au Sable River is set aside as a wilderness preserve.

A landscaped river-front on the Au Sable River provides a tamer, but attractive river setting.

Hardwood forests and high stream banks enhance the beauty of the Pere Marquette River at Rainbow Rapids

Figure 21. Typical river scenes range from near wilderness to well-landscaped lawns.

Fishing

The convenience, safety, and success of the fisherman depends in large measure on the character of the river channel, bed, and banks. A broad channel allows room for easy fly-casting. A shallow channel usually is easier and safer to wade than a deep one, if velocity is not excessive. A general rule for safe wading is that depth in feet, multiplied by velocity in feet per second, should not exceed 10 (fig. 22). This assumes a vigorous fisherman and a stream having a firm sand or gravel bottom. If bottom materials are slippery rocks or clay the safe depth and velocity would be considerably reduced.

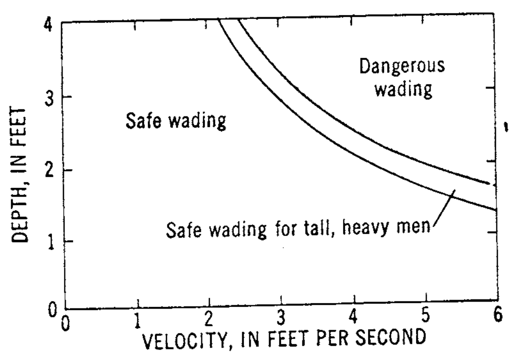


Figure 22. Safety in wading depends on the depth and velocity of the stream. Character of bed materials and skill of the wader also are important.

The success of the fisherman, in terms of number and size of fish caught, is dependent to some extent on fish populations, although other factors limit the catch on some streams. River bed materials are critical to trout populations--especially where populations are maintained by natural reproduction. Shetter (written communication, 1970) described bed materials favorable to trout reproduction as follows: "Trout, in order to reproduce, need gravels ranging from pea to hen's egg size in which to deposit their eggs. Preferably such areas remain sediment-free during egg development, and are porous enough to permit cool, well-oxygenated stream or ground water to circulate freely around the eggs. Since trout deposit their eggs from 2 to 12 inches below the surface of the stream bottom, the eggs are protected from ice, snow, waterborne debris, and most predators, until emergence as yolk-sac or free swimming fry in good habitats."

Bed materials also are important to the trout fishery in the production of smaller organisms on which the fishes feed. Gravel bottoms are most productive whereas sand bottoms are relatively barren. Not all gravel beds are equally productive. Clean gravels may be expected to be more productive than gravels that are choked and partly buried by silt or sand. Some of the gravel beds in the Manistee between M-72 bridge and Sharon appear to be silty or sandy. Possibly the reported low trout productivity of this part of the Manistee may be attributed in part to scarcity of clean gravels. Clay bottoms may contribute to turbidity of streams, but clays in most streams in the study area usually occur in small intermittent patches and make up only a small part of the bottom area. Muck and silt occur as bottom materials along the banks of most rivers in the study area, but they are not mapped as predominant bottom materials because they are limited to a narrow strip along the banks and rarely, if ever, extend to mid-channel.

Boulders, drowned logs, and fallen trees, in the river channel provide resting places and cover for trout (fig. 23). Reilly (1962) found that on a southern Michigan trout stream lack of cover was a major limiting factor in trout populations.

Figure 23. Drowned logs provide cover for trout.

In addition to the direct effects described above, the channel, bed, and banks of a river influence fishing and fish populations indirectly by affecting the sediment load and temperature of the stream. Clay banks may contribute to the turbidity of a stream, and sand banks may contribute to bed load. Hansen (written communication, 1971) found that high banks on the Pine River recede at about the same rate as low banks. Thus, high banks contribute a relatively large amount of sediment which may cover gravel spawning beds.

A broad, shallow river, such as the North Branch Au Sable River near Lovells, exposes a large area to sunlight, causing warming of the water. Sunlight also stimulates growth of aquatic plants. The plants contribute to the growth of the small organisms on which trout feed, but where plants are too dense, they choke the stream and cause an undesirable daily variation in dissolved oxygen content. A narrow and deep channel, such as the Sturgeon below Wolverine, exposes a relatively small area to the warming rays of the sun. Plant life is discouraged, fish food may be less abundant, and the daily variation in dissolved oxygen is reduced. A deep channel generally provides more cover for trout than a shallow one.

Bank vegetation is important in shading the stream, especially the smaller streams, and maintains cooler summer water temperatures. A shaded stream may have less abundant bottom vegetation than one that receives much sunlight. Thus, productivity of organisms that are fish food is reduced. Bank vegetation is important in reducing erosion of river banks. Trees that fall into the river are useful in providing cover for trout, but they may deflect currents and cause bank erosion. Most streams in the study area flow through forested land, with open areas limited to cabin sites. Some tributaries of the Rifle and Pere Marquette Rivers flow through cultivated fields, but even here the banks usually are wooded or bushy.

Boating

The river channel, which provides the roadway for the boater, chiefly determines the character of boating recreation. A wide, deep channel, such as the Au Sable below Parmalee Bridge, allows a great variety of boating, including power boats as well as canoes and other light craft (fig. 24). A shallow channel, such as the North Branch Au Sable near Lovells, restricts the boater to canoes and other shallow-draft boats. During drought flows the boater may be forced to "walk" his canoe through shoal areas. A narrow channel, less than 30 feet wide, often is obstructed by overhanging branches and fallen trees so that frequent portages are required. Frequent portages generally limit canoe traffic to the enthusiastic few who consider that the effort of portaging is well repaid by the relative peace and solitude they enjoy on these rivers.

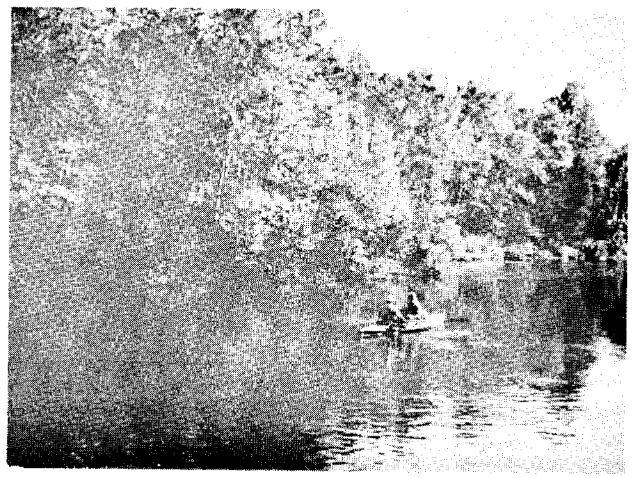


Figure 24. Kyak powered by outboard motor on Au Sable River

Overhanging branches and fallen trees obstruct the entire channel at frequent intervals in the upper reaches of almost all the streams studied. In the lower reaches, the streams are wider, and most obstructions do not completely block the channel. Consequently, portages are frequently required in the upper reaches and are infrequent or absent in the lower reaches. Some rivers, such as the Sturgeon and Pigeon, require occasional portages throughout most of their length. Others, such as the Au Sable and Manistee, are free of portages in all but the uppermost reaches and at power dams.

Braided channels, where the river breaks up into many smaller channels, are troublesome to most boaters. The channels usually are narrow and shallow, frequently obstructed by fallen trees, and unless the boater knows the river, he may find himself in a "dead end" road. Some braided reaches, such as "the spreads" on the Black River are nearly impossible to navigate. Others, such as on the Manistee below Frederic, are relatively easy to get through, because the major channels usually are easily identified.

Streambed materials are not especially important to the boater where the channel is deep, but they may become critical where the channel is shallow. Large boulders that are common in some shallow reaches of the Sturgeon River below Wolverine, coupled with a relatively high velocity, make boating difficult and sometimes dangerous to the inexperienced. Most streams in the study area are characterized by sand and gravel bottoms and constitute no threat to the boater. However, an occasional boulder or cobble may dent or crease the bottom of his canoe.

The character of the streambanks influence the boater chiefly in the quality of the esthetic enjoyment they provide. But they are of more direct interest where obstructions make portaging necessary.

Steep high banks, low swampy banks, or dense brush make portaging difficult. The ideal place for a portage has a gently sloping sandy bank to pull the boat out on, a dry sandy path through scattered trees or grassland, and another sloping sandy bank at the lower end to launch the boat. Such portages are rare in the study area. Foutunately for the boater, however, most portages are short--less than 100 yards from take out to launch point.

Alexander and Shetter (1966) made a study of boating on several segments of the Au Sable River and its tributaries. Statistics resulting from this study are tabulated with hydrologic data in (table 2). Boating activity, in man hours per mile per season, was greater in the upstream segment of the Au Sable than in the downstream segment, and much greater than all segments of the South and North Branches. Accessibility and convenience of facilities no doubt were the major controls of the relative amount of use of these stream segments. Canoe traffic on the main stem begins at Grayling, which is on Interstate Highway I-75. Several canoe liveries at Grayling supply rental canoes and pick-up service. The greater boating activity of the upper segment of the main stem as compared to the lower segment simply reflects the short trips made by most canoists. Only about half the canoes leaving Grayling go as far as Wakely Bridge, a river-distance of about 14 miles. The South Branch is also easily accessible by hard-surfaced roads, but access points are further from the Interstate Highway. The greater activity in the upper section here also is attributed to short trips originating at Roscommon, where canoe liveries are also located. The sparse boating activity on the North Branch is explained in part by the distance from well travelled roads and lack of rental facilities, but shallowness in parts of the upper and middle reaches probably is also an important factor. During drought flows canoes may be dragged through some of the shoal areas, and damage to canoes may be so great as to make canoe rentals unprofitable.

Camping

River banks that are moderately high and well-drained with scattered trees and grassy areas generally are desirable as campsites. An attractive river view also is important (fig. 25). The factors that influence campground attendance are many and varied, and the influence of non-hydrologic characteristics in many instances are predominant (table 3). Accessibility appears to be an important consideration, especially the distance to the campground from a hard-surfaced road. Some campgrounds are so remote that many campers do not know of their existence. Or, if they have heard of them, they are unwilling to risk getting lost while trying to find them. Two of the four campgrounds having less than 200 camper days per space are more than 5 miles from a hard-surfaced road, whereas each of the five campgrounds having more than 300 camper days per space are less than 2 miles from a hard-surfaced road. Another factor that may influence campground attendance is the availability of camping spaces affording a view of the river. Each of the five campgrounds having more than 300 camper days per space have campsites overlooking the river.

Pigeon River Bridge campsite equipped with drinking water, picnic tables, and toilets. No open view of river.

Boardman River campsite with all above facilities. Permits open view of river.

Figure 25. Camping facilities range from primitive to well-developed.

Table 3.--Hydrologic Conditions and Campground Attendance at Fourteen Riverside Campsites in Michigan

Campsite name	Location	Stream	Character Channel and Banks: Width (ft)	Depth (ft)	Bottom material	Aquatic vegetation	Bank height 1/	Bank material 2/	Open view of river	Access: Distance from freeway (miles)	Distance from hard road (miles)	No. of camps	Campground use, 1969: No. spaces	No. campers	Camper days	Camper days per space
Pigeon Bridge	SW1/4 sec.17, T.32 N., R.1 W.	Pigeon River	40	2	Gravel	Sparse	3	Sand	No	11	2.5	7	7	415	1,350	193
Pigeon River	SW1/4 sec.10, T.32 N., R.1 W.	Pigeon River	40	2	Gravel	Sparse	3- 5	Sand	No	14	5.5	22	22	870	3,230	147
Pine Grove	SW1/4 sec.16, T.33 N., R.1 W.	Pigeon River	50	3	Sand	Sparse	3	Clay and Sand	No	12	12	8	8	400	1,340	168
Manistee # 1	NE1/4 sec.7, T.27 N., R.4 W.	Manistee River	50	3	Sand	Sparse	5- 6	Sand	Yes	9	2	8	8	1,400	5,400	675
Manistee # 2	SE1/4 sec.7, T.27 N., R.4 W.	Manistee River	50	3	Sand	Sparse	5- 6	Sand	Yes	9	2	8	8	1,700	5,800	725
Manistee Br.	NW1/4 sec.31, T.27 N., R.4 W.	Manistee River	80	3	Gravel	Moderate	10-12	Sand	Yes	10	0	24	24	5,000	14,000	583
CCC Bridge	SE1/4 sec.26, T.26 N., R.6 W.	Manistee River	120	5	Sand	Moderate	10-15	Sand	Yes	21	11	21	21	2,370	5,700	271
Graves Crossing	SE1/4 sec.32, T.31 N., R.6 W.	Jordan River	40	3	Gravel	Sparse	3	Sand	No	30	0	10	10	920	2,300	230
Boardman Forks	SE1/4 sec.4, T.25 N., R.9 W.	Boardman River	35	2	Gravel	Sparse	3- 5	Sand	Yes	40	0	5	5	720	1,780	356
Au Sable Canoe Camp	NW1/4 sec.10, T.26 N., R.3 W.	Au Sable River	100	4	Sand	Dense	3	Sand	Yes	5	2	18	18	1,265	6,680	371
White Pine Canoe Camp	SW1/4 sec.7, T.26 N., R.1 W.	Au Sable River	150	4	Sand	Moderate	3- 6	Sand	Yes	13	3	25	25	2,300	3,860	154

1/ Camp sites usually are substantially higher than height of banks.

2/ Muck occurs at water's edge at most sites. Pine grove campsites are 10 to 20 feet higher than river bank

Cabin Living

Realtors in northern Michigan generally agree that "prime" river frontage for cabin sites is characterized by streambanks that are 5 to 15 feet high with the building site at least 4 feet above high water table. A favorable view of the river is another requirement of prime frontage which usually is afforded by moderately high banks (fig. 26). Mature trees, especially conifers, add to the value. Sandy soil is preferred to clay, because it is quickly drained after heavy rains, and does not become muddy in wet weather. Sandy soil is desirable also for good drainage of septic tank effluent. Realtors also agree that, other things being equal, frontage on a large river is in greater demand and brings a higher price than frontage on a small stream. Many non-hydrologic factors also influence the price of the river frontage. The distance from major population centers, distance from hard-surface roads, and the quality of access roads are important non-hydrologic controls.

The current (1970) price of some river-front properties, together with some hydrologic data and information on accessibility is listed in table 1. The prices listed are based on information furnished by realtors and Chambers of Commerce in various cities of the study area. Frontage on rivers that are wide and deep generally brings a higher price than frontage on narrow, shallow rivers. The influence of other hydrologic parameters on price of frontage is not apparent from this table, partly because the sample is too small and partly because the sites are very similar in most characteristics. For example, the bank materials at all sites are predominantly sand, and banks generally range from 3 to 5 feet high. Bottom materials are either sand or gravel at all sites and all the sites are on rivers that are cold and clear with high sustained flow.

Swimming and Wading

Swimming is not usually considered an important recreational asset of cold-water rivers, because water temperatures usually are too low for the comfort of most swimmers. However, in recent years, as family camping has become more prevalent, more and more children are swimming or wading in these streams (fig. 27).

Bed materials are important in swimming, as most people prefer sand bottoms to gravel or clay. Silt and muck bottoms, which are common near the banks of most streams are least desirable. Width and depth of channel determine whether the river is suitable for swimming or limited to wading. Parents of small children prefer a shallow stream for safety's sake; older children and young adults prefer the deeper waters.

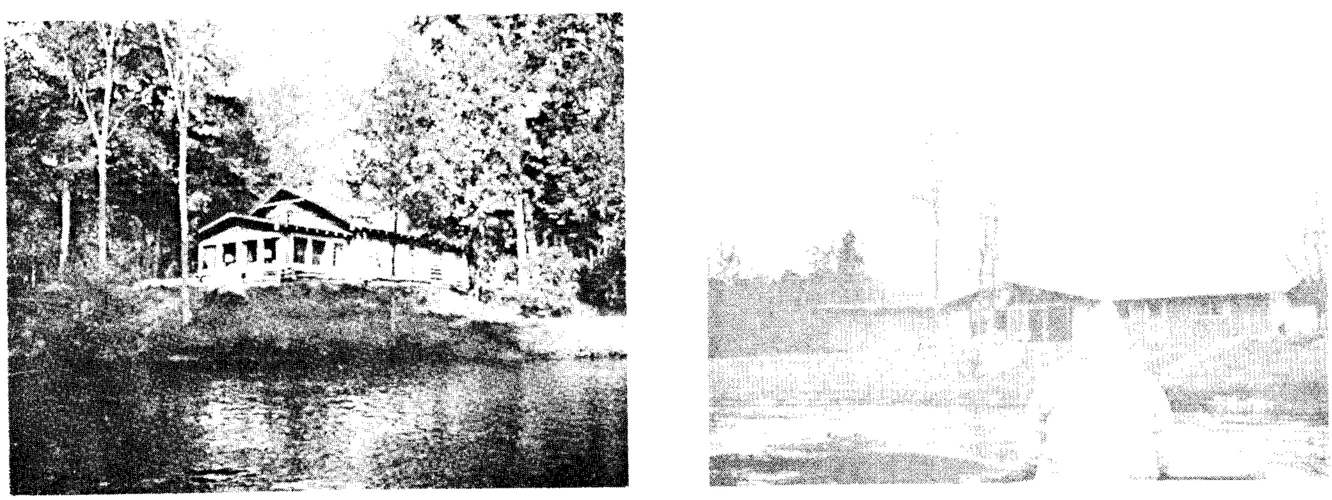


Figure 26. River-front cottages range from rustic cabins to year-around homes.

Water temperature of 59°F did not discourage wading and swimming on the Manistee River near Frederic.

Water temperature of the Au Sable River at the time of this picture was 65°F.

Figure 27. Swimming and wading are popular in some of the cold-water rivers.

STREAMFLOW

Those who are familiar with many rivers known that their flow characteristics vary widely. Some rivers are remarkably steady, rising only slightly in response to heavy rains or snowmelt, and declining very slowly during droughts. Others are very flashy, frequently overflowing their banks during snowmelt and heavy rains and dwindling to a trickle in dry periods. These differences in flow characteristics largely determine the recreational potential of the streams.

The relationships of streamflow to recreational values are complex, and can best be described by considering separately the major components--discharge, velocity, and stage. <u>Discharge</u>, in its simplest concept, means outflow. As used here, it is the volume of water moving past a given cross section of the stream in a unit of time; <u>velocity</u> is the speed of water movement; <u>stage</u> is the height of the water surface above an established datum plane. These components are related. When discharge increases, stage is higher, and velocity generally increases. The relationship between discharge and stage is used to define discharge at intervals of time between direct discharge measurements. Typical stage-discharge relations are shown graphically in figure 28. When the stage-discharge relation is significantly affected by ice or stream vegetation, two or more curves may be used. The curves may be changed from year to year as changes in configuration of channel change the relationship. The relationship of velocity to discharge is also apparent (fig. 29) although not so uniform as the relation of stage to discharge.

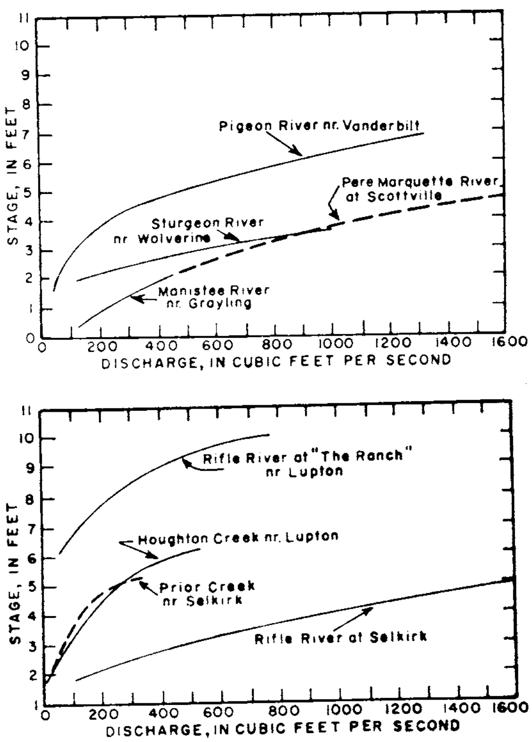


Figure 28. Increasing discharge is marked by rising stage.

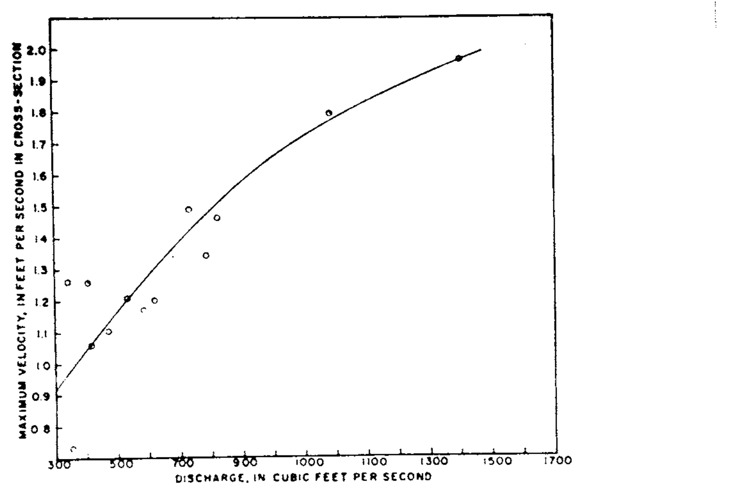
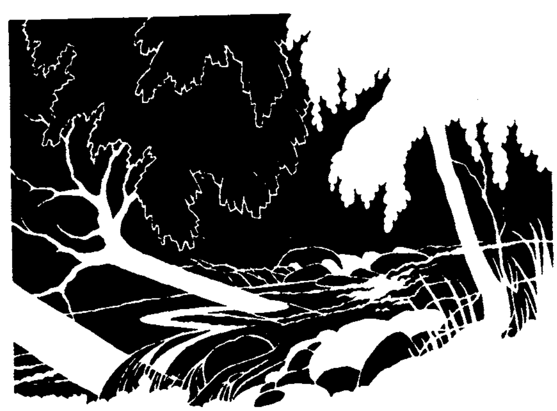


Figure 29. Velocity of flow increases when discharge increases.



Discharge

The discharge of a stream is perhaps its most fundamental characteristic, and all recreational values depend on it. Records of discharge of Michigan streams are published annually by the U.S. Geological Survey. Summaries of flow characteristics are compiled in two recent reports (Knutilla, 1967, 1970). Discharge may be expressed in various units. The average discharge for the period of record at a given station may be expressed as cubic feet per second (cfs), cubic feet per second per square mile (cfsm), or inches per year--the equivalent volume of water in inches on the drainage area above the gaging station. Runoff is that part of precipitation that appears in streams. Annual runoff in the major river basins in the study area varies from about 8 to 16 inches a year (fig. 5). Annual runoff in some of the smaller basins is as great as 36 inches, but these rivers receive some ground-water inflow from adjacent basins. Annual runoff is relatively large where the glacial drift is thick and composed chiefly of outwash and sandy moraine (figs. 6 and 7), and relatively small where the drift is thin or composed largely of lake beds and ground moraine.

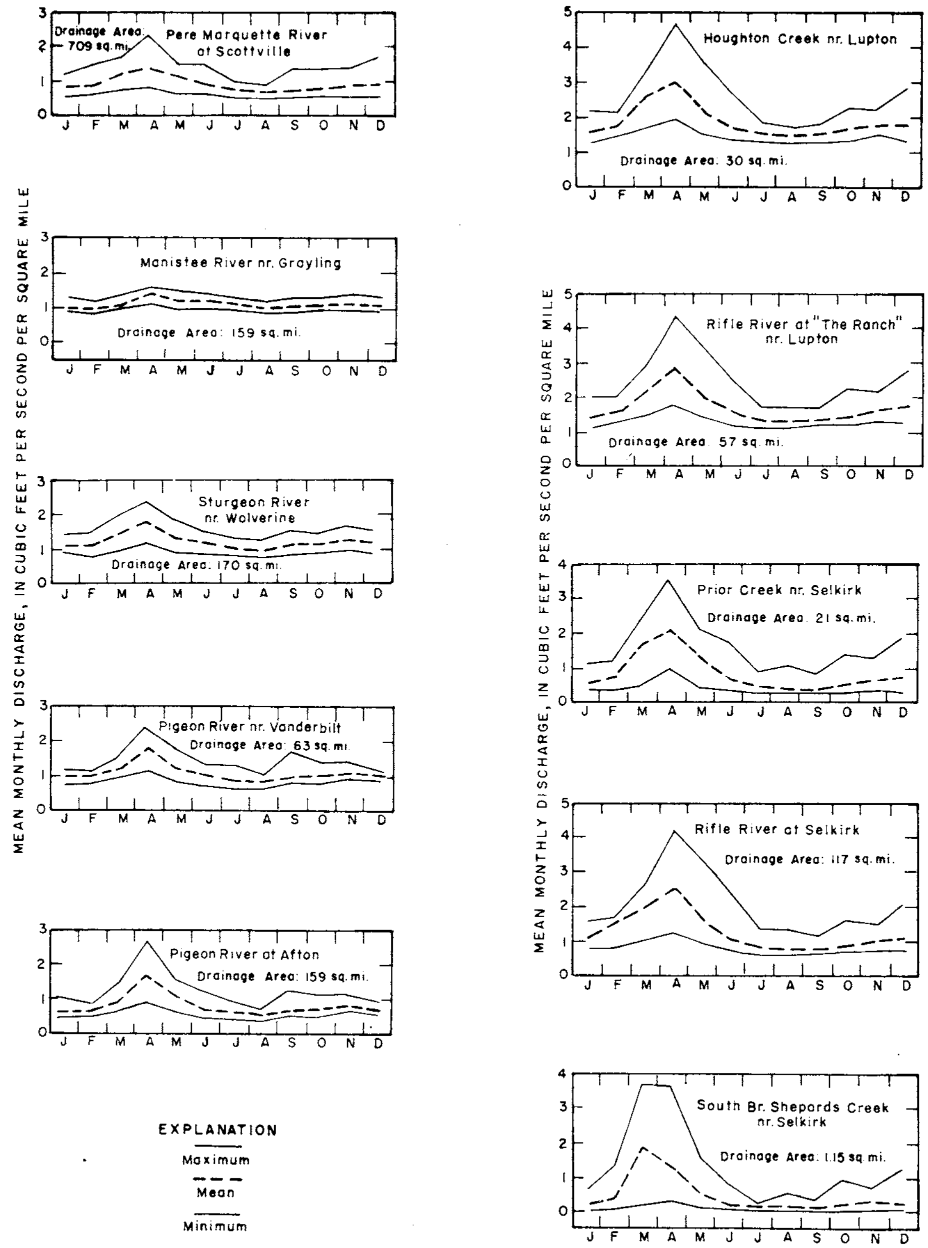


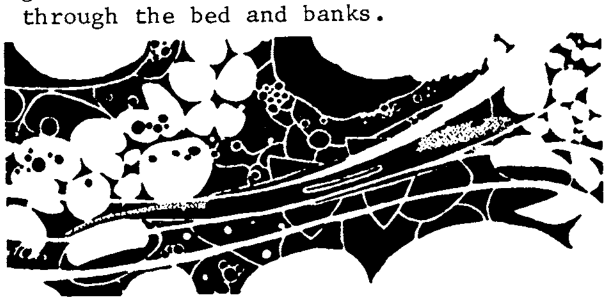
Figure 30. Discharge usually is greatest during the snowmelt period in early spring. Discharge declines during the growing season, when plants use large quantities of water. After killing frosts in the fall, discharge may increase slightly, but declines again in winter when most precipitation falls as snow.

Variations in Discharge

Average discharge is only one measure of the flow of a stream and is not necessarily the most important. More significnat to recreational values is the variability of discharge and the low flow or drought flow. A stream having highly variable flow usually has a relatively low flow during droughts.

Variations in discharge with time in an unregulated stream are caused by variations in precipitation, snowmelt, and evapotranspiration. Highest discharge normally occurs during the spring snowmelt (fig. 30). The magnitude of the "spring rise", or increase in discharge, depends on the water content of the snow, amount of frost in the ground at time of snowmelt, rate of melting, permeability of the soil, and slope of the land surface. Discharge usually declines during the late spring and summer months because growing plants use up (transpire) large quantities of water, and increased temperatures cause increased evaporation. Killing frosts in the fall reduce transpiration, and usually cause a slight increase in discharge. Much of the winter precipitation is in the form of snow and does not reach the river until the following spring. Thus, discharge declines during the winter months. Usually intense rains at any season may cause high rates of discharge (fig. 31).

The seasonal variations described above are common to all streams in this area, but the magnitude of variations ranges widely. The differences in magnitude of variations generally result from differences in the relative amounts of water derived from surface runoff and ground-water discharge. <u>Surface runoff</u> is that part of the runoff which travels over the soil surface to the nearest stream channel. <u>Ground-water runoff</u> is that part of the runoff which has passed into the ground, has become ground water, and has been discharged to a stream channel. Ground-water runoff may be concentrated in springs with visible openings, but most ground water enters the river as seeps through the bed and banks.



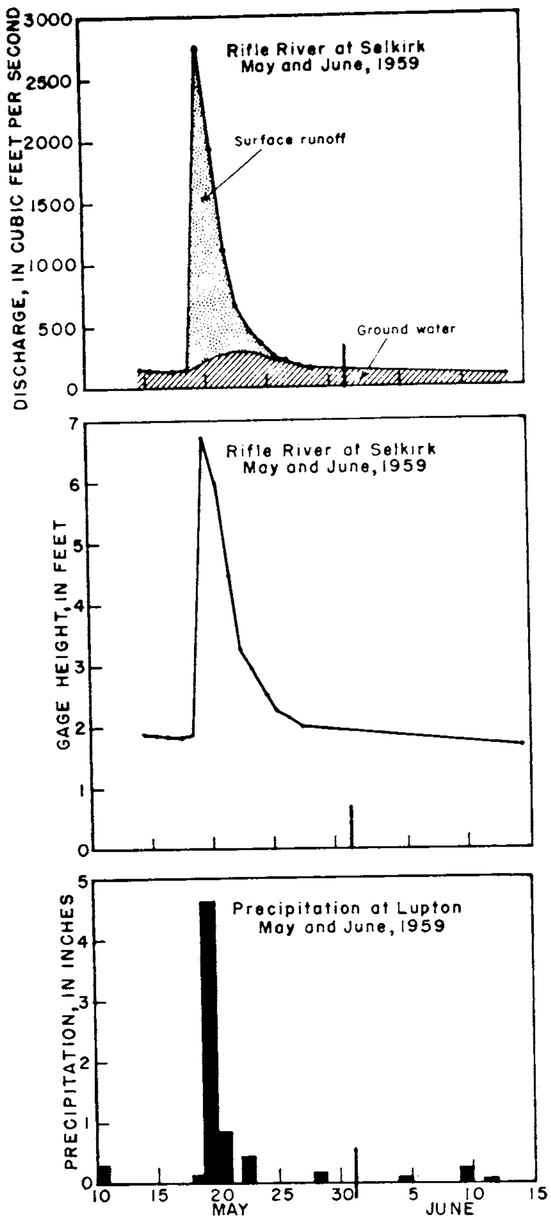
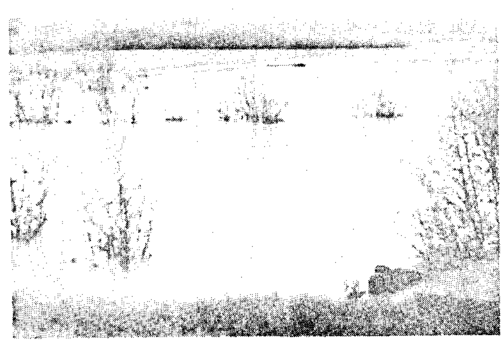


Figure 31. Unusually heavy rains, even during the growing season, cause abrupt rises in stage and increases in discharge on some streams.



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

Surface runoff reaches the river a short time after rains (or snowmelt)--usually within a few hours. After reaching the peak discharge, surface runoff declines rapidly (fig. 31). Ground-water runoff is slower to reach the stream and slower to decline after reaching a peak. It is ground-water runoff that keeps the river flowing during rainless periods. In general, the greater the component of ground-water discharge the more uniform the flow. Hydrographs showing estimated surface runoff and ground-water runoff on several streams are in figure 32.

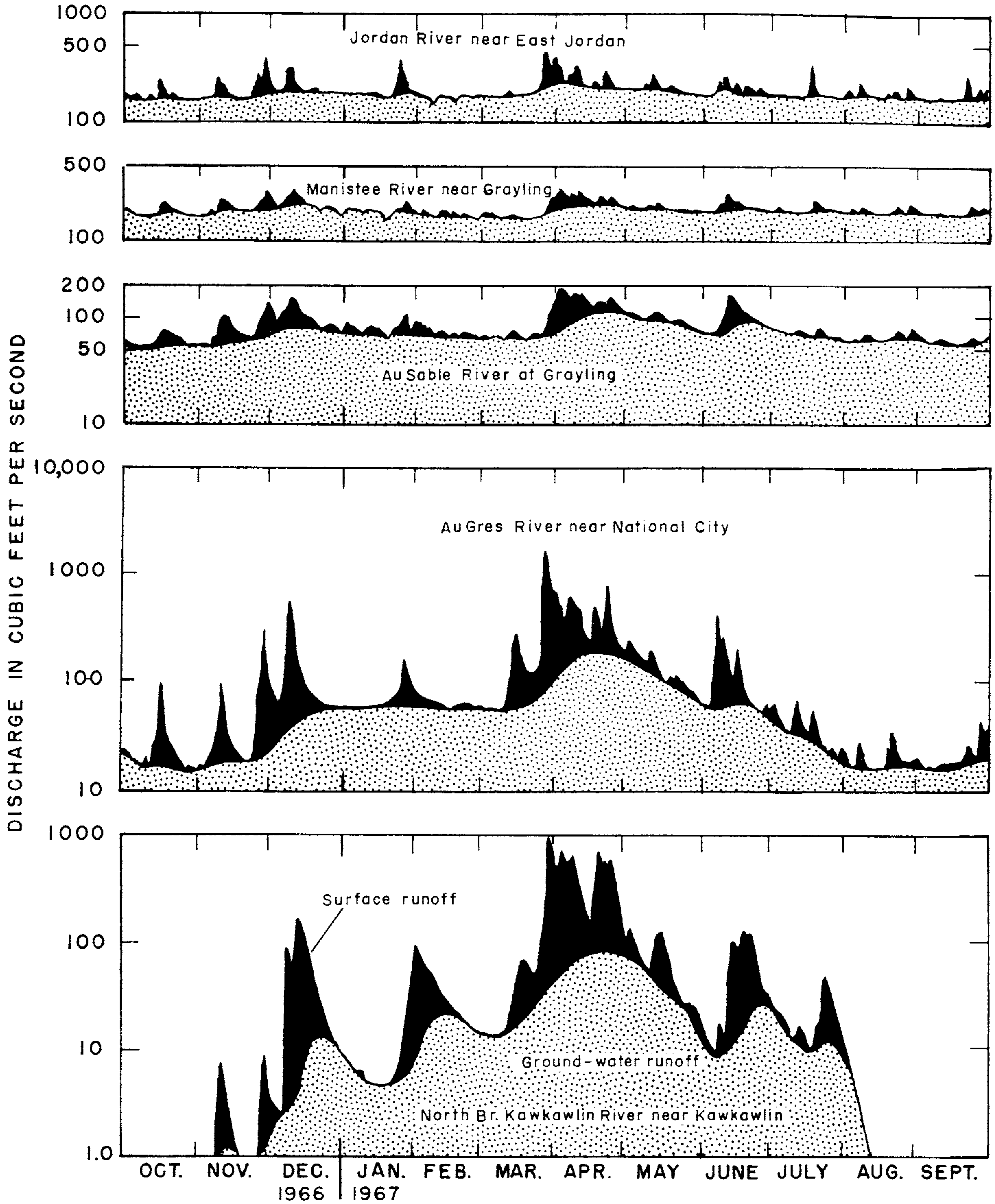


Figure 32. The relative amounts of ground water and surface runoff varies widely in different streams. The discharge of the Jordan, Manistee and Au Sable Rivers is 80 to 90 percent ground water. Discharge of the Au Gres and North Branch Kawkawlin Rivers is less than 50 percent ground water.

During prolonged rainless periods, when stream discharge is entirely from ground-water inflow; the water table in the drainage basin falls as water is removed from storage (fig. 33). The rate of decline varies with the rate of ground-water discharge and with the storage coefficient (the volume of water in cubic feet, released from storage in each vertical column of the aquifer having a base of 1 foot square when the water table declines 1 foot) of the aquifer. The storage coefficient of sand and gravel aquifers may be as great as 0.3. Thus, with this storage coefficient, a water table decline of 10 inches represents a release of 3 inches of water to the stream. If this decline occurs over a period of 90 days, the release from storage would be equivalent to an average discharge of about 0.9 cfsm.

Sand and gravel in glacial outwash deposits may store large quantities of ground water which is slowly released to streams.

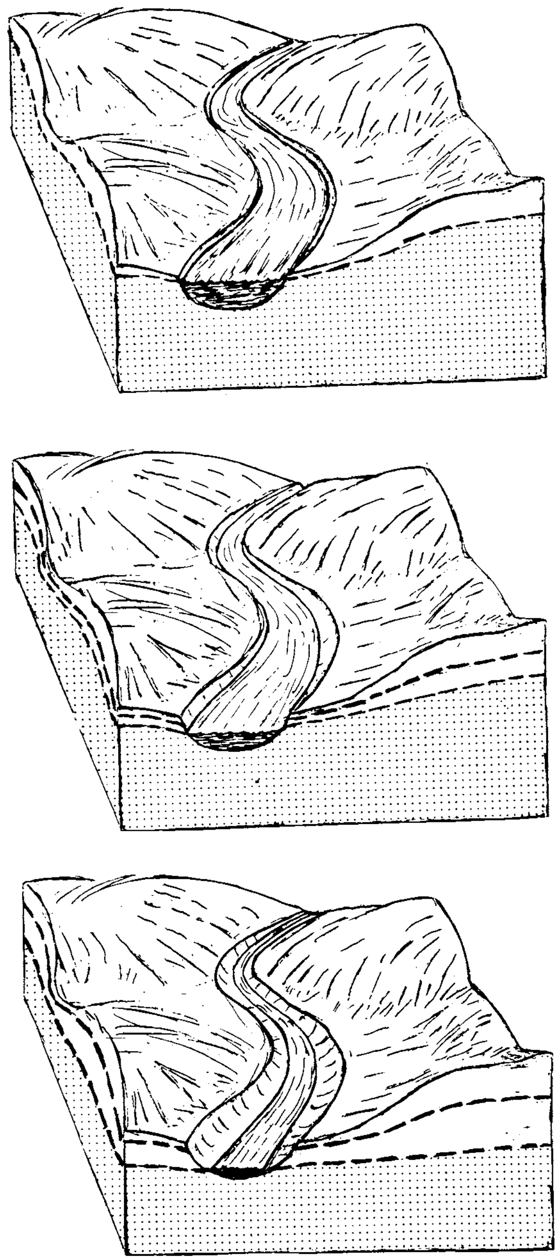


Figure 33. During prolonged rainless periods the water table falls as water stored in the aquifer is discharged to streams.

In addition to the variations in discharge with time, described above, are the variations at different sites on a stream. Normally, discharge increases downstream, as a greater area is drained. But in some reaches during base-flow conditions streams may decline in discharge as water percolates through the streambed into adjacent permeable materials. The water lost from one reach of stream may reenter the stream at some downstream reach, may be lost by evapotranspiration, or it may move out of the basin to discharge into another stream at a lower elevation. Losses to the water-bearing materials can occur only where the water table is lower than the stream surface. The relationship of water table to stream surface may be complex, with some reaches of the stream gaining water from the ground-water reservoir, and other reaches losing water to it (fig. 34).

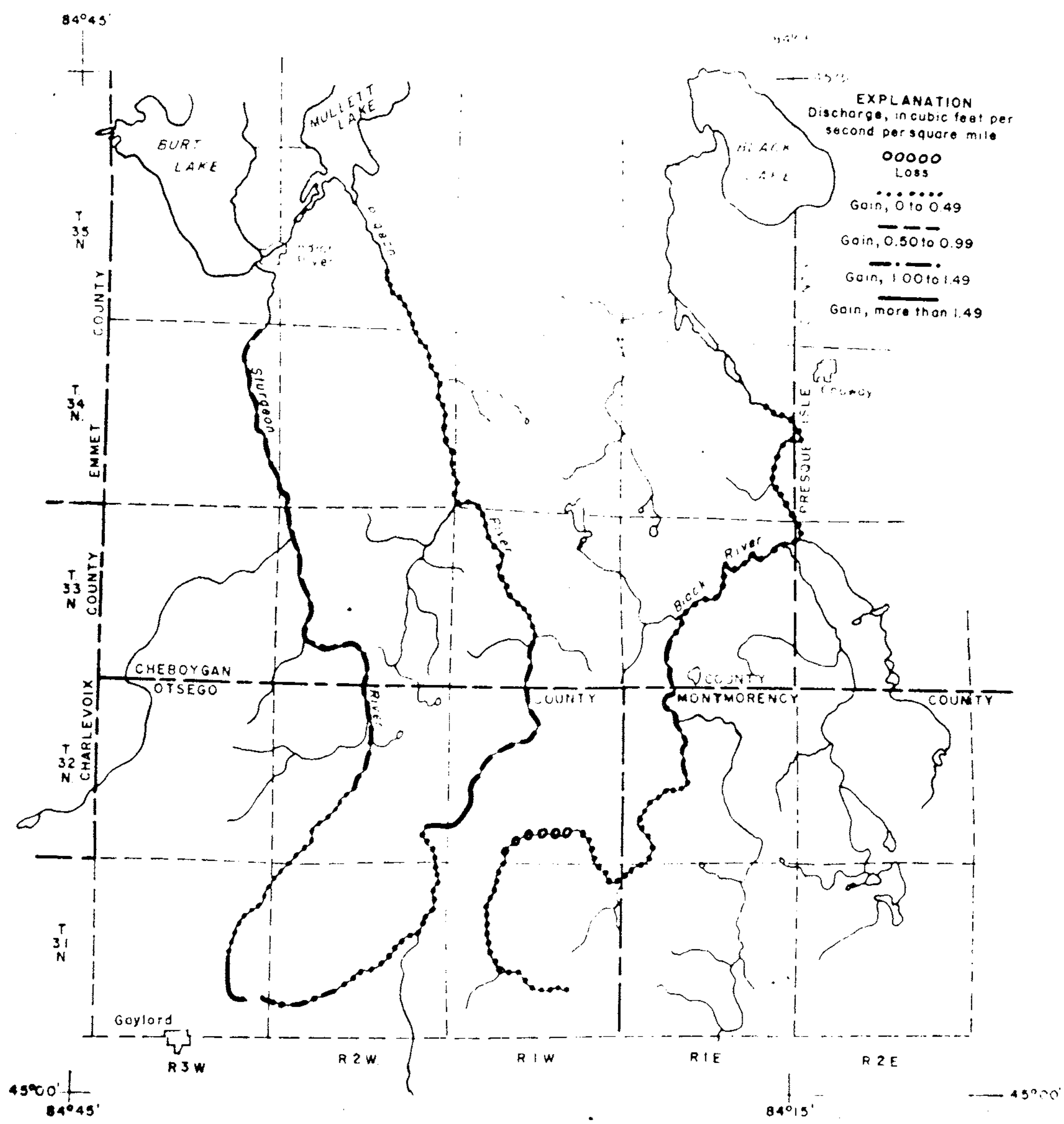


Figure 34. The rate of increase in discharge with increased drainage area varies in different reaches of stream. Water lost from the upper Black River may reappear at a lower elevation in the Pigeon, or it may be lost chiefly to evapotranspiration. (Sturgeon, Pigeon, and Black Rivers, July 18, 1966.)

Flow-Duration Curves

The variability of discharge of a stream can be shown graphically by flow-duration curves. These curves show the percentage of time that specified discharges are equaled or exceeded (fig. 35). For example, discharge of the Manistee River near Grayling is at least 210 cfs (1.3 cfsm) 10 percent of the time and at least 160 cfs (1.0 cfsm) 90 percent of the time. The small difference in discharge between the 10 percent and 90 percent duration is typical of a river with a very high component of ground-water discharge. By way of contrast, discharge of the Au Gres River near National City varies from 200 cfs (1.2 cfsm) at the 10 percent duration discharge to about 18 cfs (0.1 cfsm) at the 90 percent duration. The Au Gres is typical of a river with a relatively large component of surface runoff.

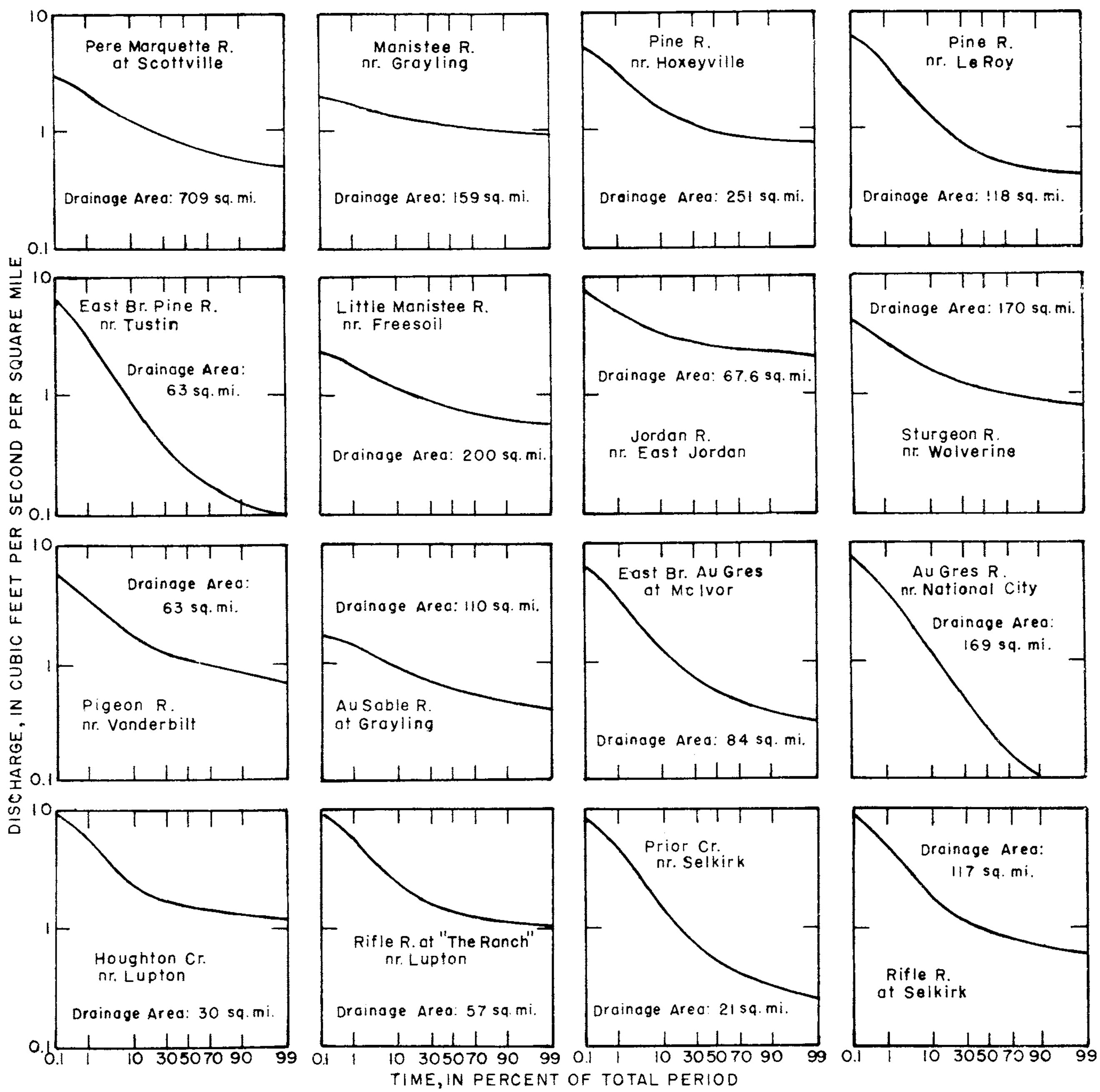


Figure 35. Flow duration curves show the percentage of time that specified discharge are equaled or exceeded. Streams having a large component of ground-water flow, such as the Manistee near Grayling, are characterized by relatively flat curves. Streams with small ground-water discharge, such as the Au Gres near National City, have relatively steep curves.

Bar graphs of the 10 percent and 90 percent duration discharges for several Michigan streams indicate a considerable difference in relative amounts of ground-water discharge and surface runoff received by the streams (fig. 36). The graphs are shown in units of cubic feet per second per square mile for convenience in comparing streamflow characteristics of basins of different drainage areas. Seven of the 18 stations shown in figure 36 have discharges greater than 0.8 cfsm 90 percent of the time. Probably most of these streams receive some ground-water discharge from adjacent basins. The large discharge of the Jordan River near East Jordan at both the 90 to 10 percent durations is attributed to a large increment of ground water from adjacent basins to the southeast. The relatively low discharge of the Au Sable at Grayling at both low and high flows is attributed to interbasin leakage of ground water to the Sturgeon and Pigeon Rivers to the north, and probably to the Manistee River to the west.

Ratios of the 90 to the 10 percent duration discharge are also shown on figure 36. The larger ratios indicate greater stability of flow and a larger contribution of ground water to the flow. Ratios vary from 0.75 on the Manistee near Grayling to less than 0.01 on the North Branch Kawkawlin near Kawkawlin. Eight of the 18 stations have ratios greater than 0.5 indicating a relatively large contribution of ground water.

The annual reports of surface-water records can be used to obtain a rough estimate of the variability of discharge of a stream where flow-duration curves have not been prepared. For example, records of discharge of the Manistee near Grayling for the 1967 water year show a mean April discharge of 251 cfs and a mean September discharge of 181 cfs. Ratio of the September discharge to the April discharge is about 0.72, or very nearly the same as the ratio of the 90 to the 10 percent duration (0.75) at that station. Records of the Au Gres at National City for the same year show the September to April ratio to be about 0.06, which is comparable to the 0.09 ratio of the 90 to the 10 percent duration at that station. The records of any given year are not as meaningful as the flow-duration curves for a period of several years, but they do give a general idea of the variability of flow at any station.

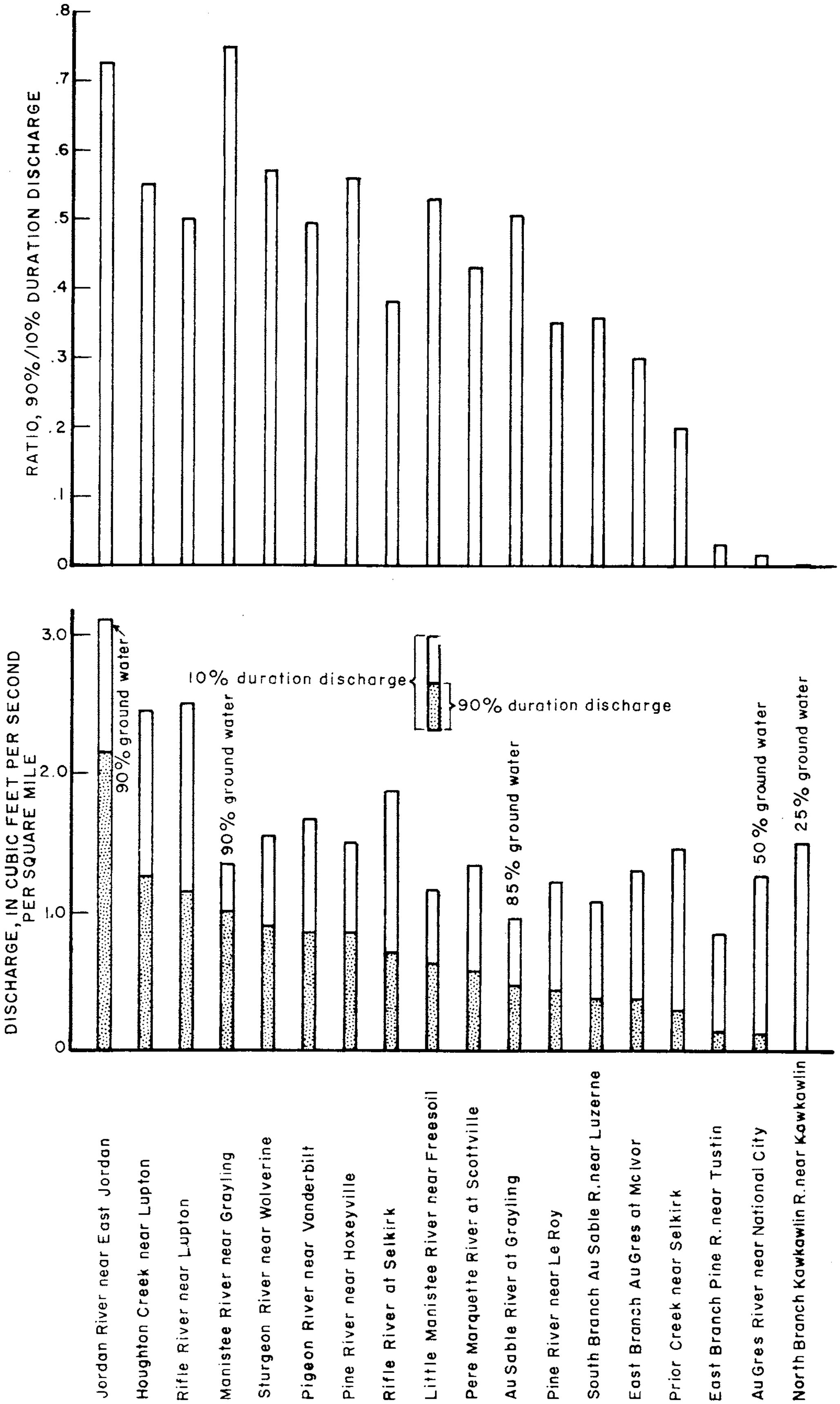


Figure 36. Discharge characteristics reflect the relative amounts of ground-water discharge and surface runoff. Streams having high flows at the 90 percent duration and streams having high ratios of the 90 to the 10 percent duration usually discharge relatively large amounts of ground water and relatively small amounts of surface runoff.

Base Flow

Flow-duration curves indicate gross differences in the relative amounts of ground-water discharge and surface runoff, but they do not directly indicate the quantities of ground-water discharge. Several methods have been devised to separate the discharge of a stream into its ground water and surface water components. Although none of these methods yields precise results, useful estimates can be obtained. Hydrographs in figure 32 separate the flow into ground-water discharge and surface-water discharge.

The ground-water component of discharge varies widely--from about 90 percent of the total flow in the Manistee River near Grayling to about 25 percent in the North Branch Kawkawlin River near Kawkawlin. These differences, as indicated above, are largely the result of differences in geology, topography, and soils of the basins.

During the season of the year when there is no snow cover it can generally be assumed that essentially all water in the smaller streams after about 5 rainless days is ground-water discharge. Exceptions are regulated streams and streams draining lakes and wetlands. This probably holds true for all streams draining areas less than 100 square miles. Accordingly, a series of measurements at such a time at various stations in a river basin, or in several adjacent basins, provides an approximate indication of the relative amounts of ground-water discharge at these stations. Records of this kind were used to supplement the records at the regular gaging stations to show the general base-flow conditions in Michigan (fig. 37). The area of high base flow (more than 0.6 cfsm in the northwestern part of the Southern Peninsula includes large areas of permeable glacial outwash with soils having high rates of infiltration (figs. 6, 8). Areas of low base flow near Lake Huron and Saginaw Bay are underlain by relatively impermeable lake beds and tight soils.

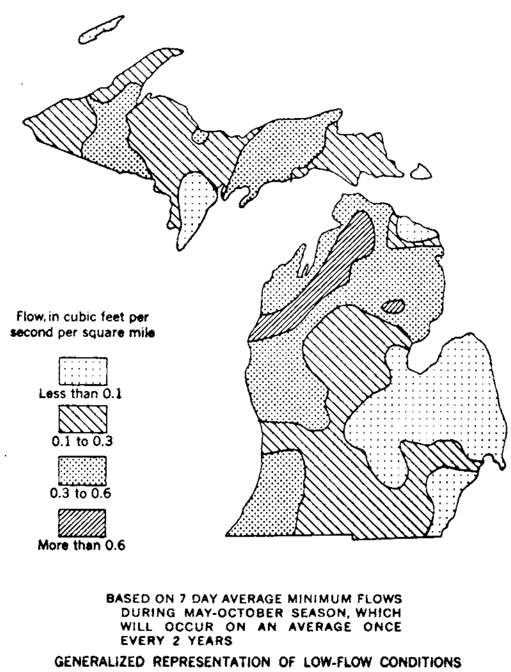


Figure 37. Discharge of streams at low-flow conditions ranges from less than 0.1 to more than 0.6 cubic feet per second per square mile. (Based on 7-day average minimum flows during May-October season which will occur on an average once every 2 years.)

Frequency of Low Flow

The frequency of low flow of a river is of interest to recreationists because periods of excessively low flow are unfavorable for most recreational uses. Because the low flow of a stream is essentially ground-water discharge, the natural controls of low-flow characteristics of a river are the climate, geology, topography, and soils of the basin. Man-made controls are discussed in a latter section.

Frequency of low flows on several rivers for periods of 7 and 30 days occurring during the 6 months May through October are shown on figure 38. Low flow characteristics vary widely on streams in the study area. A wide gap between the 30 day and 7 day curves, such as those for the Au Gres River, usually indicates a stream with a small component of ground-water discharge. Closely-spaced and nearly-paralleled curves, such as those for the Manistee River, indicate a stable flow with a large component of ground water.

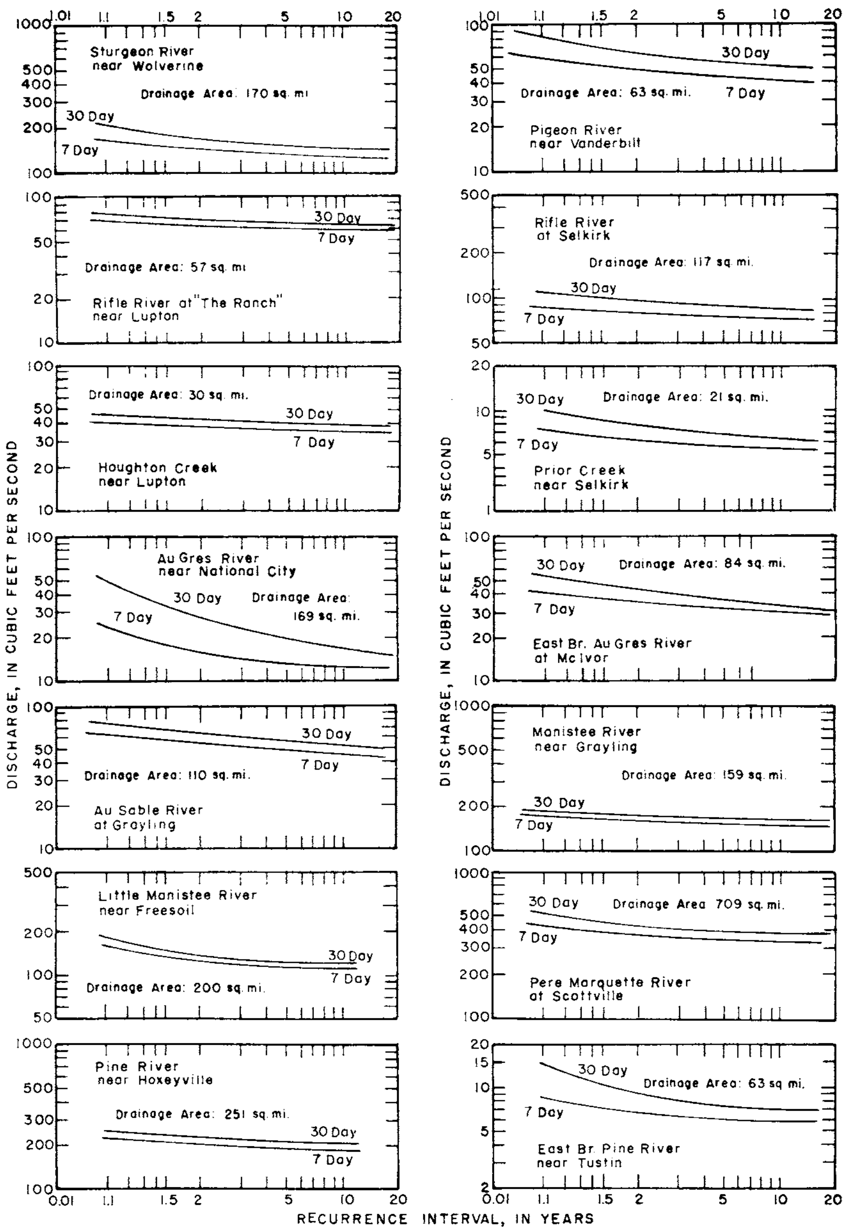


Figure 38. Frequency of low-flows (May through October) on cold-water rivers are of interest to recreationists because periods of excessively low-flow are generally unfavorable for recreational uses. The curves show, for example, that a discharge no greater than 50 cfs for 7 consecutive days can be expected on the Pigeon River near Vanderbilt about once every two years.

Flood Flows

Flood flows on most cold-water rivers of the study area are not a serious problem, because the permeable materials in the river basins generally do not contribute excessive surface runoff. However, some of the river basins, such as that of the Rifle River, are underlain by areas of clay till or lake beds, and flood flows in these basins may occasionally damage highway structures, cabins and campsites and accelerate erosion of sandy river banks. As indicated above, the amount of frost in the ground at the time of snowmelt strongly influences flood flows. However, the very porous sandy soils in much of the study area usually have relatively small amounts of frost.

Velocity

The velocity of a stream at a given point usually is greater at high than at low rates of discharge (fig. 29). The plotted points on figure 29 are the results of discharge measurements which may be made at different places because of stream conditions at time of measurement. Had all measurements been made in exactly the same cross-section the correlation no doubt would have been better. Maximum velocities in some streams are as much as 10 times greater at high than at low flows. Velocities also vary at different stations on the same stream. The average velocity is equal to the discharge divided by the cross-sectional area. If discharge remains constant, any change in cross-sectional area must be accompanied by a change in velocity. This is quite apparent in most streams where water moves slowly through deep pools and rapidly through shallow riffles. Most streams in the study area have velocities ranging from several tenths of a foot per second in the pools to 2 to 4 feet per second in the riffles. Velocities in a few of the rapids may be as great as 6 feet per second. The gradient of a stream also affects velocity, a stream generally flowing faster in steep reaches than in flat ones. If discharge remains constant while velocity increases, the cross-sectional area of the stream is decreased (fig. 17).

Velocities also vary within a given cross section, usually being slower near bed and banks than near the surface at midstream (fig. 39). Rocks, drowned logs, and submergent vegetation on the streambed tend to lower the velocity.

Stream velocity influences the sediment load, and the erosion and deposition of sediment on the bed and banks. Streams at high velocity generally carry a larger volume of sediment and move larger particles than streams at low velocity. Increased erosion at times of high flow and high velocity normally is followed by deposition as velocity declines. Thus, fluctuations in velocity results in movement of materials from upstream to downstream reaches.

High velocities are associated with turbulent flow which promotes the interchange of oxygen between air and water. This interchange permits uptake of dissolved oxygen by the stream where ground-water inflow has reduced dissolved oxygen below saturation levels. Where organic wastes have reduced dissolved oxygen content below critical levels the uptake of oxygen induced by turbulent flow may be of importance.

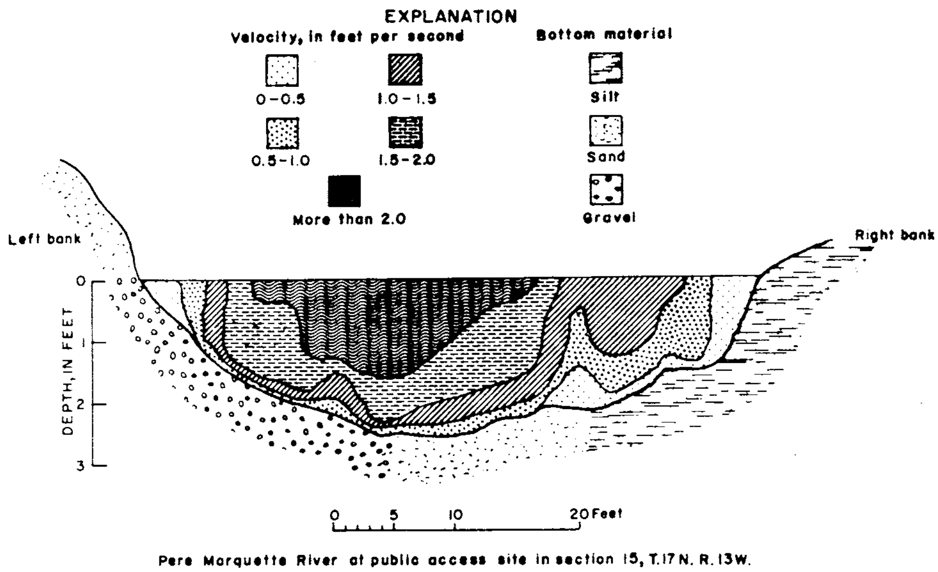


Figure 39. Stream velocities are higher near the surface in mid-channel than near the bed and banks.

Stage

The rise in stage, or water level, with increased discharge was described above (fig. 28). This rise in stage with increased discharge is relatively large in reaches where the stream is narrow and banks are high; it is relatively small where the stream is wide and banks are low. Ranges in stage at several stations on unregulated streams are shown graphically in figure 40. Relatively stable rivers, such as the East Branch Au Sable and Manistee Rivers near Grayling, have an average range of less than 2 feet. "Flashy" rivers such as the Salt near Bradley, have an average annual range of 9 feet or more. In general, rivers with a large component of ground-water flow have relatively small fluctuations in stage, whereas rivers with a large component of surface runoff have relatively large changes in stage. However, some streams with a large component of ground-water flow also occasionally receive large amounts of surface runoff from steep morainal hills. Fluctuations in stage on these streams are relatively high. For example, the Pigeon River near Vanderbilt, which has a large component of ground-water flow from the high outwash plains to the south, occasionally carries large amounts of surface runoff from the steep north slope of the Port Huron moraine. The average annual range in stage of the Pigeon River near Vanderbilt is 3.3 feet, which is greater than that of most Michigan rivers of comparable drainage area having a large component of ground-water flow.

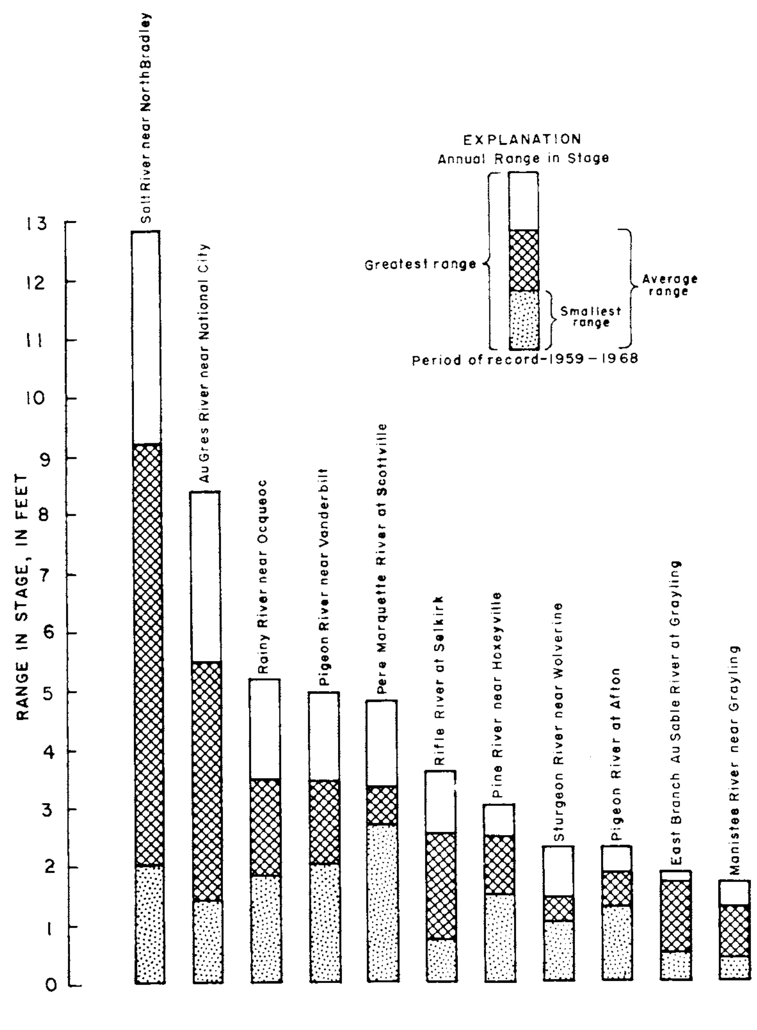


Figure 40. Some reaches of rivers in the study area rise and fall more than 9 feet each year. Most trout streams fluctuate less than 4 feet.

Recreation and Streamflow

All recreational values of cold-water rivers are dependent on streamflow characteristics. In general, a river with a relatively uniform flow is esthetically more attractive, provides better fishing and boating, and is more desirable for camp and cabin sites than a river with extremely variable flow. However, streamflow requirements of some recreational uses are more critical than others. For example, a "flashy" river may provide esthetic attraction at some seasons of the year, whereas it may be essentially barren as a trout stream. The influence of streamflow characteristics on esthetic values, fishing, boating, camping and cabin living, and swimming and wading are described in the following paragraphs.

Esthetic Considerations

Streams with relatively stable flow are more attractive to most users than streams that alternate between muddy flood flows and a feeble trickle with intermittent stagnant pools. A relatively high flow during rainless periods reduces odors that may result from decay of organic wastes. A high rate of discharge is related to size of stream channel and to velocity and is generally desirable. A fast-flowing stream, especially one where shallow channels result in riffles or rapids, is more attractive to most people than is a sluggish stream.

Fishing

Probably the most significant characteristic of the better trout streams in the area is a relatively stable flow sustained by a large component of ground-water discharge. This keeps the rivers cool in summer and enhances their oxygen content. Streams that lack a substantial ground-water flow do not support a significant trout fishery. Benson (1953) pointed out the importance of ground-water to trout populations and spawning redds on the Pigeon River.

The amount of ground-water discharge received by a stream can be determined by analysis of discharge hydrographs. In this type of analysis streamflow is separated into its components of surface and ground-water runoff as shown in figure 32. The amounts of ground-water runoff and surface runoff can also be approximated from the ratio of the 90 percent to the 10 percent flow duration discharge (fig. 36). Streams that have stable discharge and remain relatively cool even during hot summer months also reflect large ground-water inflows. An additional indicator of the amount of ground-water discharge to streams is their magnitude of low flow, in cubic feet per second per square mile (fig. 38).

Stream having a large component of ground-water flow have a high sustained discharge even during dry periods. Large drought flows dilute sewage and other contaminants, maintain cover for trout, and support animal life upon which fish feed. Fluctuations in trout populations on the Pigeon River appear to correlate with fluctuations in summer discharge (fig. 41).

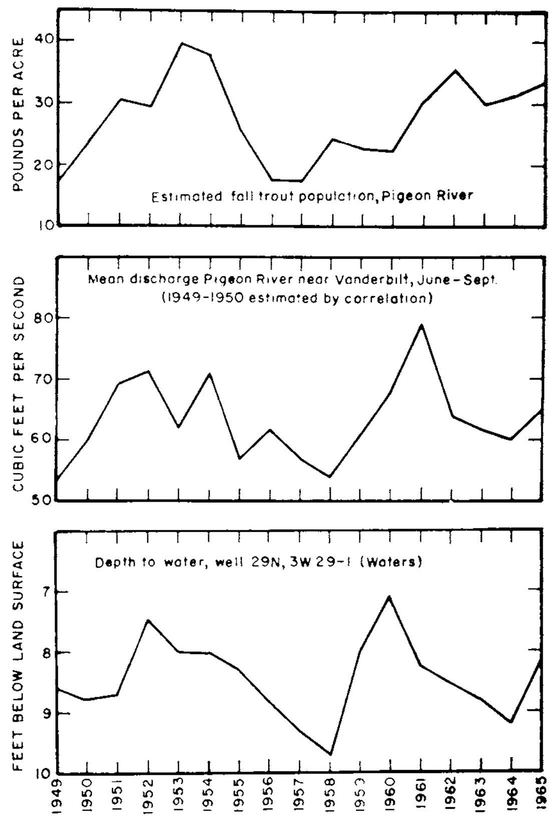
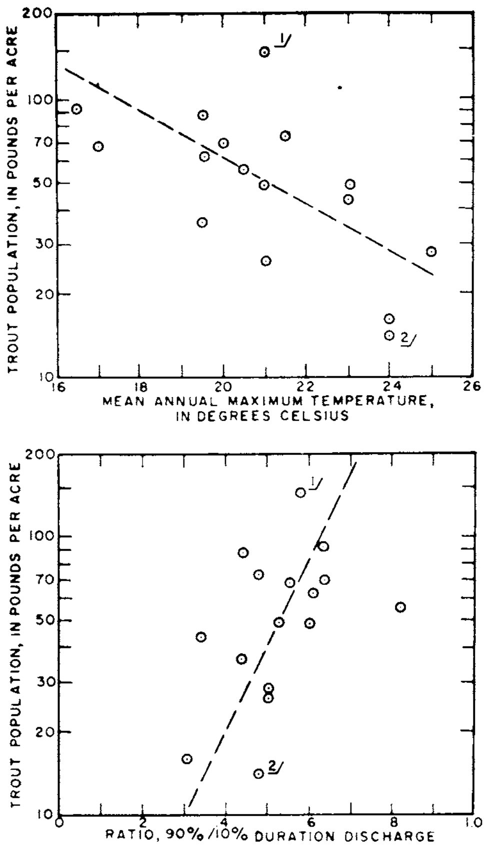


Figure 41. Fluctuations in trout populations in the Pigeon River appear to correlate with summer discharges, which are related to ground-water levels.

A correlation analysis of hydrologic parameters and trout populations in 16 stream segments in the study area suggested a general relationship between the 90 and 10 percent duration discharges and trout populations (tables 4, 5, fig. 42). The higher populations generally occurred in streams having the more stable streamflow. The population data used in this analysis is from a report by Alexander, Shetter, and Gowing (1969). Streamflow and water-temperature data for some stream segments are based on long-term records, but these data for most segments are estimates based on partial records or occasional measurements.



1/ High population may be attributed to nutrient enrichment.
2/ Low population may be attributed to deterioration of water quality by sewage wastes.

Figure 42. Trout populations generally are higher where streamflow is relatively uniform and maximum water temperatures are not excessive.

A better correlation between hydrologic parameters and trout populations probably could be obtained if data on stream segments were available to include streams that range from marginal to those that are highly productive. The 16 segments included in this analysis are on streams known to be highly productive. Additional records on streamflow and water temperature would improve the accuracy of these parameters and probably improve the correlations. Another difficulty is that some important parameters, such as streambed materials, were not determined quantitatively and were not used in the analysis.

Other characteristics of streamflow that influence the trout fishery, although not so critically, are velocity and range in stage. Most streams in the study area are characterized by alternating pools and riffles. Because the size of particles moved by flowing water is limited by velocity, swifter streams are more likely to have gravel bottoms, whereas slower streams have sand, silt, or mud bottoms. High velocities over gravel beds help to keep the gravel free of silt and sand. High velocities, with turbulent flow, speed the uptake of dissolved oxygen which may have been depleted by decay of organic matter. Slower velocities in the deep pools and along drowned logs provide resting places for fish. Where water temperatures are marginal for trout, the trout may be favored in competition with rough fish by relatively fast water velocities. Velocities also can influence the ability of steelhead and salmon to migrate upstream for spawning. The maximum swimming speeds of various species of trout and salmon range from 6 to 27 feet per second, depending largely on the size of the fish and the length of reach of swiftly moving water (Haley, 1966). None of the streams in the study area have velocities that are too high for upstream migration.

A river that fluctuates widely in stage or water level usually is unfavorable for trout. Available cover is greatly reduced during low stages, and erosion of banks is likely to occur at high stages. At low stages shallow water contributes to warming of the water. At high stages wading may be restricted. Streams rising in stage may scour gravel beds in some reaches; during falling stages streams may deposit silt and sand. Most streams with a large production of stream-hatched trout have small variations in stage and discharge.

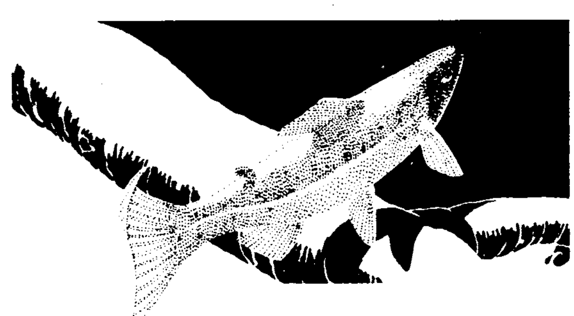


TABLE 4.--HYDROLOGIC CHARACTERISTICS, ANGLING STATISTICS AND TROUT POPULATIONS ON SIXTEEN STREAM SEGMENTS IN MICHIGAN'S LOWER PENINSULA
(Angling statistics and fish population data from Alexander, Shetter, and Gowing, 1969)

Stream segment	Map No.*	Location	Channel characteristics: Length (miles)	Ave. width (feet)	Area (acres)	Ave. depth (feet)	Pred. bottom	Area of basin (sq.mi.)	Flow characteristics: Mean discharge (cfs) 1/	Mean discharge (cfsm)	Duration disch. cfsm: 10%	90%	90%/10%
Gamble Cr.	1	Rifle R. Research area	0.8	19.0	1.8	1.5	Gravel	25.5	36 E	1.41	1.41	0.94	.48
Rifle R.	2	Rifle R. Research area	4.6	40.9	22.8	2	Gravel	56.8	90 R	1.58	2.27	1.13	.50
Pigeon R.	3	Pigeon R. Research area	6.0	41.1	29.8	2	Gravel	63	75 R	1.19	1.65	.83	.50
Hunt Cr.	4	Hunt Cr. Research area	2.0	18.0	4.3	1	Sand	11	24 E	2.20	2.45	2.00	.82
Boardman R.	5	Forks to Brown Pond	6.0	42.3	30.8	2	Gravel	122	105 A	.86	1.15	.61	.53
S. Br. Au Sable R.	6	Deerheart Rd. to mouth	16.1	67.3	131.3	3	Gravel	401	215 R	.54	.87	.30	.34
N. Br. Au Sable R. Upper	7	Dam 2 to Co. line	4.2	69.9	35.6	1	Gravel	115	80 A	.70	1.08	.65	.60
Middle	8	Co. line to Eaman's	6.9	108.0	90.3	1.5	Gravel	170	165 E	.97	1.23	.75	.61
Lower	9	Eaman's to Kellog Bridge	8.7	95.3	100.5	3	Gravel	217	224 A	1.03	1.60	.97	.64
Au Sable R. Upper	10	Grayling to Burton's	5.6	88.1	59.8	3	Sand	186	114 R	.61	.87	.42	.48
Lower	11	Burton's to Wakely Bridge	8.7	94.5	99.6	2	Gravel	219	192 E	.88	1.13	.66	.58
Little South Branch Pere Marquette R. Upper	12	Carlson Bridge to Co. line	4.7	32.2	18.3	1.5	Gravel	106	56 A	.53	.78	.34	.44
Lower	13	Co. line to Taylor Bridge	5.2	37.4	23.6	1.5	Gravel	110	69 A	.63	.91	.40	.44
East Branch Au Gres	14	Below Meadow Bridge	--	--	.9	--	--	84	63 R	.75	1.27	.40	.31
Poplar Grove Cr.	15	S1/2 sec.36, T.21 N., R.12 W.	1.0	16.0	1.94	--	Sand & Clay	15.1	15 E	.99	1.26	.79	.63
Silver Cr.	16	Sec.18, T.20 N., R.11 W.	0.5	13.8	.84	--	Sand	4.94	4.7 E	.95	1.29	.71	.55

1/ R = Continuous record.
E = Estimated by correlation.
A = Approximated from limited record.

* See Fig. 1.

Stream segment	Site of discharge and temp. records	Water Quality: Mean annual max Temp. °C 1/	Mean annual min DO mg/l	Aquatic vegetation	Angling statistics: Period of record	Regulations 2/	Angling hours per acre	Angling catch per acre: No.	Lbs.	Catch per hour: No.	Lbs.	Fall trout population per acre: No.	Lbs.	No. more than 7"
Gamble Cr.	nr. Lupton	21.5 E	--	Sparse	58-65	N	50	8	3.2	.16	.06	688	73.3	196
Rifle R.	nr. Lupton	21 R	8 A	Sparse	57-62	N	243	34	16.0	.14	.07	98	26.1	85
Pigeon R.	nr. Vanderbilt	25 R	6.5 A	Sparse	53-65	C	165	34	8.0	.21	.05	609	28.4	46
Hunt Cr.	nr. Lewiston	20.5 E	--	Sparse	56-65	C	276	127	20.3	.46	.07	1,814	55.9	73
Boardman R.	below forks	21 A	--	Sparse	60-61	C	180	44	12.6	.24	.07	877	49.6	147
S. Br. Au Sable R.	nr. Luzerne	23 E	6.5 A	Moderate	60-61	S^1	222	28	16.7	.13	.08	393	42.4	105
N. Br. Au Sable R. Upper		23 A	--	Dense	61-67	S^2	66	21	9.3	.32	.14	906	48.0	132
Middle	nr. Lovells	19.5 E	6 A	Dense	61-67	N	271	115	30.3	.42	.11	987	62.0	134
Lower		20 A	--	Moderate	61-67	S^2	109	15	6.6	.14	.06	1,475	69.4	177
Au Sable R. Upper	Below East Branch	24 E	4.5 E	Dense	60-63	N	211	48	15.8	.23	.07	54	14.0	37
Lower	at Stephans Bridge	21 E	6.5 E	Dense	60-63	S^1	387	64	38.7	.17	.10	1,499	148.2	393
Little South Branch Pere Marquette R. Upper	N. Co. line	19.5 A	--	Sparse	60-61	S^1	150	51	30.6	.34	.20	705	87.2	224
Lower	at Kennedy Bridge	19.5 A	--	Sparse	60-61	N	214	80	30.8	.37	.14	299	36.2	81
East Branch Au Gres	at McIvor	24 R	--	--	50,55	N	--	--	--	--	--	1,430	16.1	39
Poplar Grove Cr.		16.5 E			70	N						1,527	92.0	181
Silver Cr.		17 E			70	N						2,185	68.4	164

2/ Angling regulations
S^1 = Special rules, 10" min. size, 5 trout creel limit, flies only.
S^2 = Special rules, 9" min. size, 5 trout creel limit, flies only.
C = Some portion of river or years, anglers fished under special rules.
N = Normal state fishing rules, 7" length, 10 trout creel limit, any lure.

Table 5. Relationship of hydrologic parameters and trout population

PARAMETERS COMPARED	CORRELATION COEFFICIENT	STANDARD ERROR OF ESTIMATE (Percent)	SIGNIFICANCE LEVEL OF INDEPENDENT VARIABLE (T-TEST)
Mean annual maximum water temperature in °C and trout populations, in pounds per acre.	.63	53.3	1
Ratio of 90/10 percent duration discharges and trout populations, in pounds per acre.	.49	60.3	5
90% duration discharge, in cfsm, and trout populations, in pounds per acre.	.24	68.2	10
Mean discharge, in cfsm and trout populations, in pounds per acre.	.13	69.8	Not significant

Although large fluctuations in stage and discharge generally are unfavorable to trout, under certain conditions of pollution large flood flows may be beneficial. Tarzwell and Gaufin (1953) pointed out that a "pollutional blanket" composed of grayish slime growths, that develops below sewage outfalls during periods of low water, may be removed by the first severe flood.

Fluctuations in stage and discharge resulting from storage and release of water from impoundments usually are unfavorable to the fisherman. A sudden release of water may cause a rapid increase in stage and velocity that endangers the wading fisherman.

Boating

A relatively uniform streamflow with a high base flow is as important to the boater as it is to the fisherman. If a stream is reduced to a trickle during prolonged dry weather many reaches will be impassable because of shoals, fallen trees, and log jams. Changes in stage that accompany changes in discharge are important to boating even when they are relatively small. A decline of only a few tenths of a foot on the upper North Branch Au Sable, for example, can make long reaches of shoal water impassable for a loaded canoe. A high base-flow also is desirable for winter boating, because streams having a high base-flow are relatively ice-free.

Very high flood flows, usually accompanied by high velocities, may make a river exciting to the expert canoeist, but to most canoers they make the river dangerous. The danger is compounded because many novices do not realize that the river at flood is a very different challenge than the river they have experienced at normal flows. In a recent instance two youthful boaters narrowly excaped drowning in the flood waters of the Pigeon River. Their boat had capsized against a tree but luckily they were pulled to safety by a stream-gager who had seen their plight.

Camping and Cabin Living

Streamflow characteristics that contribute to the esthetic attractiveness of a stream are essential to the camper and cabin-dweller, as no one would care to camp or live on the banks of an unattractive river. Many campers and cabin-dwellers also are fishermen and boaters, and accordingly are influenced by streamflow characteristics that are favorable to fishing and boating. Thus, a relatively stable discharge is important to the camper and cabin-dwellers. Extremely high flows, with resultant high stages may cause floods that damage campgrounds and cabins.

Swimming and Wading

Streamflow characteristics favorable to swimming and wading are somewhat different than those desired for other recreational uses. The stable flow so important to the fishery usually is accompanied by water temperatures too cold for most swimmers. On the other hand, if streamflow declines too much, the decline in stage may make the river too shallow for swimming and suitable only for wading. Another problem of low flows is that wastes are not adequately diluted. Rapid changes in stage caused by releases of water from impoundments may be dangerous to swimmers and waders--especially young children.

WATER QUALITY

The quality of water in a river is expressed in terms of dissolved and suspended substances and in physical properties of the water. Dissolved substances are the solids (salts) and gases in the water. Suspended materials include all undissolved materials, chiefly clay, silt, sand, and organic material moved in the stream. Physical properties important to recreational values are temperature, pH, and specific conductance.

Temperature

The temperature of stream water is influenced by the natural controls of exposure to sunlight, stream discharge, air temperature, ground-water inflow, and snowmelt (Moore, 1967). Activities of man also influence water temperature, chiefly by removal of shade, discharge of heated water, and impoundment of water in reservoirs.

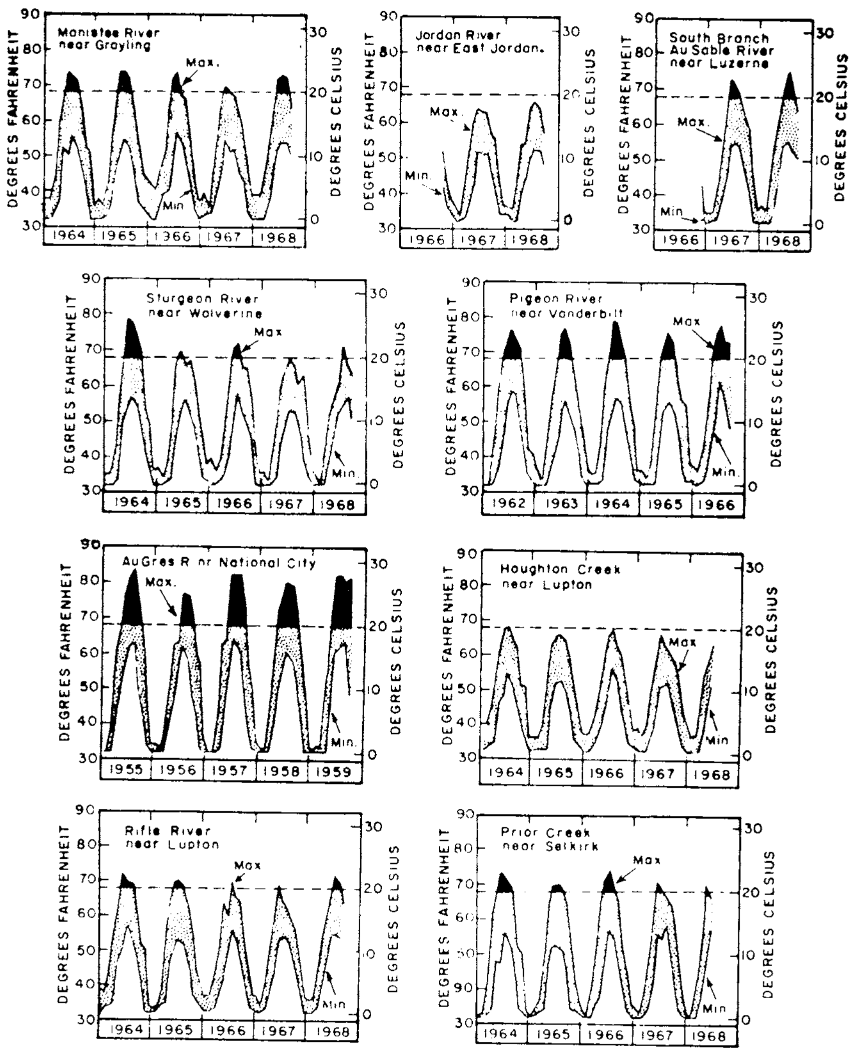
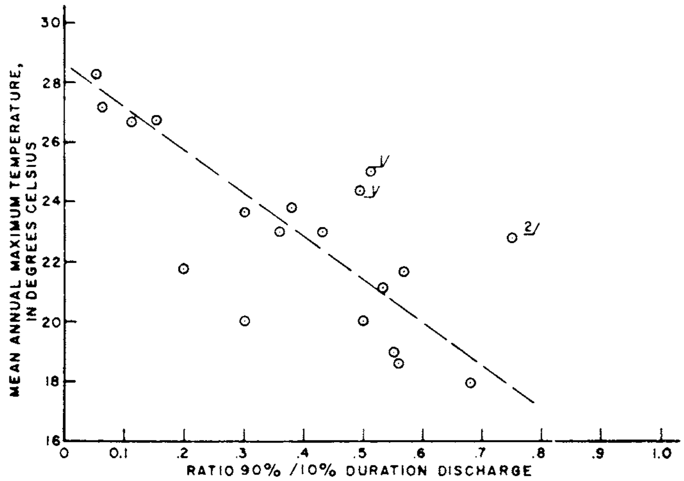


Figure 43. Maximum water temperatures on cold-water rivers generally range from 19° to 25°C in summer. Minimum winter temperatures usually are at or near the freezing point. The monthly range in temperatures usually is least in midwinter.

Maximum and minimum monthly temperature of several streams in the study area are shown in figure 43. The streams having the lower summer temperatures generally are those that have the smaller range in discharge (fig. 44). Diurnal variations in water temperature are generally smaller than diurnal variations in air temperature (fig. 45). In the summer the water usually is cooler than the air during most of the day and warmer than the air most of the night. Early morning mist above the stream surface is evidence of these differences. In summer, the usual daily range of water temperatures on the rivers studied was 2 to 4°C (3.5 to 7°F) whereas the daily range in air temperatures was about 10 to 20°C (18 to 36°F).



1/ Temperature effected by impoundment upstream.
2/ Reach of broad unshaded channel and slow velocity upstream.

Figure 44. Streams having a relatively stable discharge usually have low summer water temperatures.

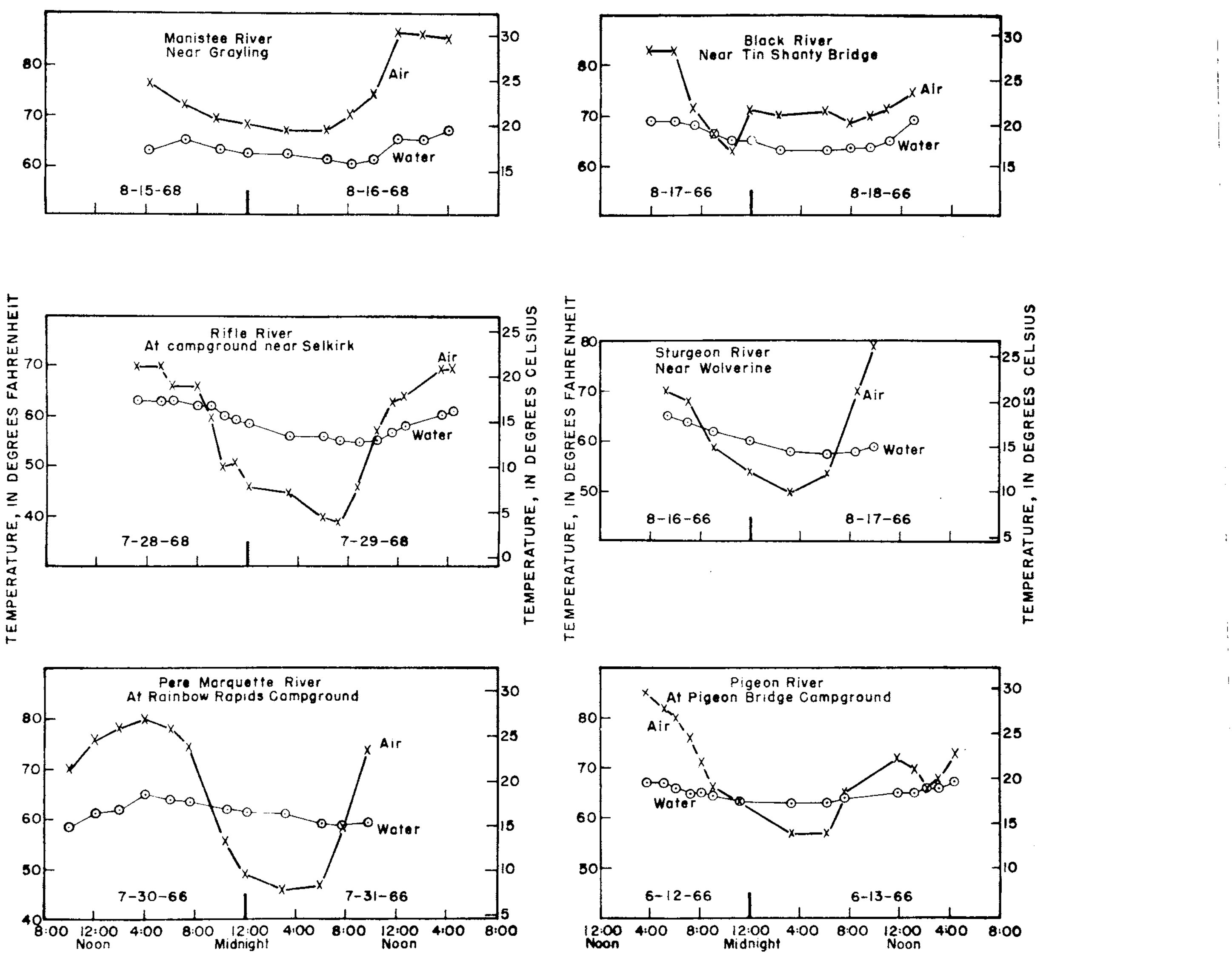


Figure 45. In summer, daily variations in water temperatures usually are less than 5°C whereas air temperatures vary 10° to 20°C.

During periods of low flow in Michigan most water in the streams is contributed by ground-water inflow. This water as it enters the stream is at or near the mean annual air temperature of the region (about 8°C or 14°C)--warmer than the air in winter and colder than air in summer. As it moves down the stream channel it is warmed or cooled by contact with the air and with the river bed and banks, and it is warmed by exposure to the sun. Following periods of snowmelt or rainfall the stream is warmed or cooled by the inflow of surface runoff, depending upon the relative temperature of land and river and exposure to sunlight.

Many streams are colder in summer in their headwaters than they are downstream (fig. 46). In winter they may be warmer in their headwaters than downstream. Streams with a large component of ground-water inflow usually remain ice free in their upper reaches (fig. 47). However, inflow of ground water and exposure to sunlight may vary considerably in different reaches of a stream, and temperatures may vary accordingly (fig. 48). In summer, streams with large ground-water inflow normally are cooler than streams with small inflow; in winter, streams with large ground-water inflow generally are warmer than streams with small inflow (fig. 49).

The influence of sunlight is always to warm the water, winter or summer, but in winter the warming influence of sunlight generally is weaker than the cooling influence of exposure to the cold air and bed and banks of the river.

Figure 47. Streams with a large component of ground-water inflow remain ice-free in winter.

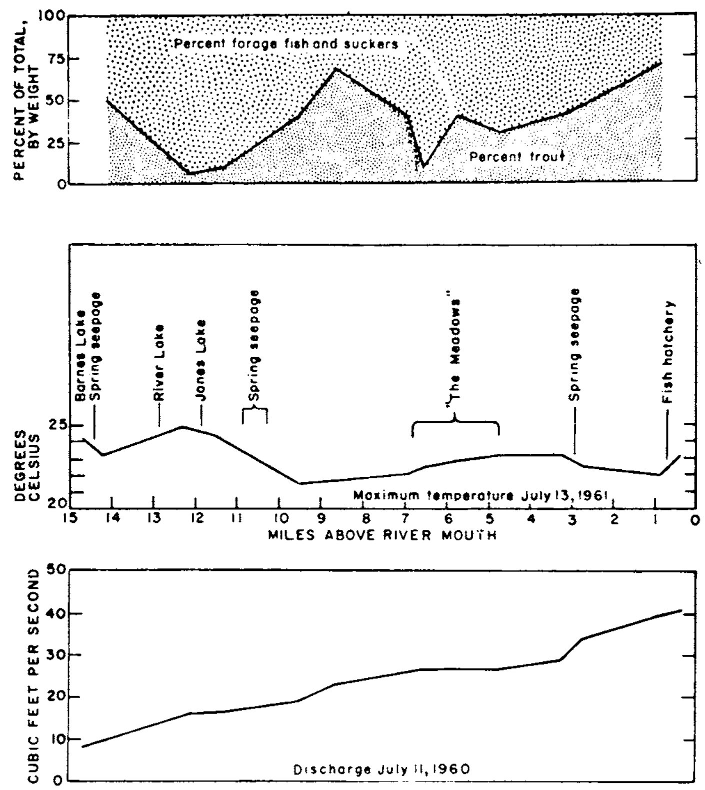


Figure 48. Ground-water inflow cools the water of the East Branch Au Sable River, whereas sunlight on the lakes and meadows warms the water. Trout are relatively abundant in the cooler reaches and relatively scarce in the warmer areas. (After Wicklund, 1962)

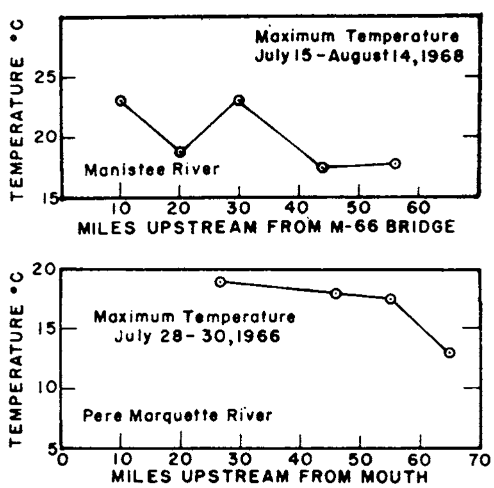


Figure 46. Most streams are colder in their headwaters than in downstream reaches but local variations in exposure to sunlight and ground-water inflow cause exceptions to this general rule.

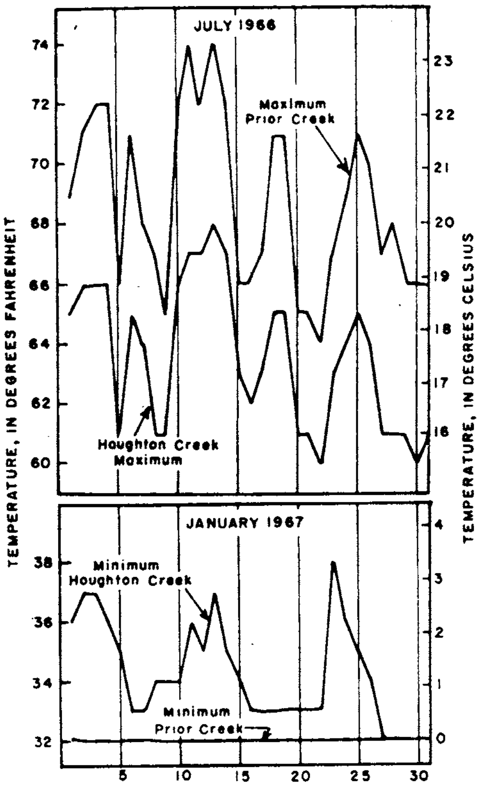


Figure 49. Houghton Creek, with a large amount of ground-water flow is cooler in summer and warmer in winter than nearby Prior Creek, which has a much smaller component of ground-water.

The amount of sunlight reaching any part of the stream surface is controlled chiefly by stream width and amount of shade. Shading is provided by streamside vegetation and by high banks, and is strongly influenced by stream orientation. In general, a north south orientation of a stream provides for greater shading than an east west orientation (Moore, 1967, p. K-17). Well-developed stream meanders, however, reduce the influence of stream orientation, as stream segments are oriented in all possible directions.

Impounding dams, by greatly increasing the area of exposure to sunlight, may cause a significant warming of the water. Shetter and Whalls (1955) found that summer water temperatures on Fuller Creek, near Lewiston, Michigan, were significantly warmer after a shallow pond was established by an earth-fill dam at the site of an old beaver pond. Most impoundments in the study area, especially those recently constructed, are relatively shallow, and probably tend to warm the water downstream. However, the effects of impoundments on stream temperatures are complex and do not always warm the stream. Moore (1967, p. K-37) found in Oregon that water withdrawn from a deep reservoir, at a level well below the surface, lowered summer water temperatures, whereas temperatures downstream from shallow reservoirs usually were raised during the summer months.

Another complicating factor in the influence of impoundments on stream temperatures is seepage of water from the impoundment through permeable ground water aquifers to return to the stream in some downstream reach. Such leakage and return flow was observed in some impoundments on tributaries of the Pere Marquette River. As the water moves through the aquifers the temperature will be modified to approach the temperature of normal ground water in the area--about 8°C (46°F). Thus, an impoundment in permeable earth materials, such as sand and gravel, by diverting water through aquifers to the stream, possibly may cool the stream in summer.

In Michigan differences in temperatures of different streams or stream segments usually can be attributed chiefly to differences in ground-water inflow. Streams with high contribution of ground-water inflow normally are cooler in summer and warmer in winter than streams with low ground-water inflow. The Au Sable, Manistee, Sturgeon, Pigeon, Jordan, and Rifle Rivers all have relatively large ground-water inflow and are generally relatively cool in summer and warm in winter. The Au Gres has a relatively small ground-water inflow and is generally relatively warm in summer and cold in winter. Many other streams in the study area have small ground-water inflow, but continuous temperature records are not available on these streams.

Dissolved Oxygen

Dissolved oxygen in streams is influenced by water temperature, density of water vegetation, sunlight, turbidity, turbulence of flow, and oxygen-consuming materials such as organic wastes. The solubility of oxygen in water decreases as temperature increases (fig. 50). Thus, at 0°C (32°F), water is saturated with 14.6 mg/l (milligrams per liter) of oxygen; at 30°C (86°F) saturation is at 7.6 mg/l. Plants growing in the water give off oxygen during daylight hours; at night, the consumption of oxygen by these plants reduced the dissolved oxygen content of the water. During the growing season this diurnal variation in production and consumption of oxygen by plants is usually great enough to mask the influence of variations in temperature (fig. 51). The magnitude of the variation depends chiefly on the density of the vegetation. For example, the Au Sable below Grayling,

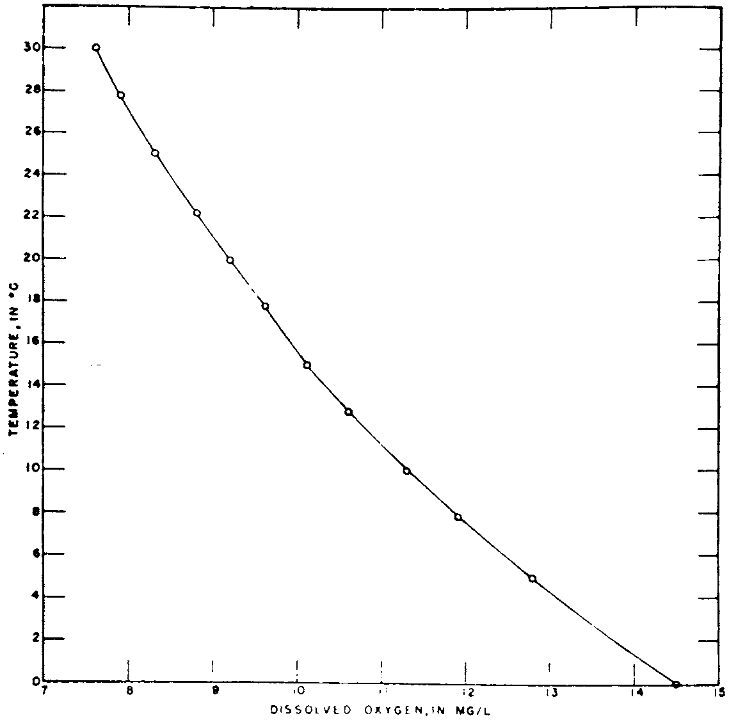


Figure 50. Solubility of oxygen in water declines with increasing temperature. (From Brown, et al, 1970)

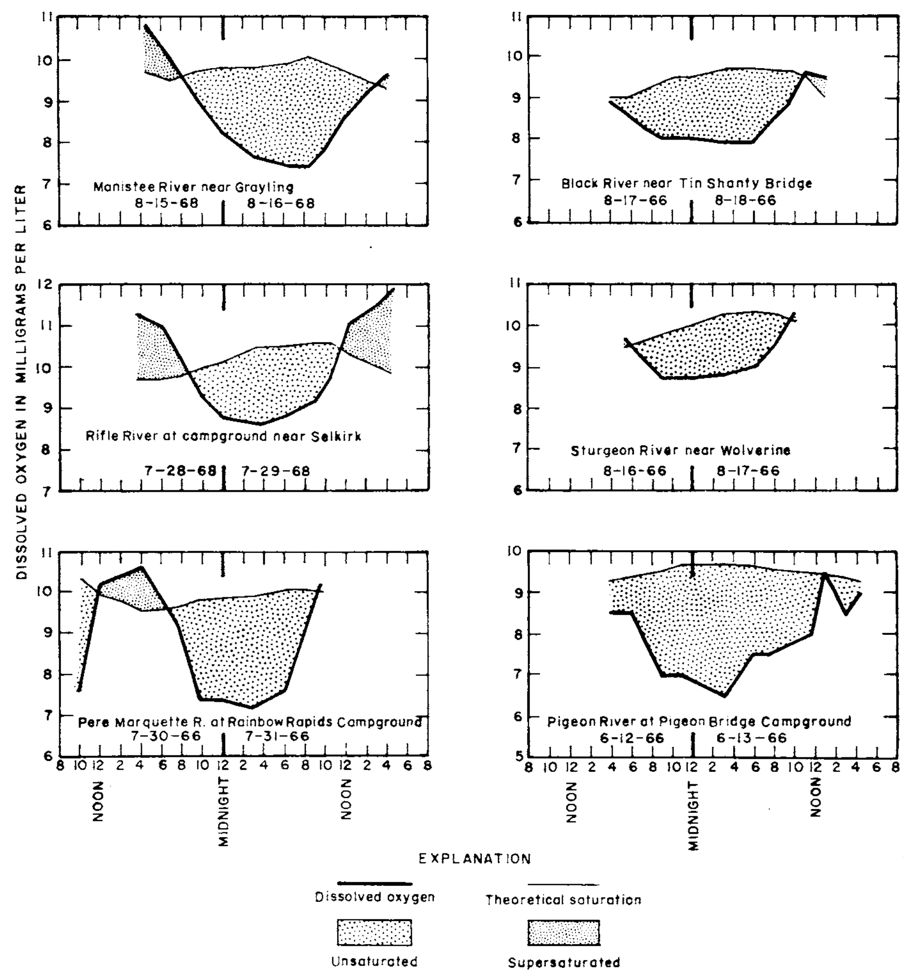


Figure 51. Dissolved oxygen increases during daylight hours because of oxygen given off by plant photosynthesis. At night the plants use up oxygen and dissolved oxygen declines. Most streams are supersaturated with oxygen during part of the day and undersaturated most of the night.

which has a dense growth of vegetation had a diurnal variation in dissolved oxygen of 7.5 mg/l, whereas the Sturgeon below Wolverine, which has a relatively sparse growth of vegetation, had a diurnal variation of only 2.2 mg/l. The diurnal variation declines in the fall and nearly disappears in winter (fig. 52).

Turbidity influences dissolved oxygen by limiting the amount of sunlight reaching the submergent vegetation. Because most rivers included in this study have low turbidity during the growing season, the influence of turbidity on dissolved oxygen could not be determined. The influence probably is small. As noted in the discussion on stream velocity, turbulent flow influences dissolved oxygen by promoting interchange of oxygen between air and water. If dissolved oxygen is near saturation, turbulent flow has little effect; if the water is highly unsaturated, turbulent flow accelerates uptake of oxygen by the water, if the water is supersaturated turbulent flow accelerates loss of the surplus oxygen. Tarzwell (1957) found that dissolved oxygen in a section of the Sciota River increased from 0.1 mg/l at the tail of a large pool to 5.6 mg/l at a point below a wide shallow riffle 200 yards downstream.

Oxygen-consuming substances strongly influence dissolved oxygen content in Michigan cold-water streams only where these streams are contaminated by discharge of organic wastes. Elsewhere, the slow decay of natural vegetation and animal matter apparently is compensated by natural aeration of the water.

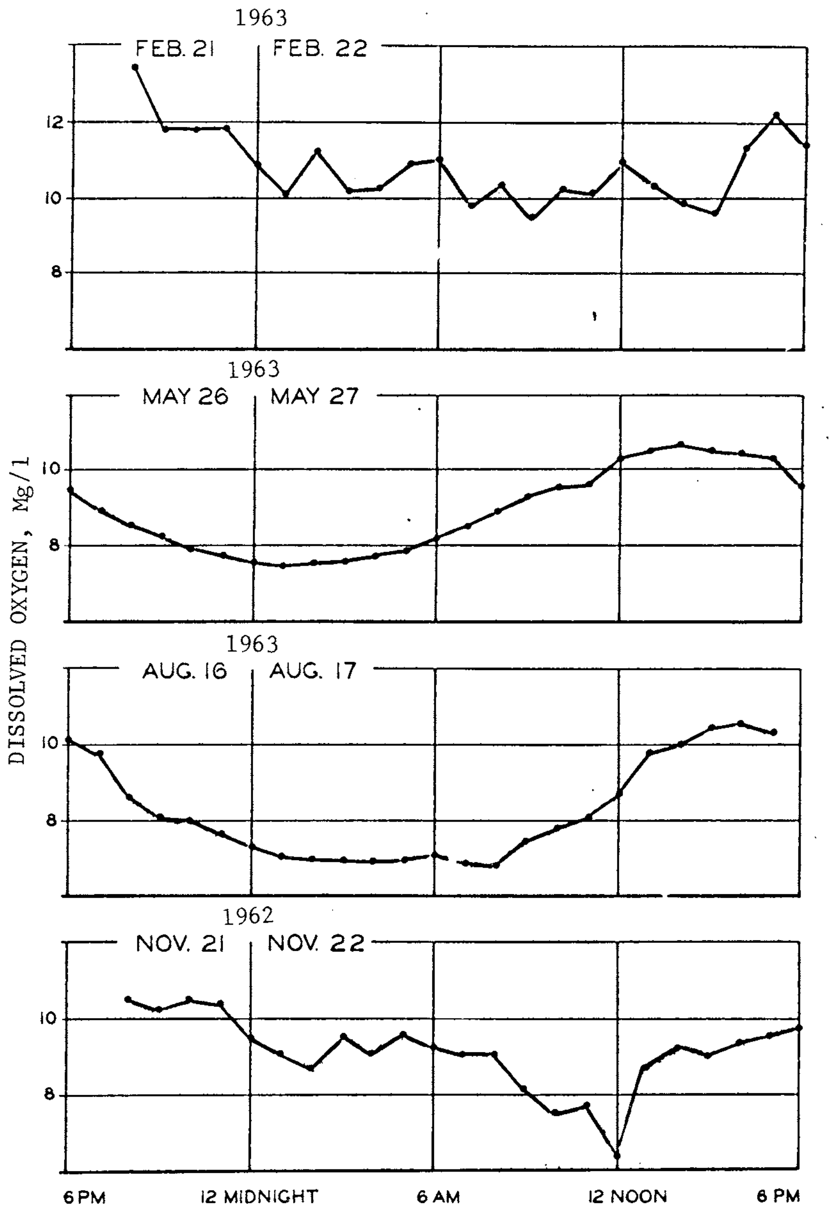


Figure 52. The daily cyclic fluctuation in dissolved oxygen is apparent throughout the growing season, but becomes indistinct or disappears in winter. (Au Sable River at Stephans Bridge.)

A study of the influence of organic wastes (sewage) on dissolved oxygen was made on the Au Sable River in August, 1966, by the Michigan Water Resources Commission (1966). A summary of the results is shown in figure 53. Above the sewage disposal plant at Grayling dissolved oxygen ranged from 7.0 to 9.6 mg/l; about 2 miles below the disposal plant the range was from 4.5 to 12.0 mg/l. The influence of organic wastes was two-fold. First, oxygen was consumed in the decay of the wastes; second the nutrients discharged in the wastes stimulated such abundant growth of vegetation that the diurnal variation in dissolved oxygen was greatly increased. At night the consumption of oxygen by the plants was added to the consumption by decaying organic material. In the daytime the production of oxygen by the dense vegetation downstream from the plant more then compensated for the consumption of oxygen by decaying organic matter. The influence of the organic wastes declined rather rapidly in the first 6 miles below the disposal plant. At McMasters Bridge, 20 miles below the plant, the influence was minor.

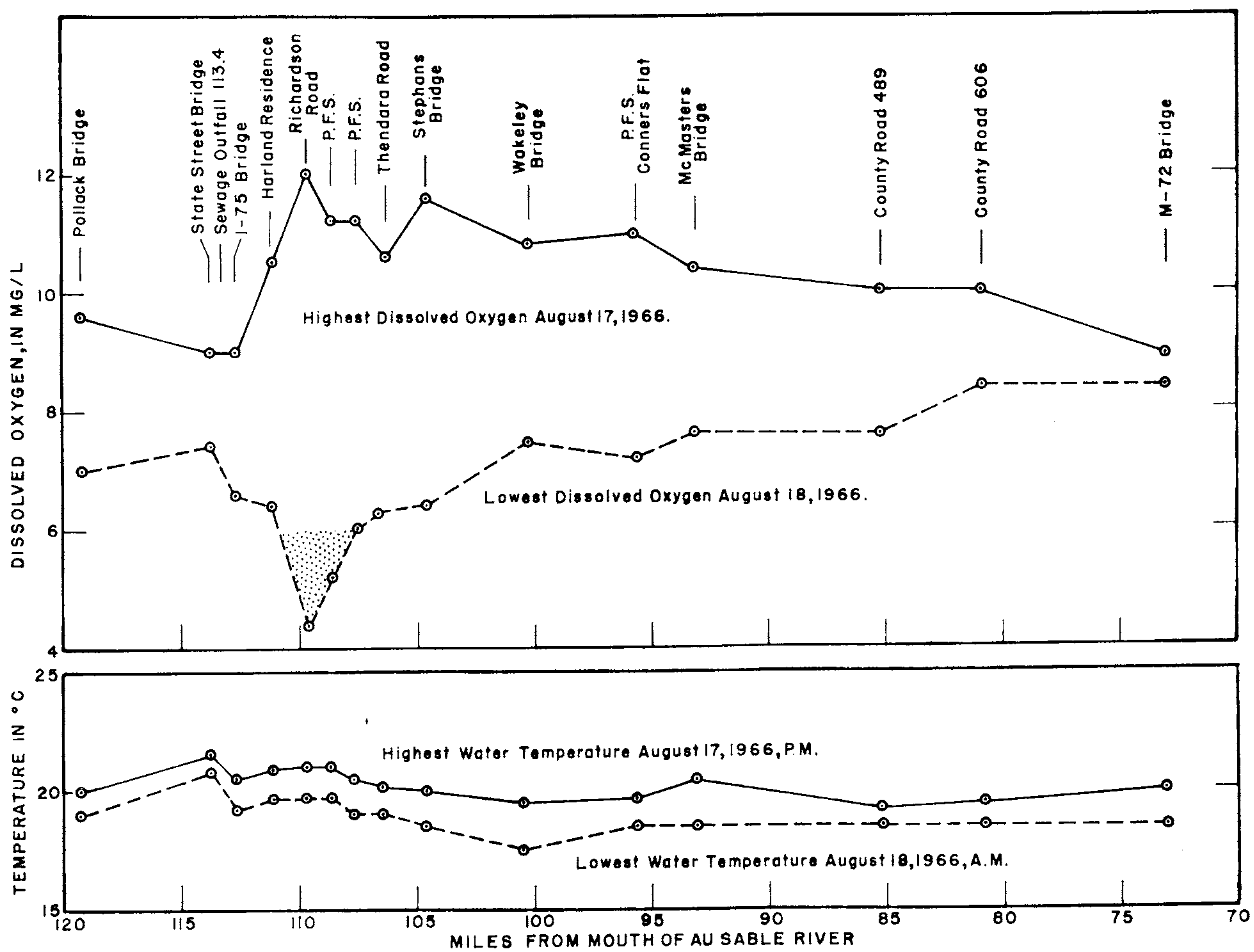


Figure 53. Sewage effluent causes a pronounced change in concentrations of dissolved oxygen below Grayling. Minimum concentrations are lower and maximum concentrations are higher. The influence of organic wastes declines downstream and is minor at McMasters Bridge. The influence of temperature on dissolved oxygen is obscured by the effects of organic wastes.

A study of the mixing of waters containing differing amounts of dissolved oxygen was made in August, 1969, in the area of the disposal plant on the Au Sable River at Grayling downstream to below the mouth of the East Branch (fig. 54). The water having a lower dissolved oxygen concentration along the left bank of the Au Sable was mixed and pushed over to the right bank by the water flowing in from the East Branch. About 500 feet downstream from the mouth of the East Branch, or about 1200 feet downstream from the disposal plant, mixing was essentially complete.

Available data indicate most cold-water rivers in Michigan are relatively uncontaminated, and dissolved oxygen is near saturation at all times--a few mg/l (milligrams per liter) above saturation in the daytime and a few mg/l below saturation at night during the growing season. In winter, ice cover on some stream segments may cause a reduction in dissolved oxygen below saturation. However, cold-water rivers in the study area are open or only partly covered by ice even in the coldest months.

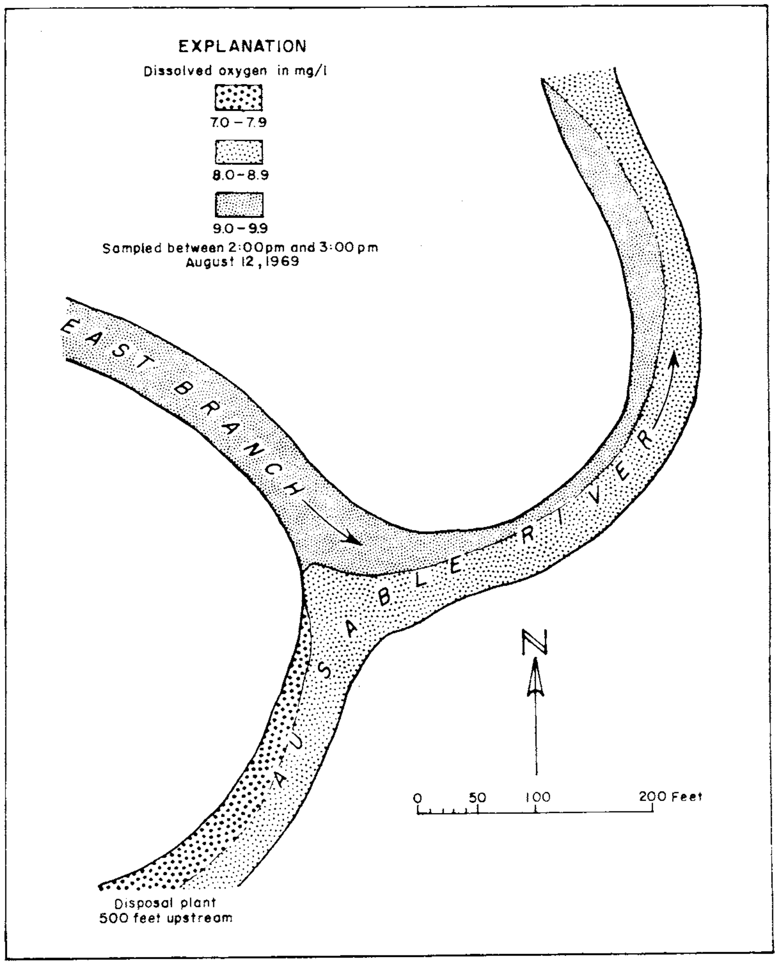


Figure 54. Oxygen-depleted water along the left bank of the Au Sable below the disposal plant was deflected to the right bank by water from the East Branch. Mixing was essentially complete about 500 feet below the mouth of the East Branch. (August 12, 1969.)

Turbidity and Sediment Load

Turbidity is a measure of the amount of light intercepted by sediment suspended in water. It is used as a general indicator of the amount of suspended sediment.

Turbidity of stream waters was not measured as a part of this study, but a general indication of relative turbidity was obtained by observing the maximum depth that bottom materials could be identified in the streams at different seasons. Most cold-water rivers in the study area are remarkably clear at all but times of highest flows, and many are only slightly turbid even then. The more turbid streams in the study area are those with a relatively large area of silty and clayey soils in the basin, such as the Au Gres and the Rifle. Streams in basins having predominantly permeable sand soils, such as the Au Sable and Manistee, have very low turbidities.

The concentration of suspended sediment, as indicated by turbidity or standard sediment sampling, is only a part of the sediment problem. Shifting sand that moves along the bottom of the stream usually is not included in routine sediment sampling, but this bottom sediment, or bed load, may seriously impair the productivity of a trout stream by reducing the growth of fish food organisms and by covering or filling gravel spawning beds. Records of the U.S. Forest Service on the Pine River near Wellston (fig. 55) showed that in water year 1968 as much as 997 tons of sediment moved past the sampling site in 1 day. The record includes bed load and suspended sediment. A comparison of the total sediment load with suspended sediment load showed that as much as 75 percent of the material moved as bed load. The total sediment load moved past the station during the water year, October, 1966 through September 1967, was 70,090 tons. This large amount of sediment moved by a stream that usually appears quite clear suggests that other streams in the study area also may transport large quantities of sediment as bed load.

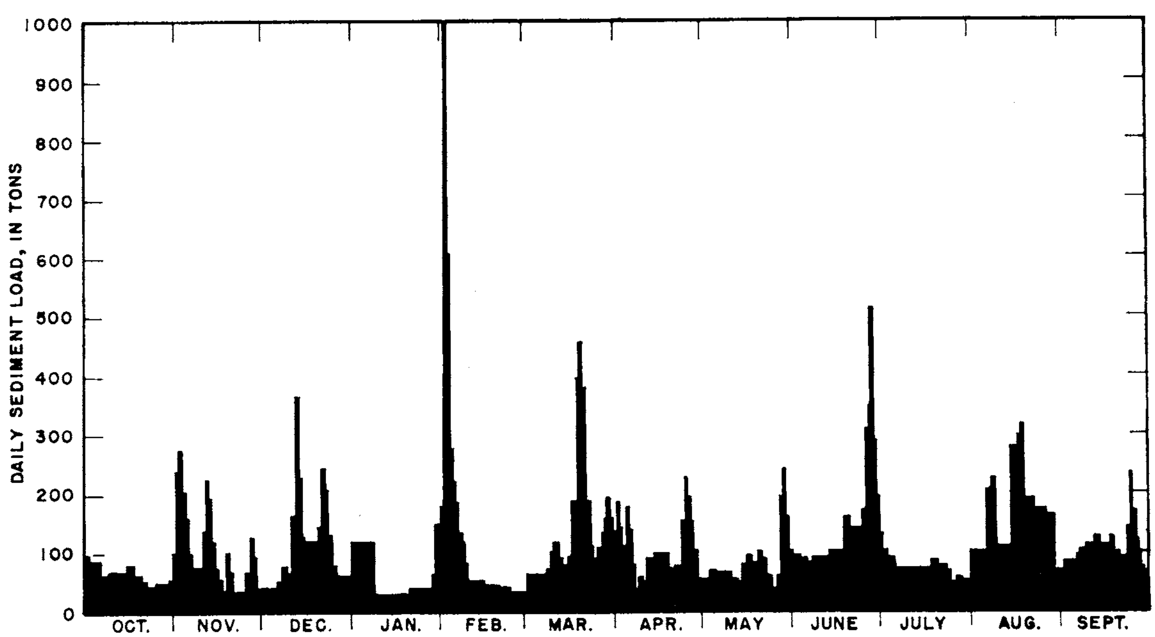


Figure 55. Sediment load (suspended sediment and bed load) of the Pine River near Wellston varied from 30 to 997 tons per day (October, 1967 to September, 1968).

Nutrients

Nutrients, chiefly nitrates and phosphates, affect the productivity of plant and animal life and indirectly affect dissolved oxygen in the stream. Calcium is also essential to productivity of aquatic life, but calcium is a critical factor only in very soft waters (Moyle, 1956). All of the rivers in the study area are moderately hard with abundant amounts of calcium.

Records of the Michigan Water Resources Commission show that concentrations of nitrates and phosphates generally are moderate to low in Michigan's cold-water rivers at all times (fig. 56). Samples collected in October and November 1967 from most of these rivers contained less than 0.4 mg/l of nitrates and less than 0.3 mg/l of phosphates. However, chemical analyses do not accurately reflect the total nutrient load during the growing season, because aquatic plants remove nutrients from the water (Ball and Hooper, 1963, Ehrlick and Slack, 1969).

Other rivers in Michigan, not classified as cold-water streams, have much higher concentration of nutrients. Most of these high concentrations probably are associated with discharge of organic wastes. However, some high concentrations in agricultural areas are probably caused by pickup of fertilizers during periods of surface runoff.

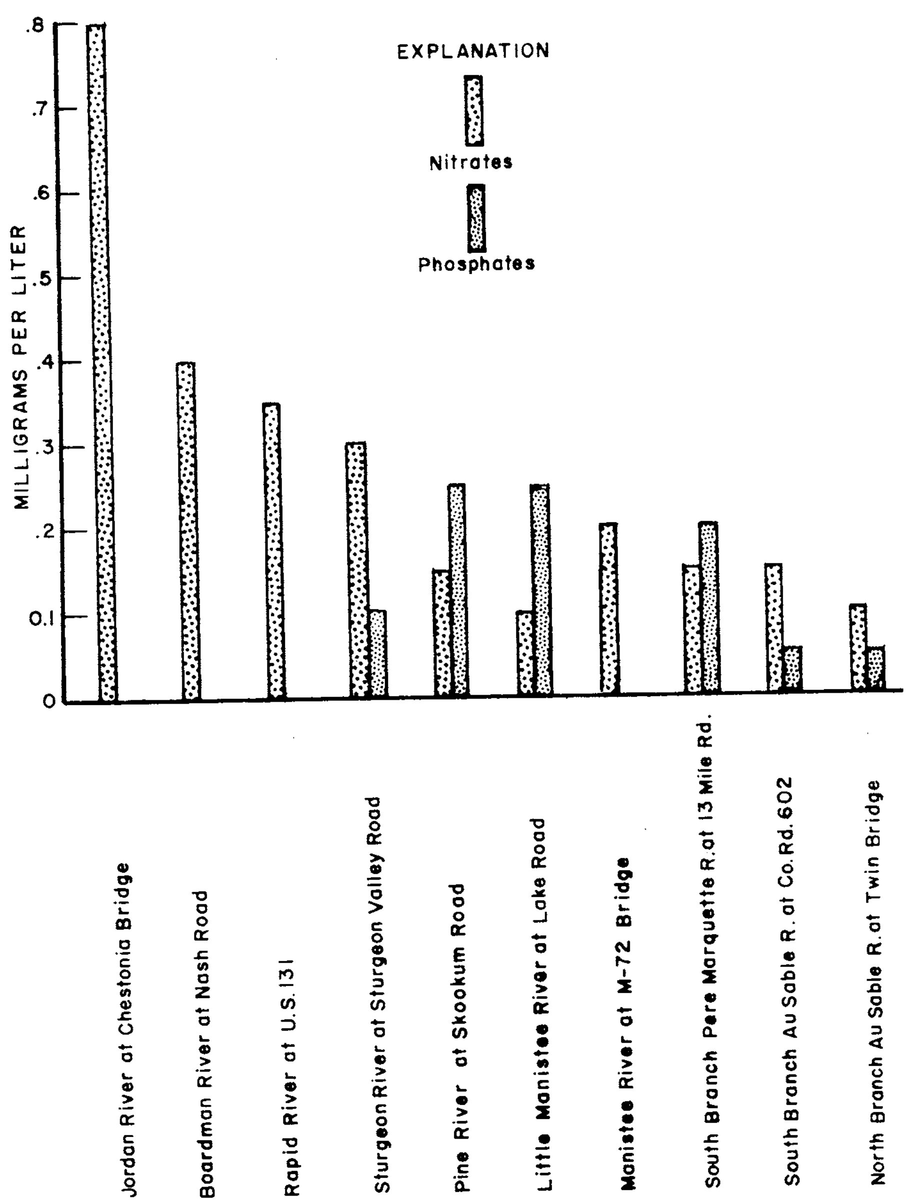


Figure 56. Nutrient concentrations are relatively low in most cold-water rivers in the study area (October and November, 1967).

pH

The pH of water is an indicator of the acidity or alkalinity of the water. Waters with a pH of 7.0 are said to be neutral--neither acid nor alkaline; waters with a pH below 7.0 are acid; those with a pH above 7.0 are alkaline. Unless values of pH are extremely high or low they have little direct influence on recreational values. The cold-water rivers sampled in this study are all moderately alkaline, with pH values ranging from 7.2 to 8.3.

Hardness

Hard waters, as pointed out in a later section of this report generally are more productive of fish than extremely soft waters, and the harmful effects of toxic metals generally are reduced in hard water. The quality of hardness is not considered to be critical to the recreational values of any of the streams in the study area. All are characterized by moderately hard to very hard waters, with hardness as calcium carbonate ranging from about 100 to 290 mg/l. Hardness generally is greater at low than at high flows.

Specific Conductance

Specific conductance (a measure of electrical conductivity of water) has no direct influence on recreational values, but it is highly significant as an indicator of concentrations of dissolved solids.

In the streams under study relatively high specific conductance is associated with relatively hard water (fig. 57). Monthly records of specific conductance have been collected on several cold-water rivers from October, 1967 to September, 1968 (fig. 58). Conductance values range from about 150 to 550 micromhos. Comparison with chemical analyses indicate that calcium, magnesium, and bicarbonate are the major dissolved constituents in most of the streams. Sulfate is an important constituent in those streams with specific conductance values greater than 400 micromhos. Differences in conductance between streams reflect differences in the earth materials of the basin, differences in the distance water travels before reaching the stream, and differences in precipitation and evapotranspiration. Streams in the southeastern part of the study area, such as the Au Gres River, have higher specific conductance than most streams in the north and west. Streams that capture substantial quantities of ground water flow from adjacent basins, such as the Sturgeon and Rifle Rivers, usually have higher specific conductance than those that capture little or no flow from adjacent basins, such as the Au Sable and Manistee. Specific conductance in most of the streams usually is lower at high flows than at low flows (fig. 59).

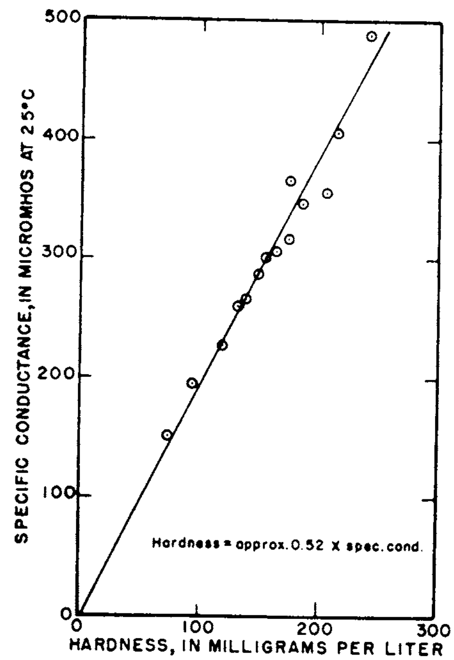


Figure 57. Hardness of river water in the study area, in milligrams per liter, is about half the value of specific conductance, in micromhos at 25°C.

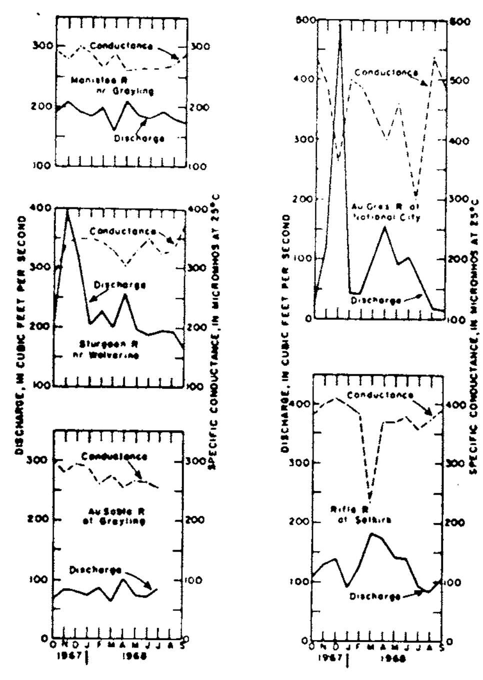


Figure 58. Specific conductance of cold-water rivers fluctuates only slightly on streams that are relatively stable in discharge. Streams with a wide range in discharge generally have a relatively wide range in specific conductance (October, 1967 to September, 1968).

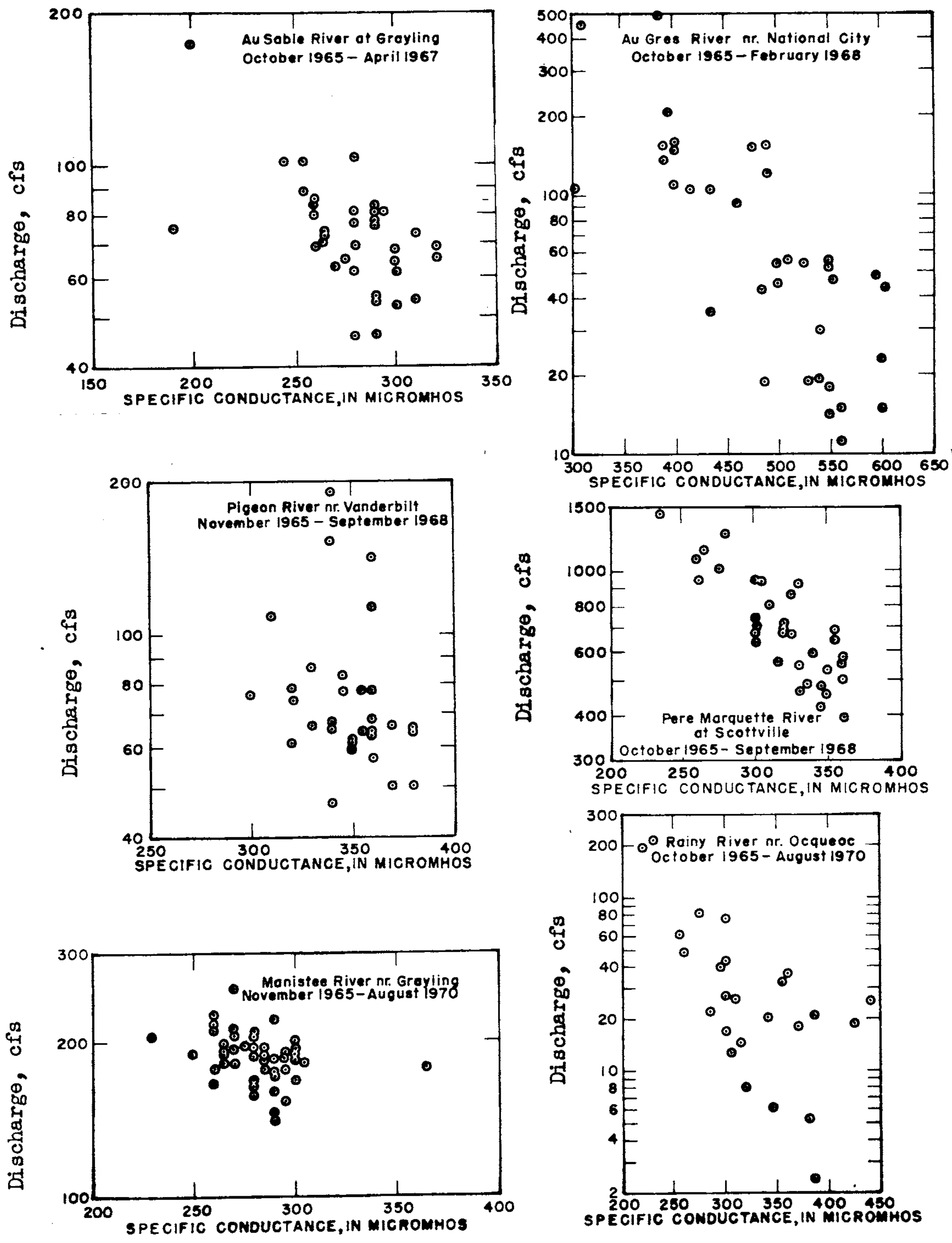


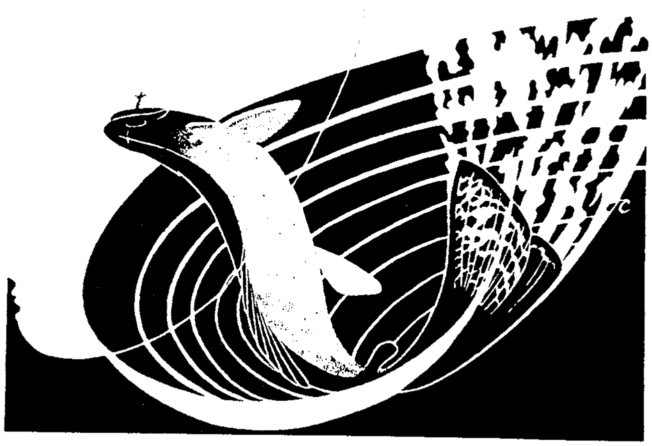
Figure 59. Specific conductance usually declines with increased discharge on streams, such as the Au Gres, having substantial amounts of surface runoff. This relationship is not well-defined on streams with very little surface runoff, such as the Manistee.

Oil Slicks and Floating Solids

None of the streams studied showed evidence of significant areas of oil slicks or floating solids. These materials, when present, degrade the esthetic quality of the streams and may reduce their productivity. The only areas where floating oil and solids are likely to be a problem at present are in the urban areas near the mouths of some of the streams.

Coliform Bacteria

Coliform bacteria may enter the water wherever human or animal wastes are washed or discharged into the stream. Ground waters discharging to the stream usually do not carry coliform bacteria because of the filtering action of the sand and gravel aquifers. Criteria for interstate waters established January, 1968, by the Water Resources Commission, Michigan Department of Natural Resources, specify a maximum of 5000 coliform organisms per 100 milliliters (geometric average of 10 consecutive samples) in waters where recreational use involves partial body contact, such as fishing or boating. Where recreational use, such as swimming, involves total body contact the maximum is 1000. Coliform organisms in streams in undeveloped parts of the study area usually are less than 1000 per 100 milliliters (Water Resources Commission, 1968). Greater concentrations occur locally where sewage or barnyard wastes enter the streams. Coliform organisms generally are high where the streams flow through urban areas.



Recreation and Water-Quality

All cold-water streams in Michigan that are highly valued for recreation are generally free of objectionable quantities of contaminants of all kinds. Freedom from harmful contaminants is a requirement of all recreational uses, but other water-quality parameters influence recreational values in different ways. Low summer water temperatures, for example, are needed for the trout fishery, but are unfavorable for swimming and wading and of minor importance to boating. The following paragraphs describe how water quality affects the various recreational uses of cold-water rivers.

Esthetic Considerations

Quality of water affects the attractiveness of streams in many ways. The unpleasant odors of decaying sewage wastes and the unpleasant sight of gray and brown growth below sewage outfalls are obvious detractors. The only stream segment in the study area that was esthetically unattractive because of sewage was the Au Sable below Grayling. Oil slicks, murky waters and unsightly floating objects are other detractors. Less obvious factors that affect a stream's attractiveness and cause changes in aquatic plant and animal life are changes in temperature, dissolved oxygen, nitrates, phosphates, pH, and other chemical and physical qualities of water. Undesirable changes in plant and animal life usually result from significant increases in water temperature and decreases in dissolved oxygen. A large increase in nutrients, nitrates, and phosphates stimulates rank growth of aquatic vegetation--usually decreasing a streams attractiveness. Drastic changes in pH, either to excess acidity or excess alkalinity, may seriously disrupt plant and animal life--usually in such a way as to make streams less attractive.

Fishing

The major water-quality requirements needed to support and continually replenish a trout population were summarized by Dr. David S. Shetter (written comm., 1970) as follows:

> "A stable flow of cold, well-oxygenated water which contains sufficient dissolved nutrients to produce food for the prey species on which the trout feeds. The water should be pure in the sense that it does not receive domestic or industrial wastes which impair its chemical or physical properties, or degrade its esthetic quality."

The most critical requirement for a trout fishery is cool water. In Michigan, most streams that are cool enough for trout habitat provide some kind of trout fishery. The Michigan Water Resources Commission established 70°F (21.1°C) as the maximum limit for intolerant fish (trout). Many excellent trout waters in Michigan have temperatures higher than 70°F under natural conditions (fig. 43), but it is believed that during the warmer periods trout congregate in the colder spring-fed reaches or along the banks where ground-water enters the stream. Benson (1954) found that brook trout in the Pigeon River were in the best condition and had the greatest volume of food in their stomachs when stream temperatures ranged between 55° and 66°F (12.8° and 18.9°C). Wicklund, and others (1961) found stream temperatures to be one of the limiting factors on trout populations on Michigan's Tobacco River, and classified all streams having maximum temperatures over 75°F (23.9°C) as "non-trout water." Tarzwell (1957) stated that brook trout seem to do best in streams with summer temperatures ranging between 52° and 68°F (11.1° to 20°C). However, the upper Black River in Otsego County, rated to be among the best brook trout streams in Michigan, has maximum summer temperatures higher than 68°F (20°C) on many summer days.

A correlation analysis of hydrologic characteristics and trout populations in Michigan streams showed a general relationship between average maximum summer water temperatures and trout populations (Tables 2, 3, fig. 42), the higher populations occurring in the streams with lower maximum temperatures.

Minimum temperatures also are important. Needham (1969, p. 51) stated that extremely low temperatures during most of the year produced stunted fish. None of the larger streams in the study area are known to be too cold for optimum growth of trout during the summer months. All streams for which we have continuous records of water temperature drop to 0°C (32°F) on the coldest winter nights. Most of them are at or near 0°C (32°F) night and day for many days during winter months. Because of the influence of ground water which enters the stream at a relatively constant temperature (about 8°C or 46°F) streams that are relatively cool in summer are relatively warm in winter (fig. 49).

The proportion of trout to other fish is largely dependent on stream temperatures. Where maximum summer temperatures are relatively cool trout generally are predominant. Where temperatures are relatively warm, suckers and other rough fish may be more abundant. Tarzwell and Gaufin (1953) found that trout made up more than 90 percent of the fish population in the West Branch Sturgeon River, a cold stream, whereas minows and other rough fish made up more than 50 percent of the fish population in the relatively warm East Branch Black and Pigeon Rivers. The percentages by weight, of trout and rough fish in several segments of the East Branch Au Sable are shown with water temperature and base-flow discharge in figure 48. The proportion of trout generally is higher in the cooler segments. However, the abundance of rough fish may also be influenced by the migration of fish from lakes in the headwaters of the East Branch (Wicklund and Dean, 1959).

Another essential element for fish is dissolved oxygen. The Michigan Water Resources Commission has established a dissolved oxygen content of 6 mg/l as the minimum requirement for trout waters. Fisheries biologists (Tarzwell, 1957, Needham, 1969, p. 59) have indicated dissolved oxygen requirements range from 4 mg/l to full saturation. The amount of dissolved oxygen required by fish increases with higher temperatures, but the amount of oxygen that can be held in solution decreases as stream temperatures increase. Thus, the dissolved oxygen content of water becomes critical at high temperatures. Nearly all streams in the study area have dissolved oxygen contents that are near saturation, well above 6 mg/l at all times except in those few reaches where oxidation of sewage wastes depletes the dissolved oxygen content. A few streams, like the North Branch Au Sable near Lovells, may occasionally drop below 6 mg/l during the night although it does not have significant sewage discharge into it. The probable cause for this drop is the warming of water in the wide shallow reaches of the river and the uptake of dissolved oxygen by aquatic vegetation during the night.

Nutrients, especially nitrates and phosphates, influence fish and fishing chiefly by stimulating growth of aquatic plants. A moderate amount of nutrients improve the trout fishery by increasing the amount of trout food. Ellis and Gowing (1957, p. 299) found that an increase in nutrients contributed by domestic sewage increased the productivity of Houghton Creek near Rose City, Michigan. White and Brynildson (1967, p. 7) attributes the high productivity of certain streams in the south, west, and central parts of Wisconsin to the relatively high nutrient content of the water. The very high trout population in the "lower" segment of the Au Sable below Grayling (table 2) may be attributed in part to the nutrients discharged into the river from the sewage treatment plant. Greater amounts of nutrients may harm or even ruin the fishery. Excessive nutrients stimulate growth of aquatic vegetation to an extent that the diurnal cycle of dissolved oxygen is exaggerated, and night-time levels of dissolved oxygen become critical. A study by the Michigan Water Resources Commission (1966) on the Au Sable showed a zone of deterioration from below the sewage outfall to about 7 miles downstream. This deterioration was registered in the fish-population survey and a survey of the kinds and numbers of bottom-dwelling organisms (fig. 60). With increasing population and greater sewage discharge, this zone of deterioration may extend farther downstream.*

A formula for the optimum concentration of nutrients in a trout stream is difficult to determine. Concentrations of nutrients in water samples may be misleading because of the rapid uptake of nutrients by plants during the growing season (Ball and Hooper, 1963). Probably the most reliable criterion is the productivity of the stream as measured by fisheries biologists. Another criterion, more easily measured, is the dissolved oxygen content of the water. If the nutrients stimulate a growth of plants so dense that night-time content of dissolved oxygen drops to undesirable levels it can be assumed that addition of nutrients to the stream is excessive.

*In 1971 Grayling began to dispose of its sewage in a lagoon south of town. Direct discharge into the Au Sable no longer occurs. Data on changes in water quality and trout populations resulting from this change in sewage disposal are not yet available.

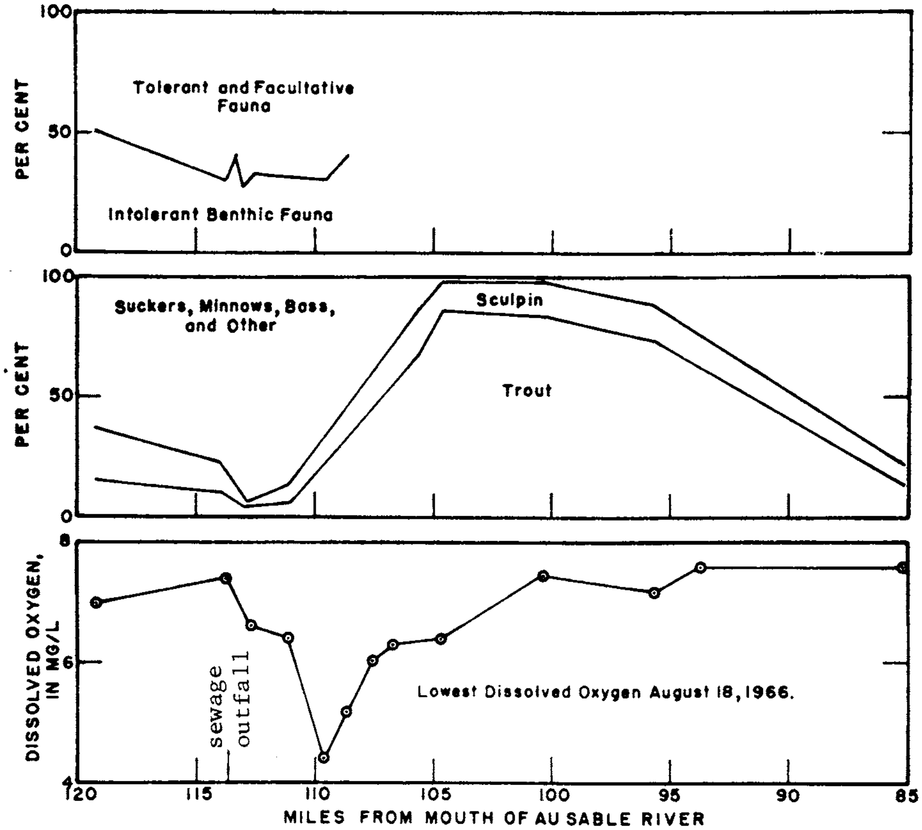


Figure 60. Deterioration in bottom-dwelling organisms and trout populations is related to deterioration in water quality below the Grayling sewage outfall.

Turbidity can lower the productivity of a trout stream by reducing the amount of sunlight that reaches the stream bottom and consequently reducing the amount of fish food organisms that are produced (Needham, 1969, p. 55). Suspended solids in unusually great concentrations can coat the gills of trout and kill them. Suspended sediments may also be deposited over gravel beds and prevent hatching of eggs or completely ruin spawning beds. Peters (1965) described the relationship of amounts of sediment and survival of trout eggs in a Montana stream. Survival was 95 percent where sediment concentrations were low (8 to 67 mg/l), but no survival was observed where sediment concentrations were high (55 to 884 mg/l). In a later paper, Peters (1967) further described the influence of sediment load on trout populations but indicated that changes in discharge and in water temperatures were contributing factors.

Turbidity is not a serious problem at present in most streams in the study area. In general, the few streams that appear turbid, such as the Au Gres, are unsatisfactory as trout streams for other reasons, such as high water temperatures and extreme fluctuations in discharge.

Suspended sediment, if we include materials moved along the stream bed, may be a serious problem in many streams. The problem is aggravated by various activities of man, including cultivation of field crops, road and bridge construction, grading of building lots, tramping of the banks by men and cattle, and dredging of the stream to reclaim swamplands for cabin building. Striffler (1964) attributed 33 percent of the suspended sediment load of Michigan's Tobacco River to eroding banks. However, the extent to which these sediments limit the trout population in any particular stream is not known (Hansen, 1968).

Excess acidity or alkalinity of a stream can destroy it as a trout stream. The Michigan Water Resources Commission specifies pH limits of 6.5 and 8.8 for Michigan trout streams. Values below 5.0 and above 9.0 interfere with the ability of fish to take oxygen from the water (Tarzwell, 1957, p. 254). The toxicity of heavy metals and some other materials is increased at low pH values (Tarzwell, 1957, p. 263). None of the streams in the study area are too acid or alkaline for excellent trout water. However, a study of the Iron and Brule Rivers in the Upper Peninsula (Galbraith, 1965) showed how quickly acid water can ruin a trout fishery. Discharge of acid mine water into the Iron River in 1962 drastically reduced the fish in the Iron and Brule Rivers. When discharge of acid mine water ceased in February, 1963, fish life in the rivers recovered rapidly.

Hardness of waters generally is not considered critical for trout fishery, but the effects of toxicants is reduced in very hard waters (Tarzwell, 1957, p. 263), and trout productivity in moderately hard waters usually is greater than that in extremely soft waters (Moyle, 1956, p. 310). The beneficial effects of hard waters is limited to waters with hardness caused by dissolved calcium and magnesium salts. Other elements causing hardness usually reduce biological productivity and are toxic (National Technical Advisory Committee Report to the Secretary of the Interior, 1968, p. 41). Hardness of water in streams of the study area is attributed almost entirely to calcium and magnesium.

The productivity of streams is strongly influenced by the dissolved solids content of the water. Streams with very low concentrations of dissolved solids, indicated by specific conductance values of less than 100 micromhos, are likely to be less productive than those with high values (McFadden and Cooper, 1964, p. 360, Moyle, 1956, p. 308). However, extremely high specific conductance, especially a rapid increase in conductance, may signal deterioration of water quality by pollutants entering the stream. All streams in the study area are moderate in total dissolved solids.

Pesticides, metallic salts, and other toxic wastes may seriously damage the trout fishery. The salmon fishery in Michigan already has been damaged by pesticides (DDT), and the trout fishery may also be affected. Accidental discharge of chlorinated water into the Au Sable River in the summer of 1969 reportedly resulted in a substantial kill of trout. A fish kill in 1970 in the Anna River in Munising in the Upper Peninsula, was attributed to discharge of cleaning solution containing napthalene. Oilfield brines, if uncontrolled, could possibly damage some of the smaller streams, but no damage of this kind has been reported in the study area. Toxic materials other than pesticides probably are not abundant in the study area, except perhaps near the larger urban areas at the mouths of some streams. The quality of water in cold-water rivers of the study area generally is quite favorable to an excellent trout fishery. The major problem is to maintain this quality in the face of increasing population and development of the area.

Boating

Quality of water is not usually an important consideration for boating unless the water becomes contaminated to such an extent that it is unpleasant to look at, offensive to smell, or dangerous to health. None of the rivers studied were contaminated to this extent except for a few short reaches near sewage outfalls.

Winter boating is influenced by water temperatures, and such activity is limited to streams that received large contributions of ground water and remain relatively ice free. Winter canoeing on the Au Sable and Manistee Rivers is now enjoyed by few, but its popularity is growing. In general, rivers that are relatively cool in summer are likely to be relatively warm and ice free in winter (figs. 47, 49).

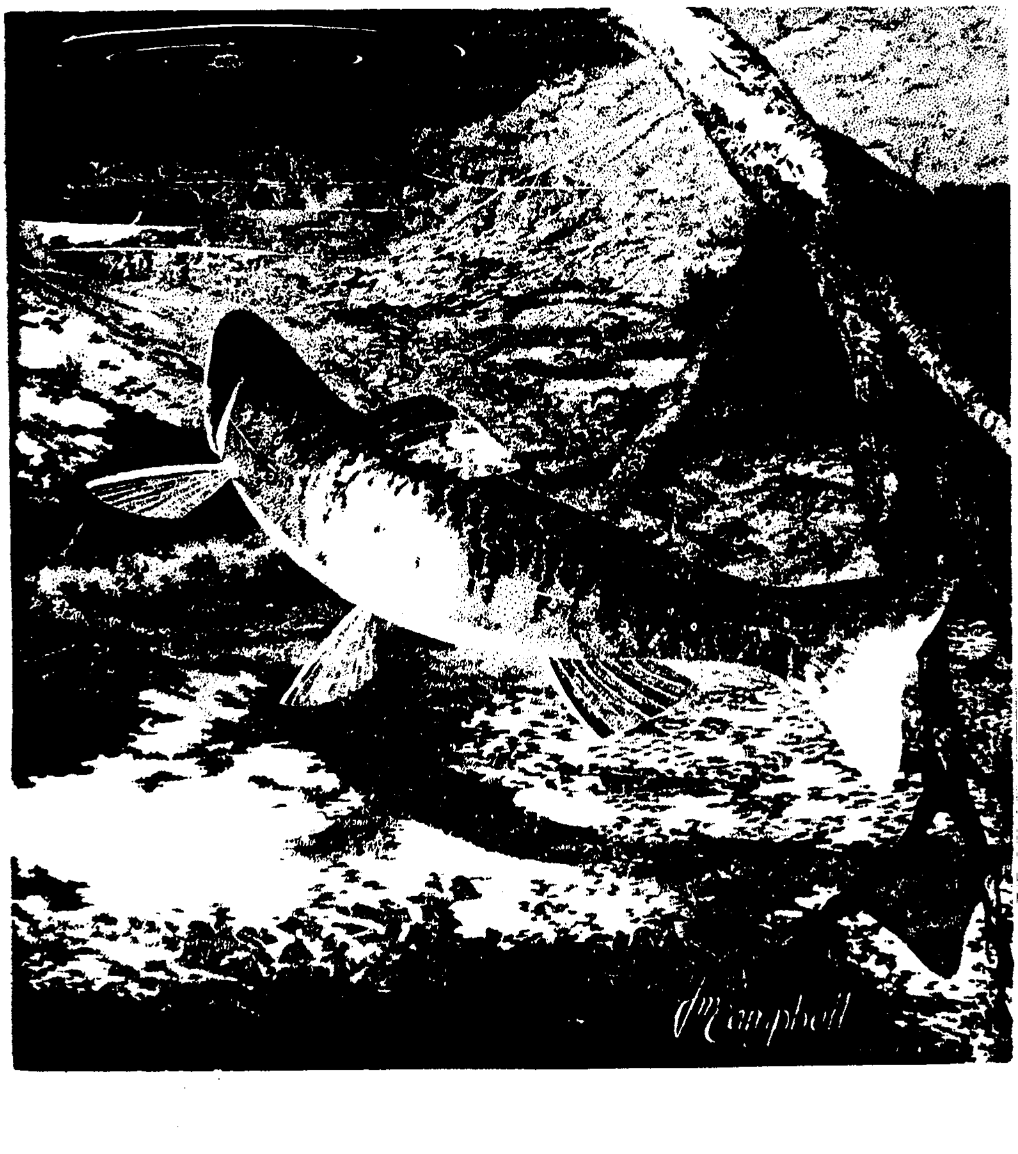
Camping and Cabin-Living

The most important water-quality considerations to the camper and cabin-dweller are those that influence the aesthetic attractiveness of the streams, as described above. Water-quality parameters that influence fishing, boating, and swimming are important to campers and cabin dwellers to the extent they engage in these additional recreational activities. The bacterial or sanitary quality of the water is especially important if water from the river is used for drinking. However, few campers or cabin-dwellers use untreated river water for this purpose, except, perhaps, in the remote headwaters where man-made development is rare or absent.

Swimming

The most important quality of water consideration for swimmers is the possibility of contamination by disease-carrying bacteria. The Michigan Water Resources Commission requires water used for swimming to conform to the following standard: "The geometric average of any series of 10 consecutive samples shall not exceed 1,000 coliform organisms per 100 ml, nor shall 20 percent of the samples examined exceed 5,000. The fecal coliform geometric average for the same 10 consecutive samples shall not exceed 100." Most rivers in undeveloped parts of the study area probably meet these requirements. Where sewage or barnyard wastes enter the rivers coliform organisms may substantially exceed the designated limits.

Other important quality considerations for swimming are temperature, turbidity, and odor. In general a stream cold enough for trout is likely to be too cold for most swimmers. However, children have been observed playing without apparent discomfort in water registering 15°C (59°F). A clear stream is more attractive to most swimmers than a turbid one. Also, a clear stream is safer for children because a submerged child can be more readily seen and rescued. Unpleasant odors are very rare in the study area except in the immediate vicinity of sewage outfalls.



PRESERVATION OF RECREATIONAL VALUES OF STREAMS

The cold-water rivers of Michigan are a fragile resource that cannot long satisfy the growing recreational demands unless the characteristics that make rivers attractive are protected from increasing abuse. Indicative of the rate of growth in demand for river-based recreation are the rapidly increasing use of river campgrounds, increase in density of canoe traffic and fishermen, and subdivision and sale of river-front property for cabin building. According to Mr. Paul Brighan, State Forest Recreation Planner (written communication, 1970) attendance at 11 State forest campgrounds increased 73 percent in the 5 years from 1965 through 1969 (fig. 61). Other recreational uses no doubt are increasing proportionally, except, perhaps, cabin development, which is limited somewhat by cost and scarcity of available land. Deterioration of recreational values are attributed in part to the effects of overcrowding and overdevelopment and partly to the effects brought about by changes in hydrologic conditions that influence recreational values. This report is concerned only with the effects brought about by changes in hydrologic conditions.

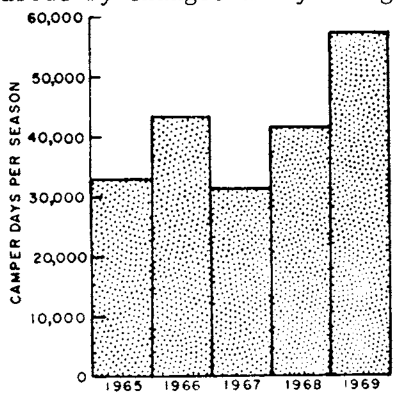


Figure 61. Attendance of 11 State forest campgrounds increased about 73 percent from 1965 to 1969.

Earlier discussions have pointed out the known and inferred relationship between hydrologic characteristics and recreational uses of streams. The following discussion will describe those characteristics that are particularly responsive to management and the results that may be expected from management practices. The same general categories used above--character of channel, bed and banks, streamflow, and water quality--will be used here.

Management of Channel, Bed and Banks

None of the streams in the study area have completely escaped the effects of man's alteration of stream channel, bed, and banks. The earliest changes probably were caused by the logging of trees during the late 19th and early 20th centuries. Subsequently, increased sunlight on the streams probably raised water temperatures, and as reported by some older residents the amount of aquatic vegetation in the streams increased. In addition, stream banks were exposed to erosion, and gravel beds may have been covered by deposits of silt and sand. Also, floating logs dragging on bottom caused some erosion of stream beds. Later, as lumbering operations essentially ceased some 60 years ago, a second growth of timber established itself and the effects of lumbering were gradually erased.

Today the river channels, bed, and banks are being changed by other works of man. Excavations and grading for cabin building, bridge construction, and pipeline laying, and tramping of the banks by fishermen, boaters, and cabin dwellers accelerate erosion and add silt and sand to the bottom materials. The rapidly growing use of trail-bikes and various "all-terrain-vehicles" may prove to be an even greater threat to the river banks. Dredging of river channels to fill lowland areas or to provide inlets for the convenience of boaters drastically alters, and usually degrades, the character of streams (fig. 62). Deterioration of river channels and banks caused by works of man are not always reversible. The river cannot be restored completely to its original condition.

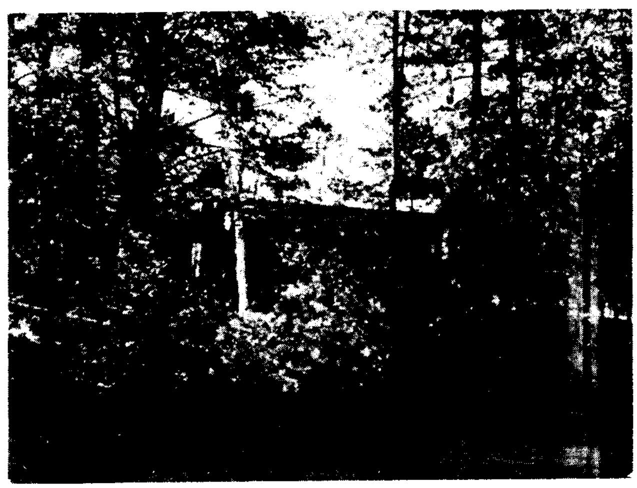
Figure 62. Dredging of the river channel on the Au Sable below Grayling detracts from the natural beauty of the river.

Not all works of man degrade the rivers, however. Some are designed specifically to protect and improve the streams. Planting of trees or shrubs on river banks, rip-rapping exposed banks, fencing to prevent livestock from grazing on river banks are examples of such improvements. Management of streams for recreation therefore includes controls to reduce the harmful effects caused by man and to increase the beneficial effects. Observations at campgrounds over the past 5 years indicate that in these areas at least, the beneficial works of man have not kept pace with the rate of destruction. Greater efforts will be required in the future than have been expended in the past if rivers are to remain a high quality recreational asset.

Reducing the Harmful Effects of Streamside Development

Private frontage far exceeds public lands on most of the rivers studied. Except for the few large holdings by public utilities, private clubs, and estates, most private frontage eventually will be developed as cabin sites or permanent dwellings. Development of closely spaced homes and cabins, if uncontrolled, can effectively ruin the recreational values of rivers. As G. E. Eddy pointed out in his "Forword" to "Michigan's Au Sable River, Today and Tomorrow" (Hendrickson, 1966), "If the fate of the river is left to chance, certain changes are inevitable, if not irreversible. Dwellings will line the banks everywhere except on public lands or on large private tracts. Protective forest cover will decrease. Water temperatures will rise, and the purifying oxygen content will fall off. Sunken logs and fallen trees, essential features in the aquatic habitat, will be removed to 'clean up' the stream, and dredging will ruin the bottom. The only trout will be those planted from year to year. Fishermen and campers will be forced to seek waters not defiled by domestic waste and litter. Declining economic benefits from recreation will cause hardships for local residents."

Grading the lot at this cabin allows silt and sand to wash into the river.



This cabin is set back from the river with trees along the banks affording privacy and protecting against erosion.

Figure 63. Development of river-front cabins does not necessarily damage the river

An example of the kinds of precautions that may be taken is shown in the Crawford County Interim Zoning Ordinance (1968) which established a "Green Belt" along all waterfront property in Crawford County (fig. 64). The "Green Belt" was designed in part to "preserve the beauty and high quality of lakes and rivers and to prevent further deterioration of water frontage." The ordinance provides, among other things, that a strip 25 feet wide shall be maintained in trees and shrubs or its natural state. Land fill is permitted only if the 25-foot native protection strip is maintained, and no material is allowed to enter the stream either by erosion or by mechanical means. Fill must be a pervious material such as gravel or sand. Sanitary disposal fields and septic tanks must at least be 100 feet from the river's edge and disposal field tile at least 3.5 feet above high water table. Other counties are considering adoption of similar regulations.

If river-front developers comply with the spirit as well as the letter of such zoning regulations, recreational values should be effectively preserved. Streams will be well shaded and will remain relatively cool; erosion of river banks will be minimized and spawning beds will remain open. In addition to providing shade, the strip of natural vegetation will help to preserve the esthetic quality of streams.

The kind of bank vegetation that will be most effective on a given reach of stream depends on local conditions. White and Brynildson (1967, p. 12) pointed out that large trees, although providing shade to keep the water cool, may be undesirable in some reaches because they shade and restrict beneficial undergrowth and thus may actually increase stream-bank erosion. Low brush and even tall grass may be adequate to shade smaller streams. Where streams are broad and summer water temperatures critically high, larger trees may be needed to provide adequate shade.

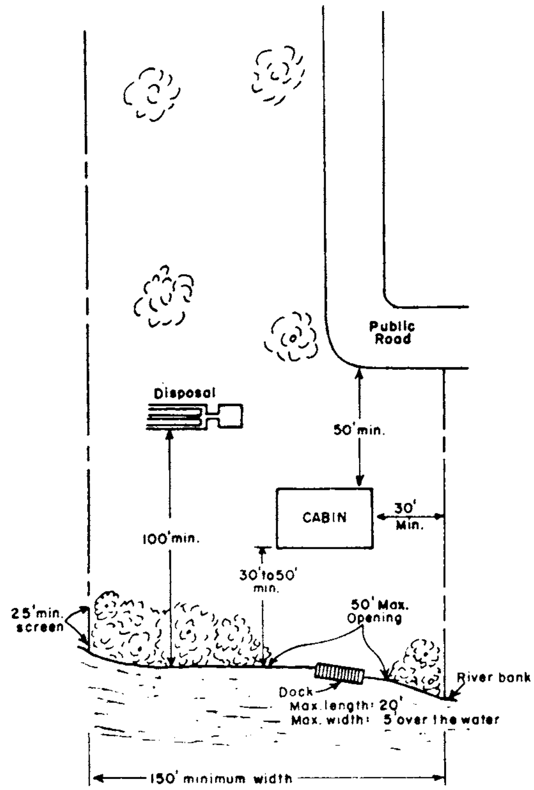
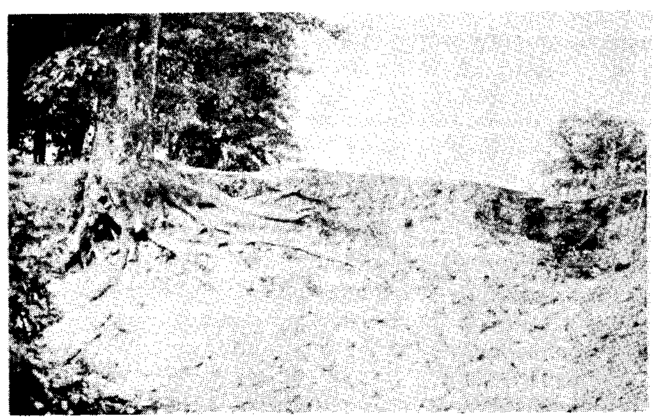


Figure 64. Green-belt zoning in Crawford County is designed to protect the aesthetic quality of the river.



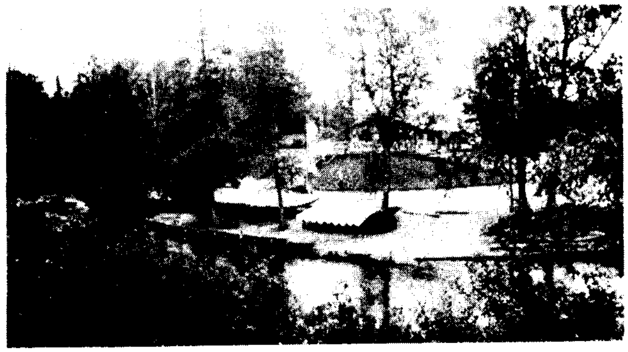
The high sandy bank of this campsite on the Au Sable below Parmalee Bridge is badly eroded. Large tree being undercut will eventually fall.

Wooden steps at this campsite on the Manistee above M-72 Bridge Failed to protect bank from erosion, because campers by-pass the steps.

Figure 65. Streambank erosion is caused by campers, fishermen, and boaters entering and leaving the river.

Public lands along the river are not immune to damaging effects. Intensive use of public campgrounds and other public access sites make them especially vulnerable. Probably the greatest damage in these areas at the present time is accelerated stream-bank erosion resulting from fishermen, boaters and others entering and leaving the water (fig. 65). Cutting or damaging trees and brush on the river banks also may contribute to erosion.

One of the major attractions in stream-side camping is the enjoyment of a view of the river. The desire for a river view is evident in the clustering of tents, trailers, and campers near the river, especially in campgrounds having no designated spaces. Many campgrounds in the study area have river views but the campgrounds administered by the State Forestry Division are now being designed to keep tents, trailers, campers, and cars back from the river (fig. 66). This restriction is not at all popular with most campers, but it is considered essential to prevent serious deterioration of the river environment. Paths leading from the campground provide access to the river, and steps are provided where needed to protect the river bank. Campgrounds designed especially to provide overnight accomodations for canoers are being provided with gravel or concrete ramps for loading and unloading of canoes (fig. 67).



Canoe Livery landing on Manistee River. Bank is protected by wood sheet piling for boat dockage.

Canoe landing in Au Sable River at Canoe Camp protected by concrete ramp. However, most canoes land upstream from ramp on unprotected bank.

Figure 67. Canoe landings can be protected from erosion by concrete ramps or wood piling.

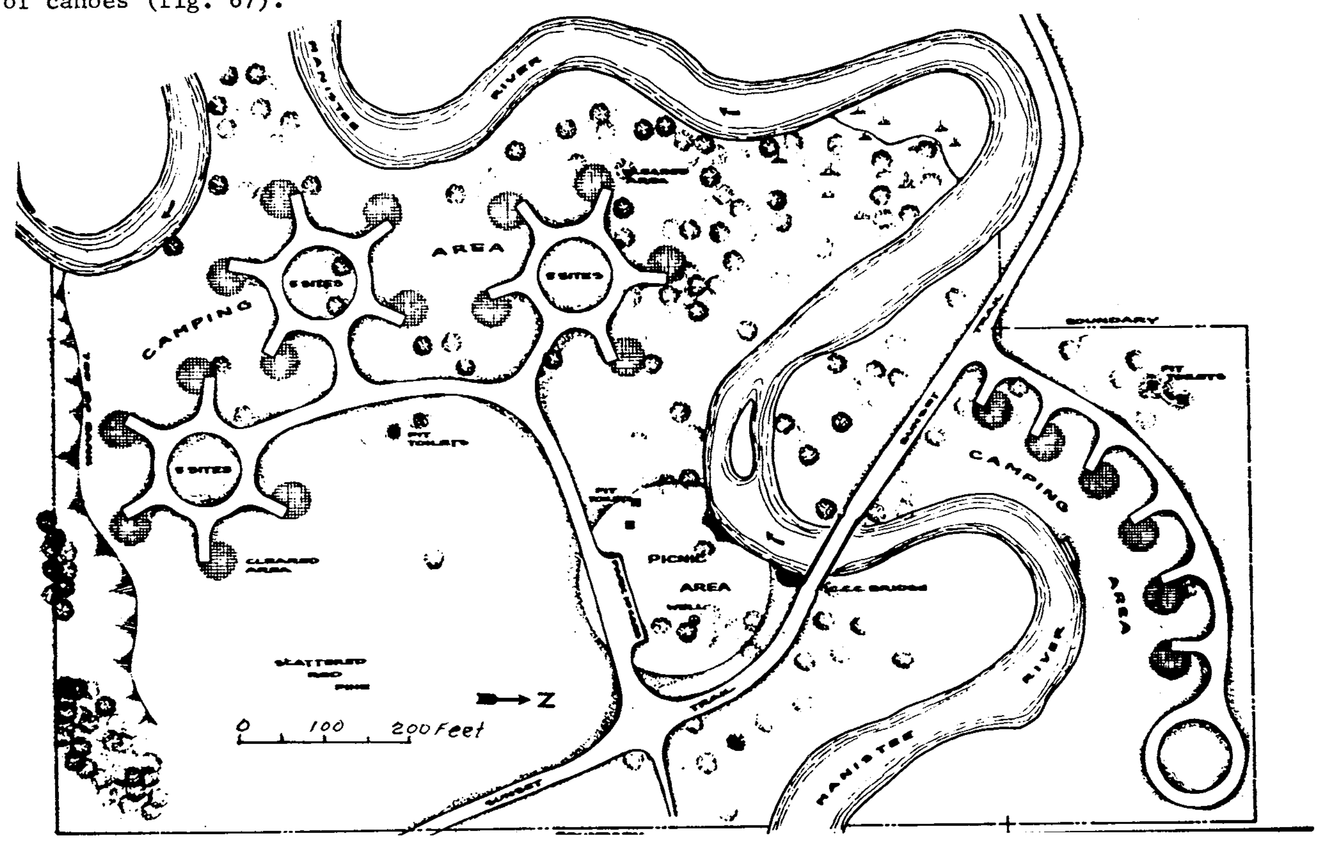


Figure 66. Campgrounds administered by the State Forestry Division are designed to protect the river banks. (Manistee River at C.C.C. Bridge.)

Erosion of banks may be especially troublesome where streams cut into high sandy banks on the outside of bends. Erosion of such banks is a natural process, and it is neither practical nor necessarily desirable to stop such erosion entirely. However, the accelerated erosion that results from removal of trees and brush is damaging to the river and should be controlled. High banks offer especially attractive views of the river and are in demand as campsites. However, cover is gradually removed from such sites as campers cut away the brush to provide room for their camp or cut down trees for firewood. As the banks are denuded, erosion is accelerated and it becomes difficult to reestablish the natural vegetation. Protecting the lower slopes with rock rip-rap, or logs and stumps helps to retard erosion in such places (fig. 68).

Unprotected canoe landing on Jordan River. Banks are eroding.

Stream Improvement

Alteration of channel, bed, and banks of streams to improve the trout fishery or to stabilize the banks usually is referred to as "stream improvement." Although the primary purpose of such work is to improve trout habitat and bank stability, the stream may also be improved in esthetic attractiveness so that recreational uses benefit. White and Brynildson (1967, p. 4) state the aim of habitat management on trout streams is "to provide the most favorable living conditions possible for trout without destroying the natural beauty."

Figure 68. Rip rap of logs and stumps protects the base of a high sandy bank at this campsite on the Au Sable below Grayling. Upper slope is eroding because some campers still climb up and down banks to enter and leave the river.

There is some uncertainty regarding the net benefits of certain stream improvement practices, especially those involving in-stream structures that alter the materials and configuration of the streambed. But there seems to be little doubt that some well-designed stream-improvement practices do improve the stream. The relative merits of various kinds of stream improvements are chiefly the concern of fisheries biologists and are beyond the scope of this paper. We are concerned here with the effects of stream improvements on the hydrologic characteristics of streams.

Reduction of sediment load from bank erosion is one of the major objectives of stream improvement. Whether this can best be accomplished by fencing to restrict livestock access to streams, by establishing a cover of trees, shrubs or grass, or by rip-rapping with rocks and other materials depends on the local situation. Hansen (1968, p. 3-10) described in some detail the various methods used to stabilize streambanks in the sand drift areas of the lake states. Because such work is costly, efforts may be confined to areas of maximum degradation. Hansen suggested that work should begin in the headwaters of a stream and continue downstream so that the treated section could attain maximum benefits before the entire project was completed.

In-stream structures of various kinds are designed to alter the physical character of river channels and bed materials to improve trout habitat. Some structures narrow the stream channel and increase the velocity of water so that sand or silt bottom materials are scoured away. The scouring action deepens the channel and may expose gravel beds. Other in-stream structures, such as low-head dams or ramps provide pools for cover in reaches of shoal water. Needham (1969, p. 180) indicated that the better trout streams usually have about equal areas of pools and riffles, spaced at relatively short intervals. White and Brynildson (1967, p. 27, 28) suggested that ramps should be spaced at intervals no closer than five to seven channel widths to conform with the natural spacing of pools and riffles. They also pointed out that the more effective pool is formed below, not above, the ramp, and cautioned that ramps should not be constructed on low-gradient streams where water may be impounded for more than five channel widths upstream.

Management of Streamflow

Flow characteristics of streams can be greatly modified by utilization of water stored in surface impoundments or in subsurface water-bearing formations. Smaller but significant changes can sometimes be effected by managing an entire river basin to increase the rate of infiltration of water to the zone of saturation. Changes in flow characteristics, usually unfavorable, also result inadvertently from urbanization in a river basin.

Earlier sections of this report have pointed out that most recreational values of streams are benefited by a relatively uniform flow, with only moderate increases during high-flow periods, and a high sustained flow during droughts. Therefore, management to improve flow characteristics of streams for recreation usually is designed to reduce flood flows and increase drought flows.

Managing Streamflow by Surface Impoundments

If surface impoundments are managed for recreational uses of streams they may store water during periods of excessive discharge and release water to augment low flow during droughts. However, if impoundments themselves are to be used for recreation, streamflow augmentation during drought may not be feasible. Impoundments used for flood control usually may be regulated to protect recreational values to some extent, but those used for power production or other industrial use cannot generally be so regulated.

Most of the larger impoundments in the study area were established for power production. Inasmuch as releases are regulated for power production, any benefits to recreational uses generally are coincidental. Rapid changes in stage and velocity that accompany changes in power production can be extremely hazardous to wading fishermen. However, use of impoundments for power production is declining in Michigan, and some dams are being abandoned. Most impoundments now being constructed are designed to provide small lakes and ponds for recreational purposes. Owners and developers of these impoundments usually are concerned with the recreational value of the lakes or ponds with little regard to recreational values of the streams on which the impoundments are built. Conflicts of interest between those concerned with recreational values of lakes and ponds and those concerned with recreational values of streams are inevitable.

An example of such a conflict is the present (1970) controversy between developers of recreational impoundments and fishermen, canoers, and others in the Pere Marquette watershed (Mainville, 1969). Several ponds, ranging in size from less than an acre to more than 100 acres, have been constructed on small tributaries of the Pere Marquette River altering streamflow patterns and creating conflict. Stream discharge below some of these ponds is substantially less than the discharge that flowed into the ponds, even in winter, indicating losses by evaporation and seepage to ground-water aquifers. At one impoundment water that had seeped into the ground was observed to reenter the stream a short distance below the dam as springs and seeps in the channel bottom and along the river banks. In another impoundment water that had seeped into the ground apparently did not reenter the stream below the dam but remained as subsurface flow eventually to discharge into another stream.

Resolution of conflicts of this kind is difficult because the effects of impoundments on streamflow in a variety of topographic and geologic settings are not well documented. Because evaporation from a free lake surface in the study area generally exceeds evapotranspiration by several inches it is sometimes assumed that the net effect of an impoundment is to reduce the flow of the stream on which it is located, especially during the hot summer months when the effects may be most troublesome. However, the area inundated by an impoundment usually is extremely small when related to the area of an entire river basin, so the influence of one impoundment in this regard may be insignificant. Furthermore, evapotranspiration figures that are valid for the basin as a whole may not be representative of the small area that is inundated by an impoundment. For example, a marshy area supporting a dense growth of phreatophytes (plants that obtain water from the zone of saturation) may transpire far more water than the average for the basin--possibly more than would be evaporated from an impoundment. In this instance the effect of the impoundment would be to increase the flow of the stream below the dam, but the increase probably would be so small as to be insignificant.

The ponded water that rises behind a dam changes the ground-water flow network. Changes may occur in direction and rate of ground-water flow and may be large or small, depending on the height of the dam, the permeability of the earth materials, and the topography at the dam site. If the impoundment is in sand and gravel beds of high permeability the ground-water divide will be shifted toward the impoundment, and the net inflow of ground-water into the drainage basin above the dam will be diminished (fig. 69). The shifting of the divide will cause a corresponding increase of ground-water flow into adjacent basins. If the earth materials are relatively impermeable the change in ground-water flow will be insignificant. Another influence of the impoundment is to divert ground-water flow from the impoundment around or under the dam to reenter the river below the dam.

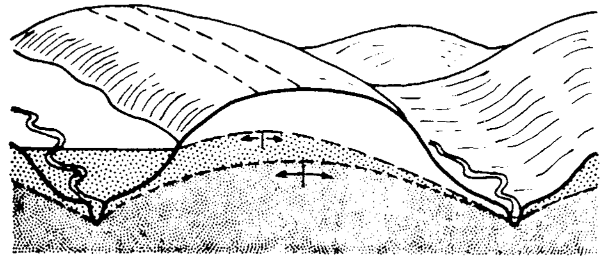


Figure 69. Impoundments on cold-water rivers may shift the ground-divide and reduce the amount of ground-water inflow to the impounded stream.

Impoundments directly influence recreational values in other ways. Unless fish ladders are provided, the dams may obstruct migration of aquatic life--including fish such as trout and salmon and harmful species such as the sea lamprey. Dams obstruct river boating, but impoundments may provide other boating on the man-made lakes.

In summary, the effects of impoundments on streamflow and recreational values are complex and cannot be predicted unless the local geologic and hydrologic setting is investigated. More factual information than is usually available is needed. Before and after records of streamflow above and below the impoundment would be helpful. With an increasing background of information of this kind it should be possible to predict the effects of impoundments with reasonable confidence.

The influence of impoundments on temperature and chemical quality of the water will be discussed in a later section of this report.

Increasing the Ground Water Discharge to Streams by Increasing Recharge

A large component of ground-water discharge usually results in relatively uniform flow and high sustained flow during dry periods. Any sustained increase in ground-water discharge requires an increase in ground-water recharge. Increased ground-water recharge can sometimes be brought about by land management on an entire river basin by increasing infiltration or by constructing recharge ponds which temporarily hold surface runoff, providing opportunity for it to seep to the zone of saturation.

Land management to increase infiltration may include management of both forested and agricultural lands. In general, total runoff is greater from open grasslands than from forests, and baseflow may be greater from hardwood than from pine forests. Urie (1967) demonstrated that net ground-water recharge was significantly larger in hardwood than in pine forests in north-central Michigan. Researchers in New York (Schneider and Ayer, 1969, Ayer, 1968) have shown that development of land from weeds and brush to dense coniferous woodlands resulted in reduction of runoff by about 26 percent. Peak discharge during the dormant season was reduced about 40 percent. However, no significant changes were found in the low flows of the streams or in summer peak flows. The greater recharge and total runoff from hardwood forests and open lands compared with coniferous forests is attributed in part to smaller losses from sublimation of intercepted snow and from transpiration.

Sandy soils that cover much of the study area are best suited to production of coniferous forests. Open spacing between trees, effected by wider initial spacing and more frequent thinning, may improve the water-yielding qualities of these forests, but the improvement in low flows probably would not be large. Heavier soils associated with some morainal areas may be utilized for hardwood forests where economically feasible, but recharge through these heavier soils under even the most favorable circumstances will be relatively small.

Agricultural practices that increase infiltration to the zone of saturation and reduce overland runoff include contour plowing, terracing, strip cropping, and pasture improvement. These same practices generally reduce erosion of the land and deposition of silt and sand in rivers. Most streams in the study area have very little agricultural land in their basins, but a few, such as the Rifle, Au Gres, and Tobacco, have some. Farm management to increase infiltration may be of some benefit in these areas, but it is doubtful that most soils heavy enough to produce substantial crops will provide infiltration great enough to significantly increase recharge. Reduction of erosion and deposition of silt in rivers may be substantial, however.

Recharge ponds have been effective in increasing the amount of ground water available in heavily pumped areas such as Kalamazoo, Michigan (Reed and others, 1966). The effectiveness of recharge ponds in increasing the low flow of streams has not been so well doucmented. Theoretically, any recharge pond that retains surface runoff that later infiltrates to the zone of saturation will increase the ground-water discharge to streams. To be most effective the ponds must be located in drainageways where water normally runs over the surface directly to rivers, at least at some seasons. They should be underlain by permeable materials so that water goes underground before much of it can be lost by evaporation. The depth to water table should be great enough so that losses by transpiration are small. And the recharge pond should be far enough away from the stream so that water stored during high flow does not reach the stream too soon to be effective in increasing drought flow.

Managing Direct Withdrawals from Streams

Direct withdrawals of water from streams generally are unfavorable to recreational values, especially during periods of drought. The reduced flow of streams makes dilution of wastes less effective. Also, reduction in discharge results in lowering of stage so that canoes may be grounded in shallow riffles, and trout cover is reduced.

In general,diversion of water from recreational rivers depletes the recreational values of streams. Where diversions are made the amount of diversion and the timing should be regulated so that damage to recreational values is minimized. Regulation usually requires monitoring of both streamflow and water quality. In some instances, diversions are permitted only when natural flow exceeds a certain rate. In others, diversion may be limited by the quality of water, or by both quality and quantity. The exact limitations in every case must be determined by local local conditions and requirements.

Maintaining Ground-Water Discharge by Managing Withdrawals from Wells

The low flow of a stream can be significantly reduced by withdrawal of water for consumptive use from wells near a stream. Reduction of low flow depends on rate of pumping, distance from the wells to the streams, character of aquifers supplying the wells, and permeability of streambed materials.

Almost all wells in the study area that supply large quantities of water are in glacial drift aquifers consisting of beds of sand and gravel. Water pumped from these wells is compensated by a reduction of water in storage, reduction in evapotranspiration, or a reduction in streamflow. Usually all three are involved. The immediate response to pumping from wells is loss of water from storage as indicated by a decline in water levels at and near the well site. In water-table aquifers the lowered water level may reduce transpiration of water by plants. The lowered water levels reduce the gradient of the water table toward the stream and thus reduce ground-water discharge to the stream. If the well is close enough to the stream the water table gradient may be reversed, and water will flow from the stream to the well.

Managing withdrawals from wells to maintain ground-water discharge to streams involves location and spacing of wells, regulations on depth of wells, and regulation of pumping. Effective management requires first of all knowledge of the hydrologic system in the area of withdrawal. If an aquifer is relatively uniform and homogeneous, with no important confining beds, the wells should be located as far from a stream as is practicable. This will permit withdrawal of large amounts of water from storage before streamflow is significantly affected. If a confining bed of relatively impermeable clay separates the streambed from the aquifer the location of wells is not so critical. In this latter situation the cone of depression will spread over a large area and the effect of pumping on streamflow will be less pronounced. If there are shallow and deep aquifers--aquifers separated by a confining layer--wells should be drilled into the deeper aquifers, if practicable, to reduce the effects of pumping on streamflow. Spacing of wells in a well field and scheduling of pumping individual wells should be designed to reduce lowering of water levels near the stream to a practical minimum, especially at times of low flow.

If streambed materials in the pumping area are highly impermeable and the water table drops below the streambed as a result of pumping, additional lowering of the water table will not increase the loss of water from the stream, but ground-water inflow in other reaches may be reduced.

Maintaining Ground-Water Discharge by Restricting Drainage of Agricultural Lands

Drainage of wetlands lowers the water table and reduces evapotranspiration, and thus may increase the net discharge of ground water. If the ground-water discharge is collected in open drainage ditches, however, it may be warmed by exposure to sunlight before reaching the stream, and thus increase stream temperatures. Also, the lowering of the ground-water table in the headwater areas reduces the discharge of ground water into the natural stream channel. In extreme cases, the natural channel may dry up and the drainage ditches become the effective channels. For recreational purposes, a drainage ditch is a poor substitute for a natural channel. Agricultural lands make up a relatively small part of the watersheds included in this study, so drainage of agricultural lands probably is not an important problem on most streams. If future agricultural development should lead to substantial drainage of wetlands, the effects of such drainage on the recreational potential of streams should be assessed.

Augmenting Low Flow of Streams by Pumping from Wells

Pumping of water from wells and discharging it to a river can increase the low flow of the stream. The net gain in flow is equal to the amount of water removed from the ground-water reservoir less the amount that might be recharged back to the ground-water reservoir from the stream. The amount of water returned depends on the amount of water pumped, the character of the aquifer, permeability of stream bottom, and the distance of the wells from the stream. If water can be obtained from a deep aquifer separated from the river by a confining layer, the gain will be greater.

A study of surface and ground-water relationships on the Little Plover River in Wisconsin (Weeks, Ericson, and Holt, 1965) showed that a well 300 feet from the stream derived about 30 percent of its flow from the stream after 3 days of pumping. This well pumped about 1120 gpm, so the net gain to streamflow from this well was about 780 gpm, or about 1.5 cubic feet per second. After a longer period of pumping the amount of water derived or diverted from the stream probably would have been greater, so the net gain would be smaller.

Wells yielding a thousand gallons per minute or more can be obtained in many places in the study area. A series of such wells along a stream of moderate size could add significantly to the low flow, possibly increasing the flow 10 percent or more. In some areas, such as the base of the moraine at Rose City, flowing wells could be developed that would significantly increase the low flow of streams.

Although hydrologically feasible, augmentation of low flow by pumping from wells may be undesirable for economic and esthetic reasons. Construction, maintenance, and pumping of wells would be too costly in most instances for the recreational values gained. Pumpage of such wells may reduce the supply available to other wells used for public or industrial supplies. Probably the most important objection is that a stream so maintained has lost the essential quality of naturalness, so that recreational uses are degraded.

Reducing Undesirable Effects of Urbanization

Flow characteristics of streams in the study area have not been seriously influenced by urbanization because there are no large urban areas except those near the mouths of some streams where they empty into the Great Lakes. The influence of urbanization usually is to increase flood flows of streams by increasing surface runoff and by decreasing the time of concentration of surface runoff. Paved surfaces and roofed areas also reduce infiltration to aquifers essentially to zero. As population increases and urban areas grow the effect on streamflow in the study area may become important. These effects can be modified to some extent by maintaining open unpaved areas within an urban complex, especially where the soils are permeable enough in their natural state to permit substantial recharge to ground-water aquifers. Recharge ponds may be used in some places to help counteract the influence of paved surfaces. The city of Kalamazoo has substantially increased ground-water recharge by such ponds (Reed, and others, 1966). The purpose of recharge ponds in Kalamazoo is to maintain the yield of well fields, but similar ponds could be used where conditions are favorable to enhance the ground-water flow to streams. The ponds can be constructed and landscaped to be esthetically pleasing and may be incorporated into a park system. Surface reservoirs could also be constructed to retain high flows and augment low flows by controlled release, but sites for such reservoirs are not always available.

Reducing Loss to Phreatophytes

Vegetation along the banks of cold-water rivers, especially in swampy areas, may intercept a substantial amount of ground water that otherwise would discharge to streams. These plants, whose roots obtain water from the zone of saturation below the water table, are called "Phreatophytes." White and Brynildson (1967, p. 40) suggest that grasses rather than trees and shrubs should be fostered in natural spring areas to reduce the amount of transpiration loss. Possibly some control of streamside vegetation may also be justified to reduce transpiration losses along small streams, but the gain in ground-water discharge to the stream should be balanced against possible warming of water caused by reduction of shade. Where tall grasses and low shrubs provide ample shade and protection from erosion it may be desirable to thin out or remove the larger phreatophytes. However, consideration should also be given to the esthetic appeal of the larger trees.

Management of Water Quality

The quality of water in a stream is most responsive to man's activities. Prevention or abatement of pollution is the most obvious management technique in protecting recreational values, but techniques other than pollution control can be used to improve the quality of water in streams. Anything that is done to increase ground-water discharge to a stream lowers summer water temperatures and consequently increases the dissolved oxygen of the stream. Increased ground-water discharge to a stream increases the drought flow. Consequently, there is greater dilution of wastes during dry periods when pollution usually is most troublesome. Increase of ground-water discharge to a stream also increases the concentrations of natural dissolved solids entering the stream, but these increases usually are not significant. Anything done to reduce erosion in a river basin may decrease suspended sediment and turbidity of a stream.

Cooling the Summer Water Temperatures

Temperature of water, one of the most critical factors for a trout fishery, is very sensitive to activities of man. Unless activities are planned specifically to cool the water, the influence usually is to increase summer water temperatures and deplete the trout fishery. Pluhowski (1970) found that modification of the natural environment by man's activities on Long Island increased average stream temperatures in summer as much as 5-8°C (9-14°F). When streamside trees or shrubs are cut, the river channel widened, or impoundments constructed, the increased exposure to sunlight tends to warm the water. Brown and Krygier (1970) found that clear-cutting of timber on a small watershed in Oregon increased annual maximum water temperatures from 57 to 85°F (14 to 29.5°C). Man's use of the land usually, although not always, results in decreased ground-water recharge, so that the cooling influence of ground-water discharge is lessened. Discharge of heated water to streams is another activity that increases summer water temperatures. These unfavorable effects of man's activities can be overcome by decreasing the area exposed to sunlight, increasing the discharge of ground water, controlling releases from impoundments, and limiting discharge of heated water to streams.

Decreasing the area of a stream exposed to sunlight can be accomplished by planting trees or shrubs along the river bank, narrowing the channel of the stream, and moving impounding dams. As pointed out above, planting of trees and shrubs along the river bank should be designed to suit the needs of each reach or area of stream. Streams that are cool enough in summer for trout may be more productive if shading is not excessive (White and Brynildson, 1967, p. 12). Many small head-water streams in the study area probably will remain cool enough with brush and tall grasses for shade.

Decreasing the width of channel decreases the area of exposure to sunlight, but changes of this sort may deplete the natural beauty of the stream. Narrowing of the channel also increases stream velocity which changes the character of the bottom sediments through the affected reach. Where dredging or bank erosion have artificially widened a stream, reducing the width by lining the banks with logs or rock rip rap may be desirable to help reduce stream temperature and improve the fishery. Wicklund (1959) recommended that wide shallow reaches of the East Branch Au Sable should be reduced in width by log jam deflectors. In practice such improvements usually are limited to short reaches of small streams.

Removal of impounding dams, by greatly reducing the area of exposure to sunlight, may cause a significant cooling of water. However, some impoundments that are very deep or are in very permeable earth materials may cool the downstream reaches in summer. Removal of such an impoundment would increase, rather than decrease, summer water temperatures. The decision to remove an impoundment should be made only after careful analysis of all probable effects the removal might have on recreational values. The desirable effect of cooler water, for example, should be balanced against possible undesirable effect of an added sediment load to the stream. Possibly the removal of an impoundment and lowering of the impounded waters could be engineered to reduce harmful effects to a minimum. More effective than removal of impoundments would be reduction or elimination of construction of such impoundments. The many small impoundments now being built on small feeder streams are a definite threat to recreational values of cold-water rivers.

The undesirable temperature effects of impoundments can be reduced, in some instances, by changing the spillway so that water is removed from near the bottom instead of near the surface of the pond. Wicklund, and others (1961) suggested such a remedial measure on Farwell Dam on a tributary of the Tobacco River. If the impoundment is very deep, the water spilled from the bottom may be low in dissolved oxygen (Dendy and Stroud, 1949). Because the released water is cool it will take up oxygen as it moves downstream. Uptake of oxygen can be accelerated by running the water over rocks or weirs.

As stated above, anything that increases ground-water discharge to streams influences the temperatures of water. The effect is to cool the water in summer and warm it in winter. The techniques used to increase ground-water recharge as outlined above can therefore be used to reduce summer stream temperatures. Decrease in ground-water discharge to streams caused by pumping from wells will also influence water temperature, but in opposite directions, causing a warming of streams in summer and a cooling in winter. Augmentation of low flow by pumping water from wells will lower the summer water temperatures. Novitzki (1969) found that ground water pumped into Black Earth Creek, Wisconsin, in summer lowered the water temperature of the stream as much as 5°F (3°C). The influence of augmentation was rapidly dissipated downstream, so that at about 1 mile below the point of augmentation the effect was insignificant.

Discharge of warm water into streams from any source will, of course, raise the temperature of water in the streams. Studies of thermal loading have been made on many streams. The changes generally are quite predictable, and can be controlled by limiting the rate of discharge, the temperature of the discharged water, and the timing of discharge. Cooling towers and recirculation of water can reduce thermal loading to a large extent, depending on the economics and requirements of quality control regulations. The Water Resources Commission of Michigan has established strict requirements regarding water temperatures on trout streams (cold-water intolerant species). Few streams in the study area receive significant amounts of warm water discharge, except possibly near the mouths of some streams where they empty into the Great Lakes.

Maintaining the Dissolved Oxygen in Water

The solubility of oxygen in water increases as temperature decreases. Therefore, management to lower the water temperature tends to increase the dissolved oxygen content of water. But other factors also influence the dissolved oxygen content. Because plants give off oxygen by day and use oxygen at night an increase in aquatic vegetation increases the dissolved oxygen in the daytime and decreases it at night. Decomposition of organic matter uses up oxygen, so that addition of organic wastes to the river results in lowering of concentrations of dissolved oxygen in the water (fig. 53). Ground water, when first discharged from a spring, seep, or well, usually contains little or no dissolved oxygen, (Odum and Caldwell, 1955) but it quickly takes up oxygen when exposed to the air.

All management practices described above to increase ground-water discharge and decrease summer water temperatures will also increase the dissolved oxygen content of water. Augmentation of low flow of Black Earth Creek in Wisconsin (Novitzke, 1970) by pumping ground water from a gravel pit significantly increased dissolved oxygen in the stream. Before augmentation concentrations of dissolved oxygen as low as 3 mg/l had occurred in the study reach, just below a sewage disposal plant. After augmentation, dissolved oxygen concentration did not drop below 7 mg/l. The trout population in the study reach also increased significantly.

Other techniques for improving dissolved oxygen conditions in streams include treatment of organic wastes, aeration of water that is seriously undersaturated with respect to oxygen, and reduction of nutrients discharged to the streams. Primary treatment of sewage wastes removes about 50 percent of the biochemical oxygen demand (BOD). Secondary treatment could raise the efficiency to remove as much as 90 percent of the BOD. Use of sewage lagoons may reduce BOD discharge to near zero if no surface discharge is permitted. Aeration of oxygen-depleted water can be effective if little or no unoxidized organic wastes are carried in water. Aeration can be accomplished by running water over rocks or low weirs, or by use of any device that will increase the area of exposure of water to air, or by pumping compressed air into the water.

Reduction of nutrients (nitrates and phosphates) discharged to a stream reduces the growth of aquatic plants and thus reduces the diurnal fluctuation in dissolved oxygen so that dissolved oxygen does not drop to undesirably low levels during hours of darkness.

Sewage wastes from properly installed domestic disposal systems usually do not contribute significantly to the BOD of a stream unless the individual systems are closely-spaced or the stream is quite small (fig. 70). They may, however, contribute nutrients to the water that stimulate plant growth and thus lower the dissolved oxygen content of the stream at night. Drain fields from septic tanks should be located where the water table is not too near the surface so that organic wastes will be fully oxidized before the effluent reaches the water table. The spacing of septic tank disposal systems may be most important in highly-developed areas. Close spacing may seriously deplete the quality of river water.

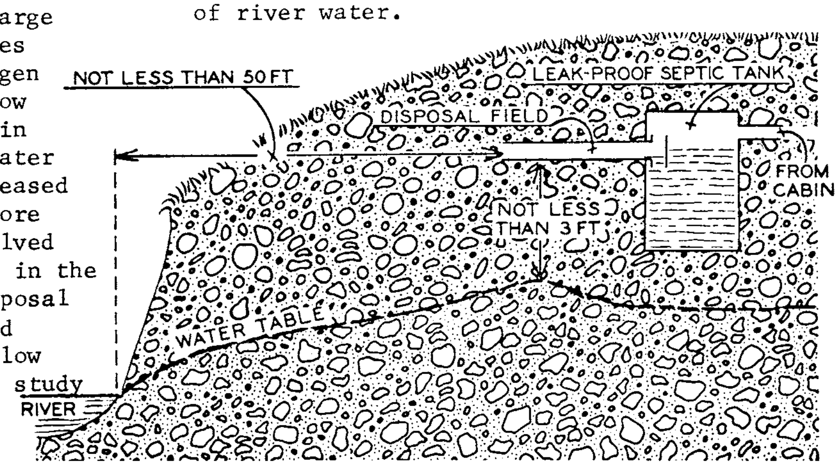


Figure 70. Disposal systems can be designed to reduce pollution.

Chemical wastes can also deplete the dissolved oxygen of a stream. Any substance that contributes to the chemical oxygen demand tends to deplete the dissolved oxygen. Such wastes are not known to be a problem in the study area.

Controlling Turbidity and Sediment Load

Turbidity, as such, generally is not a serious problem in rivers in the study area. Some rivers, draining lake-bed sediments in the eastern part of the area are moderately turbid during high flows, but these streams generally are unfavorable for recreation for other reasons, such as high summer temperatures and low drought flow. Occasionally, as in construction of pipelines across streams or in excavation for highway or bridge construction, turbidity may be relatively high in streams. Although construction activities of this kind usually are of short duration, precautions should be taken to reduce their harmful effects as much as possible.

More troublesome usually than turbidity is sediment load, including bed load, which may be deposited over gravel spawning beds. The harmful effects of excavations mentioned above are chiefly the covering of spawning beds by sand and silt. In some instances, suspended sediment derived from such excavations may be so concentrated that the gills of fish are coated and respiration is effected. The major source of sediment load, however, is erosion of bed and banks. Protection of banks from erosion was discussed in an earlier section. However, reduction of sediment load and sediment deposition in a stream may require more than protection of river banks. In areas of heavy soils, where overland runoff is high, protection of the entire river basin from uncontrolled soil erosion may be needed. Such protection requires the cooperation of all residents and landowners within the basin.

Destructive loads of sediment may be introduced into a stream as a result of the failure or abandonment of a dam. An example of such destruction was the great load of sand and silt carried down the Pigeon River upon failure of a dam on May 15, 1957. According to some observers, many spawning areas were smothered by sediments carried from the impoundment. Recovery of the stream was slow, and perhaps is not yet complete. The obvious remedy here is to take measures to prevent failures of the dams. When a dam is abandoned because it no longer fulfills its purpose, careful planning is essential to preserve the river downstream. In some instances the best practice may be to maintain the dam solely for protection of recreational values.

Controlling Nutrients

A moderate amount of nutrients, chiefly nitrates and phosphates, helps to maintain the productivity of a stream, but great amounts stimulate undesirable density of water plants. The depletion of dissolved oxygen at night by excessive plant growth has already been discussed. Control of nutrients from sewage is one of the most difficult tasks for management. Standard methods of sewage treatment do not effectively remove nutrients from sewage effluents, but new methods for nutrient removal are being developed.

In 1967 an advanced treatment of sewage wastes for nutrient (phosphate) removal was tried experimentally at Grayling (Wukasch, 1968). Concentrations of phosphates were reduced by 60 to 80 percent with a mean reduction of 72 percent. Removal of suspended solids and BOD was also significantly improved. The treatment included conversion of soluble phosphates to an insoluble form and removal of the suspended phosphate from the waste water.

Disposal in sewage lagoons also removes a relatively large amount of nutrients, especially if water lost from the lagoon is chiefly by evaporation. A sewage lagoon was constructed in 1966 at Scottville, on the left bank of the Pere Marquette River. The lagoon consists of two cells. The receiving cell is sealed so that no water is lost by infiltration. The second cell is not sealed, so infiltration from the lagoon takes place during the summer season when the water table is normally low. In the spring when the water table is high there may be some inflow of ground water into the lagoon. In normal operation the only loss from the lagoons is by evapotranspiration and infiltration. However, surface releases are made if necessary during the period of high flow of the river--usually in April. In 1969, the sanitary and storm wastes were being separated so that only sanitary wastes would discharge into the lagoon. In future years it may not be necessary to release any surface flows from the lagoon. This system does not completely eliminate discharge of nutrients to the river, because soluble phosphates and nitrates which percolate to the water table may be discharged to the river. But nutrient load is reduced, probably substantially, by precipitation in the lagoons, uptake by plants, and by adhesian to clay particles in the soil. BOD is substantially reduced, except on occasions of surface release when discharge and dilution are very high.

Control of nutrients from sources other than sewage wastes is of minor importance at this time. In the few areas where fertilizers are applied to croplands it may be desirable to reduce surface runoff by terracing or contour plowing so that large concentrations of nutrients are not carried directly into streams, especially during periods of low flow. Where dense growth of algae occur in impoundments, care should be taken so that surface releases do not carry clumps of algae into streams.

Controlling Acidity and Alkalinity

Water in all streams in the study area is moderately alkaline, with pH values well within acceptable limits for all recreational uses. Control of acidity and alkalinity is therefore not now a problem. There are no mines contributing acid mine waters and no industries at present discharging significant amounts of acid or alkaline wastes to streams. Acid or alkaline wastes added to streams could cause problems, but the buffering action of calcium bicarbonate waters that predominate in the study area would reduce the effects of small amounts of such wastes. If acid or alkaline wastes were added in excessive amounts, however, the rivers could be ruined as trout streams. The obvious management practice is to avoid disposal of excessive wastes and to monitor the pH of water in streams where wastes are being discharged.

Control of Oil Slicks and Floating Solids

Control of oil slicks and unnatural floating solids requires monitoring of waters where such materials are likely to enter the river. Detection is relatively easy because objectionable amounts usually are apparent to even casual observation. However, monitoring of the results of oil spills may not be enough. By the time the oil becomes noticeable great damage may be done to all recreational values, and the damage may not be easily erased. The handling of petroleum products near any river should be managed with great care so that disastrous spills will not occur.

Controlling Other Wastes

Many dissolved substances that are harmless in the minute amounts usually occurring in natural waters may become toxic or otherwise harmful in larger amounts. Thus, minute amounts of cobalt and copper may be essential for production of aquatic life, whereas greater concentrations may be toxic. Even the commonly occurring salts of chlorides and sulfates, when present as concentrated brines, may destroy the plants and animals in a stream.

The only effective management to avoid damage is to prevent these wastes from entering streams. The wide variety of possible contaminants makes it impracticable to continuously monitor all streams for all possible contaminants. An alternative is to monitor those stream segments where specific contaminants are likely to occur.

The Need for Water-Quality Records

Water-quality records are needed to detect contaminants that may enter a stream, as pointed out above. These records are essential for other reasons also. They establish the natural water-quality conditions of uncontaminated streams to serve as a bench-mark for comparison with other streams. They may give warning of a gradual but progressive deterioration of water quality, such as warming of the water, decline in dissolved oxygen, or increase in nutrients or other dissolved solids.

They should also be used to determine the effectiveness of any remedial measures designed to improve the quality of water in streams. For example, if cooling towers are installed to reduce thermal loading of a stream, records of water temperature before and after installation are essential to determine the effectiveness of the towers. If an improved sewage treatment plant is put into operation, its effectiveness can be determined by recording the dissolved oxygen and nutrient levels before and after the change over. Only by measuring the changes resulting from improvement practices can their true worth be determined. Only through concerted effort to increase the desirable changes in water can real progress be made in improving the quality of streams.

SUMMARY AND CONCLUSIONS

1. The recreational values of Michigan's cold-water rivers are strongly influenced by hydrologic characteristics of rivers and river basins. Activities of man impose changes in hydrologic characteristics that influence recreational values. These changes may be favorable or unfavorable, but if left to chance they usually will be unfavorable.

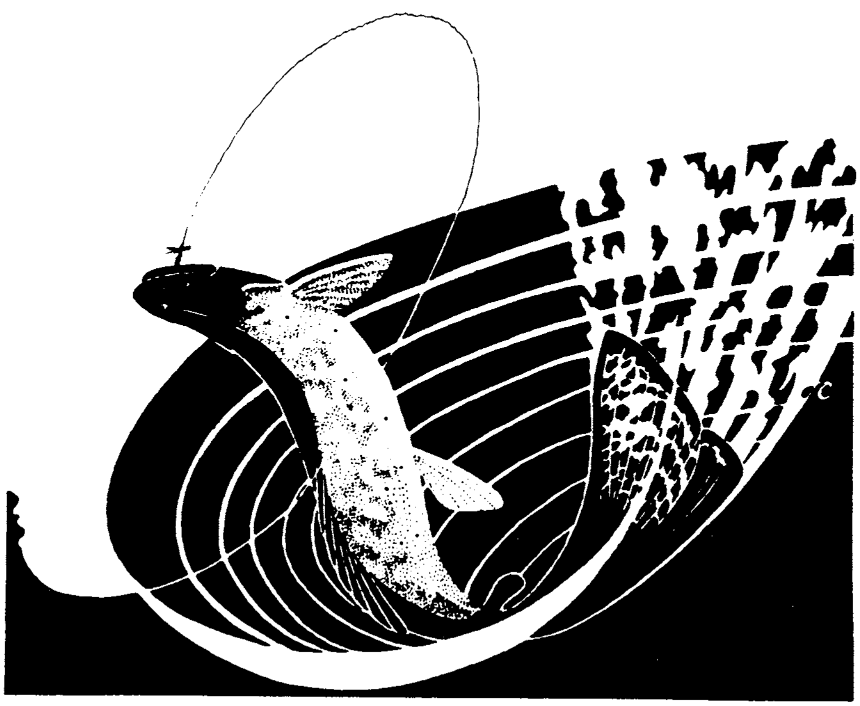
2. Hydrologic characteristics that are usually favorable to recreational values are streamflow that is relatively uniform with a high sustained flow during dry seasons. The water should be clear and free of objectionable contaminants, and river banks should be well-stabilized against erosion. Most rivers in the study area that are relatively uniform in discharge are relatively cool in summer and relatively clear most or all of the year.

3. Deterioration of recreational values result from overcrowding and over-development and from changes in hydrologic conditions in the river and river basin. Some of these changes may be irreversible.

4. Preservation and improvement of recreational values of streams can be accomplished by maintaining or augmenting the drought flow of the streams, maintaining or lowering maximum summer water temperatures, avoiding or reducing the discharge of contaminants to streams, and protecting river bed and banks from erosion. Some practical steps that can be taken are zoning to prevent over-development and deterioration of river banks, protection of bank erosion by vegetation or rip-rap, management of water withdrawals, improvement of waste-disposal systems, restriction of impoundments, and prohibition of discharge of all damaging contaminants, including warm water and sediment.

5. Streams lacking suitable conditions of streamflow, water temperature, and dissolved oxygen sometimes may be improved by augmenting the streamflow with cool waters from surface impoundments or ground-water reservoirs. Such streams may, however, lack the quality of naturalness provided by free-flowing rivers.

6. The interrelationships of hydrologic characteristics and recreational values are so complex that simple "rules of thumb" for water management generally are not practicable. Management practices that alter one hydrologic characteristic to improve recreational values may alter another characteristic to deplete these values. Each stream and each reach of stream should be carefully studied to determine, insofar as possible, the total results of any changes. Continuing studies should be made to assess the results of changes.



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