Watershed Management Research Needs in the Forests of the Lake States
Michigan State University Agricultural Experiment Station
Special Bulletin
Robert E. Dils, Forestry
Issued May 1957
36 pages

SPECIAL BULLETIN 416 • MAY 1957

WATERSHED MANAGEMENT RESEARCH NEEDS

IN THE FORESTS OF THE LAKE STATES

DEPARTMENT OF FORESTRY

MICHIGAN STATE UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

EAST LANSING

CONTENTS

Watershed Management Research Needs in the Forests of the Lake States

A PROBLEM ANALYSIS[1]

By ROBERT E. DILS[2]

INTRODUCTION

IN THE PAST FEW DECADES, the need for proper management of the water resource in the Lake States has become more and more apparent. Before we can effectively manage any resource, however, we need background information on its scope and behavior.

In the northern region of the Lake States, about 80 percent of the area is forest land. From 25 to 30 percent of the unglaciated region in southwestern Wisconsin and southeastern Minnesota falls into this same category. Since many of our water problems start on forested or partially wooded drainages, the forest researcher is responsible for providing much of this background information.

With the very names and slogans of Michigan, Wisconsin, and Minnesota indicating an abundant endowment of fresh water, the unconcern in the past over its management and conservation is understandable. Driving through "The Land of 10,000 Lakes," or living in the "Water Wonderland," one could easily acquire the comfortable and complacent feeling that the supply of clear, useful, ever-present water is one problem in our present complex life about which we need feel no concern. Our ancestors probably had this same feeling about the timber resources in the virgin forests that once covered most of these same states.

Yet danger signs are present. Warnings in regard to our water supply are appearing just as they must have when we were completing the cycle of our timber destruction. Flash flooding, erosion, sediment

[1]This investigation was conducted as a cooperative project between the Michigan Agricultural Experiment Station, Michigan State University, and the Lake States Forest Experiment Station, United States Department of Agriculture Forest Service. The Station is maintained at St. Paul, Minnesota, in cooperation with the University of Minnesota.

[2]Now associate professor of forestry, University of Michigan.

deposits, seasonal water shortages, pollution by organic and industrial wastes, and reduction of ground water levels—these are no longer words confined to technical and scientific publications. They are appearing with increasing frequency as headlines in our local Lake State newspapers.

Some of these problems are the result of apparent apathy. Some have been caused by a scarcity of basic knowledge on the behavior and management of the water resource. This same apathy and lack of knowledge resulted in the waste and destruction of the once vast timber reserve in the Lake States.

Is it to happen again? Apathy can be overcome. Lack of basic knowledge can be remedied by research such as is suggested in this report.

The purpose of this report is to suggest a basis for a research program which will provide the fundamental data needed to solve our present water problems, and to anticipate future problems involving forest lands in the northern forest region and the unglaciated area. Thus, it deals only with research needs falling within the province of forestry and forest hydrology.

Since the behavior of water within a given watershed depends upon a number of environmental factors, including climate, topography, vegetation, soils, and land use, discussion of these phases of the problem is given to set the stage.

THE STUDY AREAS

The Lake States region consists of the States of Michigan, Wisconsin, and Minnesota. It can be divided into three principal forest zones as shown in Fig. 1: The northern forest, the southern forest, and the prairie. This report is restricted to the northern forest and that portion of the southern forest designated as the Driftless Area.

The northern forest, an area of 53 million acres, extends from the Canadian border to some 400 miles south. From the prairie zone at the edge of the Red River basin in Minnesota, it ranges 600 miles east to the Lake Huron shore in Michigan.

Although 43 percent of the land area of the Lake States lies in this northern forest region, its population is only 12 percent of the 13.7 million Lake State total.

An abundance of fresh water is the outstanding feature of the area. There are literally tens of thousands of lakes and several hundred miles

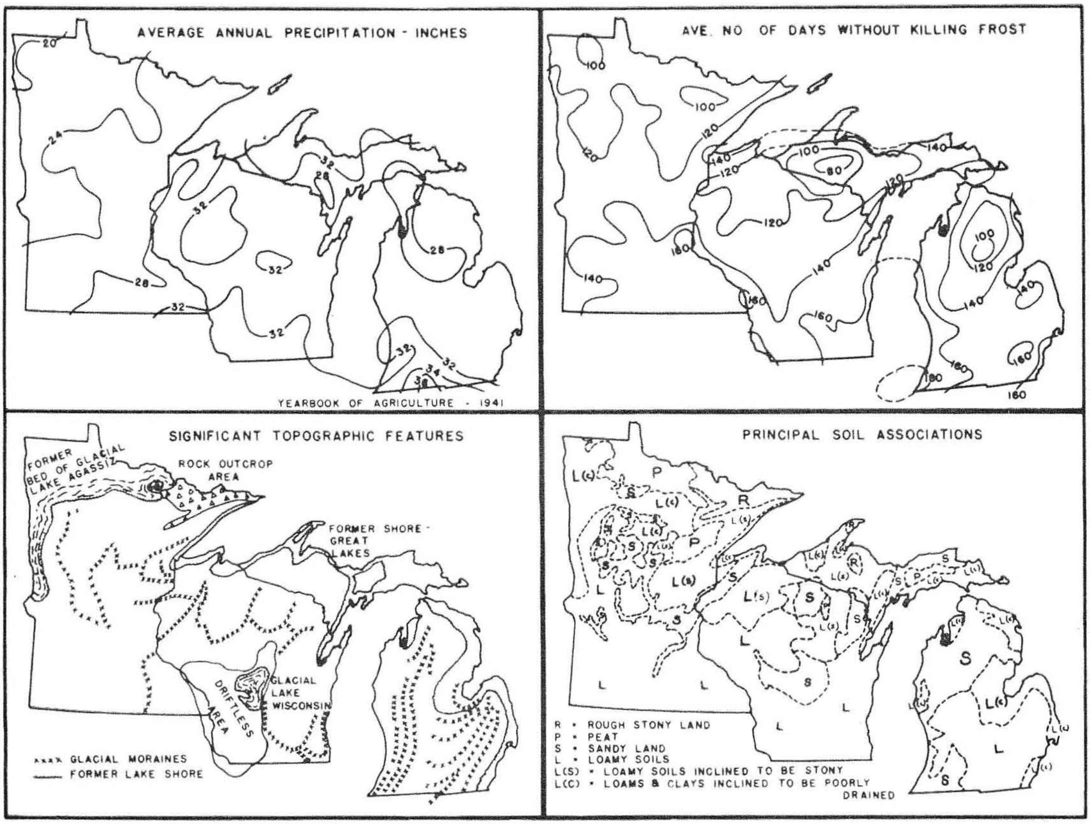

Fig. 1. Location of study areas and the principal forest zones in the Lake States. (Source: Cunningham, R. N., et al., 1950. Forest reserves of the Lake States Region. U. S. Forest Serv. Resource Report 1. 57 pp.)

of frontage on Lakes Superior, Michigan, and Huron. The area is laced by a network of streams, including the headwaters of the Mississippi.

At one time, this region was completely forested. Partial clearing has not resulted in the development of a generally successful agricultural economy. Climatic variations are severe. Heavy snowfall and some of the coldest temperatures ever recorded in the United States, combined with poor and extremely thin soils, limit agricultural development.

The Driftless Area, also referred to as the unglaciated area, presents an entirely different set of conditions. This island of some 10,000 square miles was not subjected to the refacing action of the glaciers which once covered the remainder of the Lake States. Since the

Driftless Area was not affected by the leveling action of the glaciers, it contains some of the most rugged topography of the entire region. It is essentially a limestone-capped plateau, deeply cut with steep-sided valleys.

This Driftless Area was also forested at one time, but its more fertile soils, covered with a thin veneer of wind-deposited loess, lend themselves better to agriculture. However, these soils are naturally erosive and have led to the problems typical of the area.

Climate

The regional climate is continental. As such, it is subject to marked variations, particularly in temperature. With the exception of narrow belts of land, 10 to 20 miles wide bordering the Great Lakes, which, particularly in Michigan, enjoy the tempering influence of a modified marine climate, the remainder of the northern forest area is subject to some of the most dramatic temperature extremes in the United

Fig. 2. Significant climatic and physical characteristics of the Lake States Region. (Source: Cunningham, R. N. et al., 1950. Forest resources of the Lake States Region. U. S. Forest Serv. Resource Report 1. 57 pp.)

States. The range may be from a low of 50° F. below zero to a high of 105° above.

Short, cool summers and long, cold winters are the rule throughout the area. In general, the frost-free season averages 90 to 120 days, although locally along the Great Lakes it may be as long as 150 days, again due to the moderating influence of the lakes (see Fig. 2).

International Falls, Minnesota, often headlined in weather news during the winter months, has an average temperature of 3° F. during January and only 67.5° F. for July. In comparison, the city of LaCrosse, Wisconsin, in the unglaciated area, averages 16.1° in January and 72.8° F. in July, giving some indication of the more favorable climate in the southern region. Winters are still cold, but summers are noticeably longer and considerably warmer. The growing season is extended as much as 20 to 40 days, a factor in the more successful agriculture of the Driftless Area.

The average annual precipitation within the Lake States region varies generally from 28 to 34 inches, although northwestern Minnesota can expect about 20 inches per year (Cunningham et al., 1950). Fortunately, 40 to 50 percent of the total precipitation occurs from June to September—the period of greatest supply thus coinciding with the period of greatest need. Table 1 gives the average annual precipitation by months and by hydrologic seasons for several selected stations.

We usually picture winter in Wisconsin, Minnesota, or Michigan as a landscape deeply blanketed in snow for many weeks. Such a picture is accurate, especially for the northern forest where there is invariably snow cover from December through April, with depths ranging as high as 115 to 130 inches in parts of northern Michigan.

In the southern portion of all three states, the total snowfall is about 30 inches. In both areas, however, only 10 to 20 percent of the total precipitation is received as snow.

By far the greatest proportion of the precipitation in the northern forest area results from the passage of cyclonic fronts. Some 45 such storms may be recorded here each year, while the average in the southern region ranges from 25 to 30. Generally, frontal storms produce low to moderate precipitation intensities.

Convection-type thunderstorms with high intensities occur, especially in the summer months and in the southern part of the area. Here, sometimes as many as 50 such storms are experienced per year; many

*TABLE 1—Average annual precipitation by months and by hydrologic seasons for selected stations**

Station and forest region	Period of soil moisture recharge					Period of ground water recharge (usually frozen and snow-covered)							Period of maximum evap. transp. (growing season)						Total for the water/year
	Oct.	Nov.	Dec.	Total for period	Percent of total water/year	Jan.	Feb.	Mar.	April	May	Total for period	Percent of water/year	June	July	Aug.	Sept.	Total for period	Percent of water/year	
	(inches)					(inches)							(inches)						inches
Bemidji, Minn.—North. Forest	1.93	1.08	.73	3.74	15.94	.70	.58	1.01	1.74	2.77	6.80	28.99	3.79	3.28	3.25	2.60	12.92	55.07	23.46
Rhinelander, Wis.—North. Forest	2.54	1.88	.99	5.41	17.15	1.05	1.09	1.34	2.36	3.19	9.03	29.22	4.41	4.26	3.97	3.82	16.46	53.27	30.90
LaCrosse, Wis.—South. Forest	2.34	1.83	1.25	5.42	17.07	1.15	1.10	1.78	2.39	3.98	10.40	32.74	4.17	3.85	3.79	4.13	15.94	50.19	31.76
Marquette, Mich.—North. Forest	2.57	2.88	2.38	7.83	24.68	2.33	1.70	2.18	2.50	2.80	11.51	36.27	2.19	2.23	2.61	3.36	12.39	39.05	31.73
Cadillac, Mich.—North. Forest	2.83	2.48	1.45	6.76	23.69	1.50	1.54	1.73	2.38	2.77	9.92	34.77	2.73	2.61	2.90	3.61	11.85	41.54	28.53
Lansing, Mich.—South. Forest	2.39	2.28	2.03	6.70	21.95	1.78	1.77	2.43	2.77	3.44	12.19	39.94	3.28	2.67	2.65	3.03	11.63	38.11	30.52

*Based on data from: U. S. Department of Agriculture (1942). *Climate and Man.* Yearbook of Agriculture, 1941. U. S. Department of Agriculture, Washington. 1248 pp.

of these give rise to local flash floods. Intensities in excess of 7.5 inches per hour for 5 minutes and 6.9 inches per hour for 10 minutes have been recorded at the LaCrosse Erosion Experiment Station (Scholtz, 1938). The maximum 24-hour precipitation recorded at LaCrosse over a 50-year period is 7.23 inches.

Evaporation rates are comparatively low, particularly in the northern forest. The range of potential evaporation in this area is 20 to 30 inches per year. Throughout much of the Driftless Area, this figure is increased to 30 to 35 inches.

Topography and Geology

The topography of the Lake States is, in general, level to rolling. As previously mentioned, all of the Lake States region, with the exception of the Driftless Area, has been subjected to the action of glaciers. As a result, surface features are relatively young.

Most of the region lies between 800 and 2,100 feet above sea level. The highest point is about 2,200 feet in northeastern Minnesota; the lowest, about 600 feet, is near the Great Lakes. Fig. 2 shows a few of the significant topographic features of the region.

The northern forest region is covered with a mantle of glacial drift of variable thickness which gives rise to typical glacial features: gravelly moraines, sand plains, swamps, ridges, and old lakebeds. Some of the preglacial valleys and stream channels, now buried, provide excellent storage facilities for ground water.

Thousands of lakes dot the landscape in all three states; some of these, such as Leech Lake in Minnesota and Houghton Lake in Michigan, are rather large. Characteristic, too, are the thousands of acres of swamps scattered throughout the region.

Three major drainage systems originate in the northern forest area: the Mississippi River, the Red River (Hudson Bay) drainage, and the Great Lakes-St. Lawrence system.

Underlying the glacial drift throughout much of the north and west portions of the northern forest area are the stumps of Pre-Cambrian mountains. Physiographically, this portion of the area is referred to as the Superior Upland. It includes the Mesabi and Marquette iron ranges of Minnesota and Michigan, and the copper range in Michigan's Keweenaw Peninsula.

The Pre-Cambrian rocks are crystalline and sedimental and have been tightly compressed and metamorphosed. Along the southern margin of this upland, Paleozoic deposits that have resisted erosion are superimposed upon the Pre-Cambrian material. Throughout the rest of the northern forest area, the bedrock underlying the drift mantle consists of Paleozoic sandstones, limestones, conglomerates, and shales.

As indicated in Fig. 2, large portions of the area were former lakebeds for the once vast glacial lakes.

Both the topography and geology of the Driftless Area are distinctly different from the surrounding glaciated country. In general, the topography is rolling to rough, although the more weakly dissected area along the northeastern edge often becomes nearly level, except for scattered Cambrian and Pre-Cambrian butts and monadnocks. An aerial view would show rounded ridgetops and rather narrow flood plains and valleys (for the most part in farmland), and steep side slopes where most of the remaining forests are located.

The principal rivers draining the area are the Wisconsin, Black, Trempeleau, Root, Zumbro, and the Upper Iowa, all of which flow into the Mississippi. All the streams have essentially a dendritic drainage pattern. Lakes and swamps, conspicuous in the glaciated area, are almost entirely absent here. All of these factors indicate a much more mature landscape.

The geologic bedrock throughout much of the northern and eastern portion of the Driftless Area is Cambrian sandstone, although in the extreme northwestern corner is a small area of Pre-Cambrian granitic material. Ordovician limestones (magnesium and Galena-Trenton) are dominant in the southern part of the region, while lower magnesium limestone predominates throughout the central part of the area.

Soils

The soil, more than any other factor of the environment, controls the water regime of a given area. Soils, in turn, are materially influenced by vegetative cover, topography, land use, and parent material.

In the northern Lake States, soil parent materials have been mixed by glacial action. Therefore, the topography and drainage are immature in a large part of the area. Furthermore, man has brought about major changes in vegetative cover and has introduced diverse land uses. All these factors have resulted in a wide variety of soils (Fig. 2).

Soils range from structureless sterile sands to heavy compact clays. This variety is due primarily to the complex nature of the glacial material from which the soils were derived. The area is covered with a mantle of glacial debris, varying from a few feet thick in northeastern Minnesota to many hundreds of feet of fill in the preglacial valleys. After the retreat of the glaciers, sediments borne by streams were deposited in some of the broader valleys. Many former glacial lakebeds harbor level heavy clays. Peats and mucks are found in the emerging swamps and poorly drained depressions.

Although soils in the northern forest range from coarse sands, sands, loams, and peats to heavy clays, the sandy soils predominate. Sandy loams are found on glacial till plains. Coarse sands are characteristic of the outwash plains, and the morainic soils are commonly a mixture of sands, loams, clay, gravel, and boulders.

Sandy and gravelly soils have high infiltration capacities and high permeability rates. Because of their low water holding capacities, they are often poor for plant growth. With a good vegetative cover, the sandy and loamy soils are relatively stable. Once the vegetative cover is removed and the surface soil disturbed, however, these soils are subject to both wind and water erosion.

Fig. 3. A gully in Jackson County, Wisconsin (U. S. Forest Service).

In this northern forest area, clay layers or lenses are often present in the sandy soils. Depending upon their depth from the surface, they may play a major role in determining the quality of the site and its hydrologic characteristics. When confining layers occur near the surface, low storage capacities and waterlogging result.

In the heavier soils of the former lakebeds, water enters and permeates the profile very slowly. Although generally fertile, such soils are often limited to grassland farming or forestry because they warm up slowly or are waterlogged until quite late in the spring. The red clay soils bordering Lake Superior in Wisconsin and Michigan are subject to erosion.

The soils of the Driftless Area are essentially silts, silt loams, and sand. Genetically, they are gray-brown forest soils intermixed with islands of prairie soils. Throughout much of the area, particularly near the Mississippi River, varying depths of wind-deposited loess are found on the more level uplands. These deposits, like the residual soils over which they lie, are silty and highly erosive.

These silts and silt loams are fertile and productive; as a result, they have been used extensively for agriculture. They are, however, the crux of much of the erosion problem now facing this area.

In the northeastern part of the Driftless Area which is dominated by Pre-Cambrian granites and Cambrian standstones, the soils are sandy. Such soils have relatively high absorption rates; in many cases, they have almost single-grain structure.

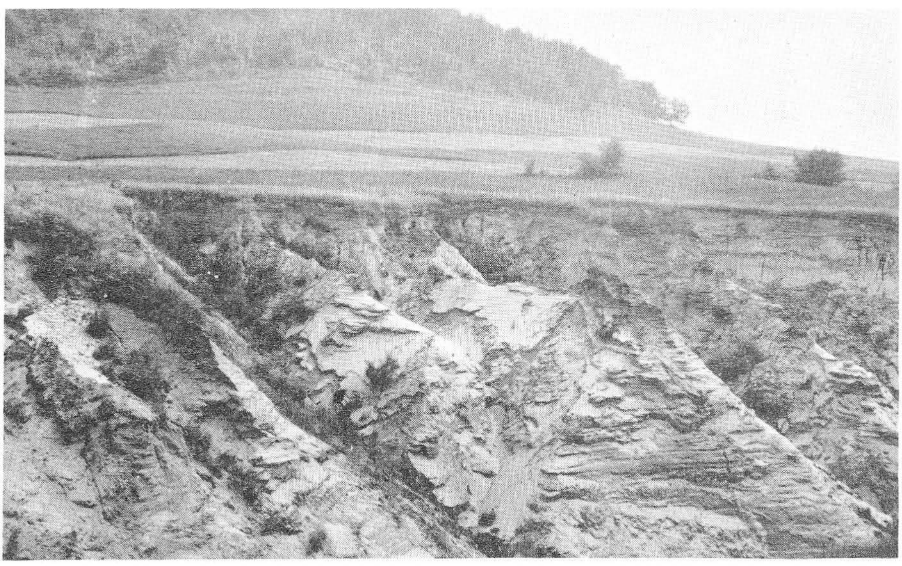

Fig. 4. Gully in Buffalo County, Wisconsin, showing deep bed of river terrace sand (U. S. Forest Service).

The silts and silt loams generally have low absorption rates and are subject to compaction under grazing pressure.

Both soil conditions are subject to erosion; coupled with topographic features, they have given rise to spectacular gullies throughout much of the unglaciated area.

Land Use

Northern Forest Area

It took only 50 years to complete one of the most ruthless exploitations of a natural resource in the history of the United States. Between 1870 and 1920, almost all the original forest acreage in the Lake States was cut over. The "cut-and-get-out" logging procedure almost always was accompanied by repeated fires which damaged the region even more.

Once the valuable timber was gone, land speculators seized the opportunity to sell the cutover land for conversion to farms. Especially in the northern forest area, soil, climate, and marketing limitations doomed many of these agricultural ventures before they began. Today, only 20 percent of the original 57 million acres of once-forested land in the northern forest region can be classified as farmland.

The failure to establish an agricultural economy has caused vast acreages of land to revert to State ownership through tax delinquency. In 1920, less than 10 percent of the forest land in the Lake States was in public ownership. From 1925 to 1945, the states and counties, through tax forfeiture, took over about 25 percent of the privately-owned forest lands. During this same period, about 7 million additional acres of such land were obtained by the Federal Government through purchase and exchange (Cunningham et al., 1950).

Today, public agencies control about 44 percent of the forest land. Almost all of it consists of cutover forests and abandoned farms which are now part of State or National forests.

The people of the United States have paid a heavy price for this lack of knowledge, foresight, and planning, whether the cost is figured in terms of the loss to individuals whose farms have failed, the loss of tax revenue, or the money spent in acquiring and restoring what can be salvaged now.

In the northern forest region today, the major land uses are forestry, recreation-resort, farming, mining, and industry. Forests still play a major role in the economy. They are being managed for lumber, pulpwood, poles and posts, and Christmas trees. The northern forest types include pine (white, red, and jack pines), spruce-fir, spruce and tamarack swamp, upland and swamp hardwood, and mixed conifer-hardwood. Aspen, which formerly occurred only to a limited extent, now occupies almost two-fifths of the commercial forest acreage (Cunningham et al., 1950).

A continued expansion of the resort industry is expected, since the Lake States and the six nearby states support 25 percent of the population of the United States. To many people who live in the densely populated areas, or in the Prairie States which are poorly endowed with forests and wildlife, the lure of the northern vacationland is strong.

The relative abundance of game attracts the hunter. Cold winters with their ice and snow provide ideal conditions for winter sports—skiing, ice fishing, tobogganing, and the like. Cool summers and ample facilities for fishing and swimming bring large numbers of visitors to the northland during June, July, and August. The rapidly growing resort industry offers accommodations ranging from the isolated fishing camp to the most luxurious of hotels, and it should continue to expand for some time to come.

The mining industries (primarily iron and, to a lesser extent, copper) are concentrated in the western part of the Upper Peninsula of Michigan and in the Mesabi iron range country in northeastern Minnesota. The largest iron deposits in the United States are in this region.

The recent development of taconite beneficiation methods makes the use of low-grade ore economically feasible. Both the ore deposits that were formerly too low-grade to be mined at all, and tailings from which higher grade ore has already been extracted, will furnish raw materials for taconite plants. This phase of the mining industry will probably be considerably expanded.

Industry other than mining is connected primarily with the processing and conversion of forest products. Lumber mills, plywood plants, and pulp and paper mills are located along the Great Lakes or along major streams where water, water power and, often, water transportation are available. The greatest concentration of these industries is along the Wisconsin River in central Wisconsin, often described as the "Nation's hardest-working river."

Driftless Area

Major land uses in the Driftless Area differ markedly from those in the northern forest region. Here agriculture is the key word, with dairy farming predominating in much of the area. Substantial acreages are used for the production of small grains and tobacco, as well as for the corn-beef-hog type of farming.

The best farms are found on the uplands where the topography is much more favorable. In the valleys, the farms are smaller and more broken. Increasing agricultural pressure is causing the creation of new cropland and pastures on land that is of questionable value for permanent agriculture. Many of the steep slopes support woodlots, most of which are grazed (Fig. 5). Valley farms are subject to flooding and the depositing of silt and sand from the deep gullies being washed out on the slopes above them.

Industry is limited in the Driftless Area. It is concentrated mainly in the larger cities, primarily LaCrosse and Prairie du Chien, Wisconsin; Dubuque, Iowa; and Winona, Minnesota. Industries are likely to be connected with the local agricultural pursuits; breweries, cheese factories, meat packing houses, and food processing plants are among the most important.

Despite the fact that forests and woodlands still occupy 25 to 30 percent of the land in the Driftless Area, they do not contribute substantially to the regional economy except in the northeastern portion.

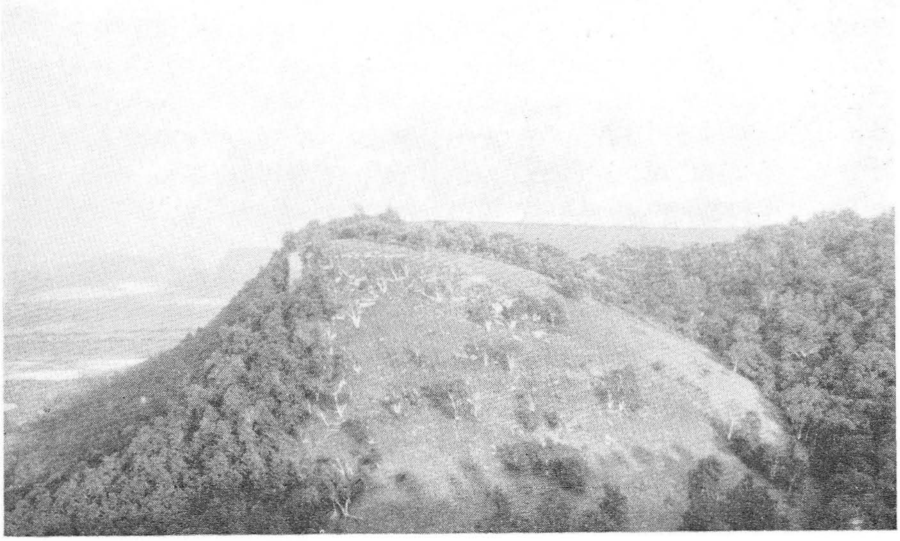

Fig. 5. Scant vegetation in center of photo is typical of south and west exposures near Winona, Minnesota (U. S. Forest Service).

This is due to the generally poor condition and stocking of the woodlots, resulting from overgrazing and from destructive cutting practices. Forests are usually limited to oak and oak-hickory types.

The exception to this general rule is found on the sandier soils in the northeast part of the area where forestry and forest industries again play a major role in the economy. Here, large acreages are now in forest plantations and managed second-growth stands. Such plantations and stands are often either on tree farms or are part of industrial forests established by the pulp and paper companies located along the Wisconsin River.

The resort industry assumes importance only in the bluffs area on the Mississippi River and, to a greater extent, in the area near Wisconsin Dells and Baraboo, Wisconsin, where unusual geologic formations have resulted in a thriving tourist center.

Almost all of the land is in private ownership. Exceptions are several small state parks and game refuges along the Mississippi River and a number of county forests in the northeastern portion of the area.

WATER RESOURCES

The Indian names of Michigan, Minnesota, and Wisconsin recognized that one of the greatest natural resources of the area is an abundant supply of fresh water. Michigan, the "Great Water," claims 36,000 miles of streams, 11,000 lakes with some 640,000 acres of water area, and the longest shoreline of any state in the country (Mich. Dept. Econ. Dev.,). Approximately 7 percent of Minnesota is made up of its "Sky-Colored Water" from some 10,000 lakes. Of these lakes, 37 exceed 5,000 acres each, and 17 are over 10,000 acres in area (Minn. Committee on Land Utilization, 1934). In addition to the lakes, which give the state its well-known slogan, "Land O' Lakes," there are thousands of miles of streams and several hundred miles of Lake Superior shoreline.

Wisconsin means "Gathering of the Waters," an appropriate phrase in view of its more than 7,000 inland lakes, 10,000 miles of fishing streams (Wis. State Plan. Bd., 1946), and several hundred miles of frontage on Lake Superior and Lake Michigan.

In addition to their lakes, streams, and shorelines, these three states have hundreds of thousands of acres of swamp and muskeg which provide water storage to feed streams and ground water reservoirs.

Fig. 6. How important is snow in the northern Lake States forests to the supply of clean water? (U. S. Forest Service)

The headwaters of three major drainage systems are located within the Lake States. Precipitation falling in northern Minnesota drains into Hudson Bay via the Red River of the North. Runoff from a large part of the area finds its way into the Mississippi, which has its origin in Itasca State Park in Minnesota. Waters from the land adjoining the Great Lakes eventually reach the Atlantic through the St. Lawrence River.

As noted before, the average precipitation ranges from about 28 to 34 inches. A comparatively high percentage of this precipitation finds its way into streams as runoff in the northern forest region. Annual figures on the precipitation that is yielded to the streams range from 10 to as much as 20 inches—due largely to relatively cool summers and low evaporation rates.

In the Driftless Area where evapo-transpiration losses are greater, this value may be less than 10 inches (U. S. Dept. Agr., 1956). Table 2 gives, for a period of short duration, the average annual precipitation and runoff data from some representative stations within the Upper Mississippi River watershed.

*TABLE 2—Average annual precipitation and runoff for several stations in the Upper Mississippi River Watershed**

Station (watershed)	Precipitation	Runoff			Total runoff related to precipitation
		Surface	Ground water	Total	
	(inches)	(inches)	(inches)	(inches)	(percent)
LaCrosse River (above W. Salem, Wis.)....	30.35	2.64	7.28	9.92	30.6
Root River (above Houston, Minn.)....	27.98	2.42	3.00	5.42	19.4
Kickapoo River (above Gays Mills, Wis.) ..	29.67	3.64	5.47	9.11	30.7
St. Croix River (above Rush City, Minn.)..	25.32	3.76	3.51	7.27	28.7
Black River (Above Neillsville, Wis.)...	30.99	7.84	1.48	9.32	30.1

*Adapted from a Special Survey by the United States Geological Survey, Water Supply Paper No. 772.

Glacial drift is usually highly permeable and provides excellent water storage. Since the entire northern forest area is covered by a mantle of drift of varying thickness, ground water supplies are generally adequate to excellent. Where shortages do exist (as in the western part of Michigan's Upper Peninsula, parts of northern Wisconsin, and in northeastern and extreme western Minnesota), they usually can be traced to the thinness of the drift layer. Local seasonal shortages are becoming real problems in areas of concentrated population, such as South St. Paul, Minnesota; Fond du Lac and Green Bay, Wisconsin; and Escanaba, Michigan.

In the Driftless Area, local ground water shortages are due to the scarcity of good aquifers throughout the region. Soils here overlie massive formations of limestone, dolomite, and compacted sandstone, none of which yield extensive ground water supplies.

WATER USES AND REQUIREMENTS

Agriculture, industry, and municipalities in the Lake States region all require adequate supplies of good quality water. In addition, nonconsumptive demands are made by the recreation and tourist industry, as well as by navigation interests. These widely diversified and often incompatible requirements need careful study and investigation to best balance conservation of natural resources, growth of industry and recreational interests, and sound economics. In many cases, present needs are known and predictable increases in demand can be forecast.

Agriculture

For many decades, agricultural uses of water were determined only on an "Act of God" principle. Farmers grew successfully whatever crops the rainfall and existing soil would produce. In most parts of the Lake States region, the agricultural economy still operates on those principles.

However, pressures to boost crop yields and produce a wider variety of crops are increasing. Local and seasonal shortages of water are restricting agricultural expansion. Irrigation equipment and techniques have been greatly improved. All of these factors have led to the introduction of supplemental irrigation into the area and a steady increase in its use.

Widespread use of supplemental irrigation will probably never be necessary, particularly in the north. However, where such methods prove beneficial, local problems of water supply will continue to arise.

McGuinness (1951) indicates that Michigan used about 26,000 acre-feet of water to irrigate some 52,000 acres in 1949. Although conflicting with these acreage figures, data from the 1950 Census of Agriculture (U. S. Bur. Census, 1952) indicate a marked increase in the area of land under irrigation: In 1939, the three Lake States irrigated 8,273 acres; by 1949, this figure had more than tripled to 27,917 acres.

Industry

Throughout the Lake States, industry makes the heaviest and most predictable demands upon the water resource. In Michigan, industrial use is estimated to be in excess of 2 billion gallons per day. This supply is largely from surface waters.

Very little factual data have been compiled on actual water consumption per day by industry in Minnesota. A large proportion of such use is concentrated around the Twin Cities area, and both surface water from the Mississippi and ground water from deep industrial wells are employed.

In Wisconsin, the industrial use picture is complicated by the fact that many of the industries use municipal water systems. These supplies are obtained about equally from ground and surface water. In the area around Milwaukee-Waukesha and Green Bay, many industries have their own wells (McGuinness, 1951).

Surface water is heavily utilized by industries along the Mississippi, Wisconsin, and Kalamazoo Rivers. The Wisconsin River is particularly well developed for both power generation and manufacturing processes. One pulp mill, 12 paper manufacturing plants, and 13 electric utility companies use the energy of that river to produce in excess of 188,000 horsepower.

Although industries are more heavily concentrated in the southern part of the Lake States, studies of water conditions in that area alone will not be sufficient. With the development of the new taconite plants and the expansion of the pulp and paper industries in the north, heavier industrial demands will originate from that area. Further, the surface water required in the heavy-use areas of the southern section often comes from streams whose headwaters are within the northern forest region.

Considering future requirements for the United States as a whole, industrial demand for water is expected to increase by nearly 270 percent by 1975. Jordan (U. S. Dept. Agr., 1956) indicates that daily industrial use in the United States in 1950 amounted to about 80 billion gallons — 43 percent of total use (municipal-rural was 17 billion; irrigation, 88 billion). He estimates that by 1975, industrial requirements will be about 215 billion gallons per day, or 62 percent of total water needs (municipal-rural would be 25 billion; irrigation, 110 billion) .

The greatest single deterrent to industrial expansion usually is an inadequate water supply. If the Lake States are to conform to this general prediction of growth and expansion in the future, the need for thorough research on the utilization, supplementation, and management of this vital resource is clear.

Municipal and Domestic Needs

Throughout much of the Lake States area, specific figures on water consumption for municipal and domestic uses alone are not readily available because a large percentage of the municipal water supply is utilized by local industries.

Wisconsin uses 280 m.g.d. (million gallons per day) for public and industrial needs, with this water coming about equally from surface and ground water supplies. Michigan almost triples that figure, with the Detroit area alone requiring 375 m.g.d (McGuinness, 1951). Michigan uses 200 m.g.d. from ground water supplies and 500 m.g.d. from available surface water. Specific figures on public use in Minnesota are lacking, mainly because most areas have had an ample supply of water for almost all needs.

Only in recent years have individual cities — South St. Paul, Escanaba, Flint, Fond du Lac, Green Bay, and Lansing — begun to realize that water supplies are not inexhaustible; that serious changes in this vital resource, either in quality or quantity, can effectively throttle the growth and development of an entire city.

Newspaper articles on the curtailment of lawn watering and other household uses are not the oddities they once were. In fact, laws have been passed levying heavy fines on those who violate this method of enforced conservation of water.

In some areas, such problems have arisen as a result of mismanagement or lack of any management at all. In others, the population has been increasing continuously. This additional population is a factor in the overall increased demands for municipal water resources throughout the entire Lake States region.

Not only are there more people, but these people now demand adequate water supplies for a much wider range of uses. An automatic washer requires from 25 to 40 gallons of water for each load; a dishwasher needs about 7 gallons each time it is used. Garbage disposal units and air conditioners both depend on water for their entire cycle of operation. Within the last 10 to 15 years, these and other conveniences have added their demands to those ordinarily associated with household use.

This increased use of water in each home, plus an increase in the number of family units, will add to demands on municipal water supplies. Therefore, solving present water problems and anticipating future ones becomes even more imperative.

Other Uses

In addition to uses by agriculture, industry, and municipalities, the water resources of the Lake States are important for recreational use throughout almost all of the region.

In all three states, increasing emphasis has been placed on full usage of all existing tourist and vacation facilities. The development of such facilities has become a major part of the regional economy, and this development depends on streams and lakes for its very existence. Fishing, swimming, and boating are important parts of almost any Lake State vacationer's plans. Thus, fluctuating or declining lake levels become a matter of great public concern.

Only a few of the larger streams are used for commercial navigation. However, those in the wilderness area in Superior National Forest in Minnesota, and other rivers such as the Au Sable in Michigan, are used heavily for canoeing and fishing. Vacation trips of this kind will become increasingly important to the areas involved.

Improved transportation and the growing need of the city dweller to relax, plus his increased ability to pay for that chance, will make recreational use of these areas an important factor in future planning. Conflicts in use are occurring more often, and, when expanding industry results in changing lake levels or in stream pollution, strong protests from well-organized recreation interests will certainly be made.

SURVEY OF RESEARCH NEEDS

Throughout the interviews, observations, and reviews of existing literature made in this exploratory survey, two parallel lines of investigation were strongly suggested.

The first of these is basic research that would lead to the most effective plan for managing the existing water resource. Research programs in the management of a natural resource are usually begun only after serious shortages and problems arise, and are designed to recover what we once had — or to salvage what is left. Thus, at best, they attempt to maintain the *status quo*.

The Lake States region has a unique opportunity (almost an obligation) to go beyond this point — if we begin immediately to assemble the fundamental information necessary in evolving a sound management program that will maintain the abundance and high quality of the existing water resource.

Within the study area, there are real opportunities for the expansion of both recreational and industrial interests. But specific data on the occurrence, extent, and behavior of the water resource, with special attention to streamflow characteristics, water quality, and ground water recharge, are needed if such expansion is to be invited.

Particularly in the northern forest region, there is an opportunity to practice "preventive medicine" as well as to conduct a search for cures for existing ailments.

The second of these parallel fields of research deals with "existing ailments" and their possible remedies.

There are two main problem areas within the Lake States region in which immediate, utilitarian research is needed to answer questions which already exist. These are the Driftless Area and the red clay lands bordering Lake Superior.

Basic Research Needs

The northern forest region of the Lake States has the greatest need for basis research. Three factors underlie this need.

First, since the character of the region differs from much of the United States in climate, topography, drainage, and soils, results obtained through research in other regions often cannot be applied directly.

Secondly, as mentioned before, this region has been blessed both by the presence of a large supply of fresh water in streams, lakes, and ground water, and by the absence of widespread flooding and erosion problems. Consequently, only limited attention has been given to the water resource.

The third factor that emphasizes the need for basic research is the strict limitations of agricultural usage. Soils, climate, and geology discourage agricultural development in this area. Thus, any research that encourages industrial and recreational expansion would benefit most of the population.

Major changes are occurring in the vegetative cover. Thirty to forty years ago, a great percentage of the area was cut and burned over. Much of it was left virtually barren. Since that time, hundreds of thousands of acres of plantations have been established; they have now reached appreciable size. In addition, many other hundreds of thousands of acres of second-growth forest have grown to a point where they use large volumes of water in transpiration. Many of the second-growth forests are quite different in character and composition from the original forest cover.

Research in other regions has indicated that forests intercept and consume a large amount of water in the growth process, and that a forest cover reduces evaporation losses. Forest soils likewise are generally conceded to provide optimum soil reservoir facilities. Basic information on evaporation, transpiration, and interception losses, as well as on the soil moisture regimes under various cover conditions, is needed for this region.

About 5 percent of the total area of the northern Lake States is actually water surface. Thousands of square miles are swampland, with water surfaces exposed for at least parts of each year. The extent that these lakes and swamps feed ground water supplies is largely unknown. Many of the swamplands possess forest cover of the swamp hardwood, mixed swamp hardwood-swamp conifer, spruce, tamarack, spruce-fir, and mixed conifer types. In many instances, such noncommercial forests are too slow growing to have much economic significance in themselves.

Information is needed on the desirability and practicability of various degrees of swamp drainage to induce more rapid tree growth. It would also be desirable to determine in what ways and to what extent such drainage would influence streamflow and ground water levels (Fig. 7).

Timber in our commercial swamp forests is often harvested by clear cutting. Following the clear-cutting operation, regeneration is often difficult and slow because of higher water tables resulting from decreased transpiration. The effects on water levels of cutting swamp

Fig. 7. A northern Minnesota coniferous swamp typical of the northern forest region (U. S. Forest Service).

forests, and methods of regenerating the cutover swamps, should be investigated.

In consideration of these needs and problems, the following initial research recommendations are made:

1. Compile an annotated bibliography, including a thorough investigation of:
   a. Water research projects which are currently or have been carried on in the Lake States area.
   b. Projects developed in other areas where results might be applicable to Lake States conditions.
   c. Hydrologic data accumulated by the U. S. Weather Bureau, U. S. Geological Survey, and other agencies. (A partial list of sources and agencies conducting research and compiling hydrological data is given in the appendix.)

2. Conduct specific investigation into the hydrology of watersheds in the northern forest region.
   a. Measure precipitation, streamflow, and ground water; obtain annual, seasonal, and storm values. Watersheds selected for these measurements should have a variety of cover types. Some of the sampling areas should be of considerable size, preferably more than 10 square miles.
   b. Determine the precipitation-streamflow relationships between individual test watersheds and those of the entire basin. (Data on some of the larger basins are available from Weather Bureau and Geological Survey records.)
   c. When index values have been established, determine the desirability of treating some of the watersheds to measure the effects of cutting by various methods, altering cover types, and similar procedures.

3. Determine comparative water losses and water consumption under different vegetative covers.
   a. Locate sample plots in both swamp and upland areas and under grass, shrub, pine, hardwood, and (possibly) spruce-fir covers. (Insofar as possible, locate these plots in areas where runoff is derived entirely from ground water.)

b. Measure precipitation, interception, potential evaporation, soil moisture changes, and ground water levels under these conditions; from these measurements, deduce evapo-transpiration values.

c. Collect growth data from the forest types, and correlate them with precipitation, water losses, soil moisture, and water table levels.

The suggestion that the greatest emphasis in the northern forest region should be placed on basic research does not mean, however, that the area has no specific problems. Nor should it be assumed that a large volume of research of a broad, general nature should be carried out, results tabulated, and the resulting information then neatly filed for use at some indeterminate future date.

Much of the research outlined above will have immediate practical application in dealing with such problems as locally severe flooding, conflicts over lake levels, and deterioration of water quality. All of these problems are present in the area — not to such a general extent as to constitute major difficulties, but of increasing seriousness in recent years.

Major floods have not been a widespread problem in the northern forest area. However, when they occur locally, they cause extensive damage. For example, the annual flood damages on the Minnesota and Red Rivers are estimated at over 3½ million dollars (Minn. Legist. Interim Comm., 1955).

Because of the contribution that the region makes to the flow of the Mississippi, and because of its tremendous storage potential, some reservoirs have been developed for both flood control and navigation purposes. The utilization of reservoirs and lakes for flood control and for maintenance of navigation levels usually conflicts with the needs of recreational interests. Low reservoir and lake levels are desirable in the interests of flood control and are necessary to maintain navigation levels on the Mississippi. Fishing, boating, and resort interests want more uniform and generally higher levels.

Any anticipated use of additional storage areas for flood control will necessitate the classification of such areas according to their greatest use. Similarly, the use of additional swamplands for flood control storage purposes would have to be reconciled with their use as game refuges and breeding grounds.

Water quality becomes a problem when large amounts of organic matter discolor many of the streams draining the swamps, requiring expensive methods of purification. In specific processes, such as the manufacture of high-grade papers, the quality of the water is just as important as an abundant supply. The extent that better land management can reduce surface runoff and erosion, and thus reduce stream turbidities, is not known. Basic studies in stream ecology would certainly seem valuable in solving this phase of the pollution problem.

Problem Areas

As previously stated, two specific areas merit attention in considering existing problems in erosion, sedimentation, and flooding in the Lake States. The first, which is the largest and most seriously affected, is the Driftless Area — almost in its entirety. The second is the area of red clay soils adjacent to Lake Superior.

The Driftless Area

The basic soils, topography, and drainage pattern of the Driftless Area set the stage for the Lake States' most marked erosion, sedimentation, and flood problems. Evidence of their severity can be seen throughout the area in gullied hillsides and terraces, in streams clogged with silt and sediment, and in frequent floods.

The highly erosive loess and silty soils, and the comparatively rough topography with steep-sided drainages, have been major factors in the origin of the problems. Both past and present land uses have intensified these problems greatly.

Rapidly advancing gullies have cut deep into the river terrace soils, and shoestring gullies have developed on the hillsides (Fig. 8). Sheet erosion has affected 90 percent or more of the cultivated fields (Cunningham et al., 1950).

Tremendous volumes of sediment are poured into the Mississippi by the streams draining the area (mainly the Chippewa, Black, Wisconsin, Buffalo, Root, and Zumbro Rivers). Bates (1930) noted that most of the sediment carried by these streams comes from their downstream areas, i.e., those areas which lie within the unglaciated area. An outstanding example of the sediment load carried by these streams is provided by Gilmore Creek in Winona County, Minnesota (entirely within the Driftless Area), which sends down 40,000 to 42,000 tons of silt annually, or about 12½ tons per day per square mile.

In the 314-square mile Whitewater River watershed in southeastern Minnesota, annual flood damages are estimated by the U. S. Corps of Engineers at $210,000 for a recent 10-year period.

The primary causes for this accelerated erosion and attendant sedimentation and flooding are: Over-grazing in both pastures and woodlots, the clearing of steep woodland for pasture or cropland, poor road location and construction, and the overuse of fire as a method of clearing land.

Overgrazing is one of the most significant land abuses in the area. This particular problem is three-pronged. First, there is the actual overgrazing on legitimate pasture lands—those well suited to grazing purposes by location and development, even though not capable of maintaining the number of cattle they have been forced to support. This practice has been especially destructive in pastures bordering on the streams. The damage increases as the slope of the land increases.

The second part of the problem results from permitting grazing on woodlands, particularly on steeply sloping, wooded hillsides. Such grazing compacts the soil under the trees and virtually obliterates the understory. Thus, the value of the woods is lessened from both an economic and a protective standpoint. As its soils become less permeable and its cover thinned, the woodlot, too, becomes a source of erosion.

In addition, grazed woodlots produce vastly inferior pasture. Investigations at the Upper Mississippi Erosion Experiment Station at LaCrosse, Wisconsin, have shown that heavily shaded sods under a woodlot on a 25- to 30-percent slope produce less than half the forage value that can be expected from a good pasture (Lake States Forest Expt. Sta., 1938).

Growing agricultural and economic pressures have created the third phase of the overgrazing problem. Attempts are often made to clear, and put into pasture, land that should have remained as forest. Here again, an economic expedient has only created long-term problems while contributing short-term gains.

Not only have steep slopes been used for grazing, but attempts have been made to convert them to actual row-crop use. This procedure is often economically unsuccessful, as well as harmful to the land. Sometimes such lands are suitable for permanent pasture, but, more often, they should be left in or returned to forest cover.

Poor location of farm roads, lanes, and secondary roads has resulted in a troublesome erosion problem. Large amounts of soil surface are laid bare and subjected to increased compaction. Bare cuts and fills and steep-banked ditches on some of the secondary roads contribute large quantities of sediment after heavy rains. Poorly located logging roads and skid trails in the woodlots add their bit to the problem.

Repeated use of fire in the past to clear brushland or to improve grazing conditions has led to the destruction of soil organic matter. Because of poorer soil structure, site quality has been reduced. Increased efforts of state and county foresters to discourage this practice have lessened watershed damages from this source in more recent years.

In seeking solutions to the forestry aspects of the watershed problems in the Driftless Area, the following suggestions are offered:

1. Since the woodland grazing problem has attracted the attention of both government and private interests in other sections of the United States, a comprehensive survey of existing research on the subject is recommended. Methods and practices that have been successful elsewhere might well be applied here. Where such data are inadequate or results inconclusive, research should be initiated to provide specific answers to specific questions in this area.

   For example, where additional pastureland is needed to maintain an economic unit, would it be most practical to clear cut a strip of several acres along the lower slopes of the farm woodlot and develop it into a permanent improved pasture? Is there any validity in the theory that, where improved pastures are maintained next to woodlands, fencing would be unnecessary since cattle would go into the woods only for shade? Since one of the barriers to the restriction of woodland grazing is the cost and labor of fencing, a study to determine the accuracy of such theories appears to be warranted.

2. The Pilot Watershed Program and the Small Watersheds Act (Public Act 566) indicate the increased awareness of the importance of the water and soil resource. The current

"soil bank" plan also has aroused a great deal of interest. In some quarters, a "timber bank"—tree planting—is being emphasized as a desirable use of the acres that farmers would be asked to take out of crop and livestock production. Such programs certainly encourage both tree planting and farm woodlot improvement.

Forest plantations in the Driftless Area are largely conspicuous by their absence. Additional information is needed about the advisability of tree planting on some of the more barren slopes, overgrazed pastures, and sparsely stocked woodlots.

On some of the south and southwest-facing slopes, the soil mantle is extremely thin; only scrubby oak, shrubs, and sparse grass cover the hillsides. Possibly, some of these areas should be limited to protective forest. On those with a deeper soil cover, perhaps pine could be planted; or, if the slope is not excessive, limited grazing on improved patures might be the best use. Planting should also be considered for the severely gullied areas and along the stream bottoms and streambanks.

All these areas represent difficult planting sites. Research is needed to answer the following questions:

a. What species or mixtures of species are adapted for planting on the open, dry, thin-soiled, steep slopes? For reinforcement planting in heavily grazed, low-density woodlots? For badly eroded gullies? For streambanks?

b. Is planting necessary to improve heavily grazed woodlots, or, if protected, will they regenerate themselves within a reasonable period of time?

c. What planting methods should be employed in the areas with grass cover? Is scarification or scalping desirable? Where can planting machines be used, and where is hand planting necessary?

d. What are the planting costs on the different sites? What returns might be anticipated from forest products? From protection, wildlife, and recreation values? How do these anticipated returns compare with the returns from present land use?

The Red Clay Lands

The second area in which erosion and sedimentation pose a problem is in the red clay lands bordering Lake Superior. This problem area of roughly a million acres extends from Duluth-Superior eastward, almost to the Keweenaw Peninsula in Michigan. The soils of this region are rather heavy clays, often with sand lenses. They are highly erosive when exposed. A marked increase in erosion has been noted here in the past decade.

The economy of the region is essentially one of forestry and grassland farming. Not much land is being cultivated. Erosion on grazed land is generally confined to the steeper slopes, ravines, streambanks, and the more heavily used lanes and farm roads.

In this particular area, there are numerous cases of actual land slippage or slump, both along streams and in upland areas with relatively undisturbed cover. Much of this erosion is, in all probability, geologic. Except where such erosion is accelerated by the construction of logging roads and skid trails, or by streamside grazing, probably little can be done to control it within reasonable expense and effort. However, the area offers an excellent opportunity for research on both the actual amount and rate of geologic erosion and the possibilities of its control.

Road construction is probably the most serious cause of accelerated erosion in the area. On both primary and secondary roads, cuts and fills are often bare and subject to repeated washing out. In general, where this problem is serious, the counties are also in poor financial condition. A study to determine the cost of doing a good initial stabilization on roadbanks, compared with the current practice of carrying a relatively heavy maintenance cost, warrants attention. Specific information on the most effective methods of stabilization is also needed.

Logging roads and skid trails are often sources of accelerated erosion. Since a large percent of the area is forest land (much of it in State or Federal ownership) the method for determining locations for access roads, logging roads, and skid trails, as well as specifications for their construction, drainage and protection, should be included in timber sale contracts.

Both erosion and sedimentation problems become more acute near Lake Superior. The larger streams remain turbid for several days after a storm. Sandbars of consequence are forming along the lower reaches of the streams and at the points where they enter Lake Superior. Some of the rivers, such as the Brule, Brunsweiler, Montreal, and Ontonagon, have been ranked among the best trout streams in the Lake States; however, increased turbidity and heavy deposits of sediment have reduced their recreational value. Added protection could be provided wherever additional State or Federal land could be acquired or exchanged to include areas immediately adjacent to these streams.

POSSIBILITIES FOR COOPERATION

During the progress of this investigation, research proposals were advanced and discussed with keen interest and approval throughout the region. The need for additional watershed research of all types was almost universally expressed. In many cases, cooperation, both on-the-ground and financial, was offered to help obtain additional information.

The field of watershed research is a broad one, as shown by the suggestions for action made on the previous pages. A great deal of effort will be required to assemble and classify the data needed, particularly for projects such as an inventory of the water resource and present and future needs. The results of many of these projects will be of interest to a large number of agencies within the region. Others—such as studies to assign economic values for the various uses of water, for increased yields and improved quality resulting from land treatment, and for preventing downstream flood damages by upstream management—are of interest outside the region as well. Hence, the possibilities of setting up cooperative projects should be carefully considered.

With intelligent management, the water resource may well open the door to a new era of prosperity in the Lake States. But the cooperative research efforts of State, Federal, and private groups are needed to unlock that door.

LITERATURE CITED

Bates, C. G., and O. R. Zeasman (1930). Soil erosion–a local and national problem. Wis. Agr. Expt. Sta. Res. Bul. 99. 100 pp.

Cunningham, R. N., et al. (1950). Forest resources of the Lake States Region. U. S. Forest Serv. Resource Report 1. 57 pp.

Lakes States Forest Experiment Station (1938). The grazed woodlot–potential flood hazard and low grade pasture. Tech. Note 142. 2 pp.

McGuinness, C. L. (1951). The water situation in the United States with special reference to ground water. U. S. Geol. Survey Cir. 114. 127 pp.

Michigan Department of Economic Development. Michigan's water resources for industry. Mich. Dept. Econ. Dev., Lansing. 8 pp.

Minnesota Committee on Land Utilization (1934). *Land Utilization in Minnesota.* Univ. of Minn. Press, Minneapolis. 289 pp.

Minnesota Legislative Interim Commission (1955). Report on water conservation, drainage and flood control. Minn. Legist. Interim Comm., St. Paul. 51 pp.

Scholz, H. F. (1938). Protective and economic value of the forests of southwestern Wisconsin and adjacent Minnesota. Lake States Forest Expt. Sta. (Unpublished)

Trenk, F. B. (1943). Forest planting handbook. Wis. Cons. Dept. Bul. 504. 36 pp.

U. S. Bureau of the Census (1952). United States census of agriculture: 1950. Vols. 2 and 3. U. S. Govt. Printing Off., Washington.

U. S. Department of Agriculture (1942). *Climate and Man.* Yearbook of Agriculture, 1942. U. S. Dept. Agr., Washington. 1248 pp.

U. S. Department of Agriculture (1956). *Water.* Yearbook of Agriculture, 1955. U. S. Dept. Agr., Washington. 751 pp.

Wisconsin State Planning Board (1946). A picture of Wisconsin. Wis. State Plan. Bd. Bul. 16. 120 pp.

APPENDIX

A partial list of sources and agencies collecting hydrologic data and conducting watershed management research is given below:

Agency	Type of material
U. S. Department of Agriculture Agricultural Research Service	Soil and water investigations formerly conducted by Soil Conservation Service. Compilations of hydrologic data, largely at the Upper Mississippi Erosion Experiment Station, LaCrosse, Wisconsin, and the Michigan Hydrologic Research Project, East Lansing, Michigan.
U. S. Forest Service	Studies on the relationship of forest cover to soil and water, Lake States Forest Experiment Station, St. Paul, Minnesota.
U. S. Department of Commerce Weather Bureau	Precipitation and evaporation data.
U. S. Department of Defense Corps of Engineers	Flood and navigation control information.
U. S. Department of Health, Education, and Welfare Public Health Service	Stream pollution studies and data.
U. S. Department of Interior Geological Survey	Streamflow and ground water data.
State Geological Surveys	Streamflow, well records, and ground water compilations.

Agency	Type of material
State Conservation Departments (Water and Fisheries Divisions)	Stream improvement projects, watershed studies, stream and lake ecologic studies.
State colleges and universities, State agricultural experiment stations	Miscellaneous studies, including soil moisture, ecologic and hydrologic investigations.
Various State water control and water pollution commissions and committees	Miscellaneous surveys on pollution problems, water rights, water legislation, etc.
Private sources, particularly power companies	Streamflow and power production data, water uses and requirements. (The Wisconsin-Michigan Power Company collects rather complete hydrologic data, including soil moisture and snow survey information.)

5-57—5M