DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

THE UNIVERSITY OF WISCONSIN–EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY

HYDROLOGIC INVESTIGATIONS
ATLAS HA-524 (SHEET 1 OF 3)

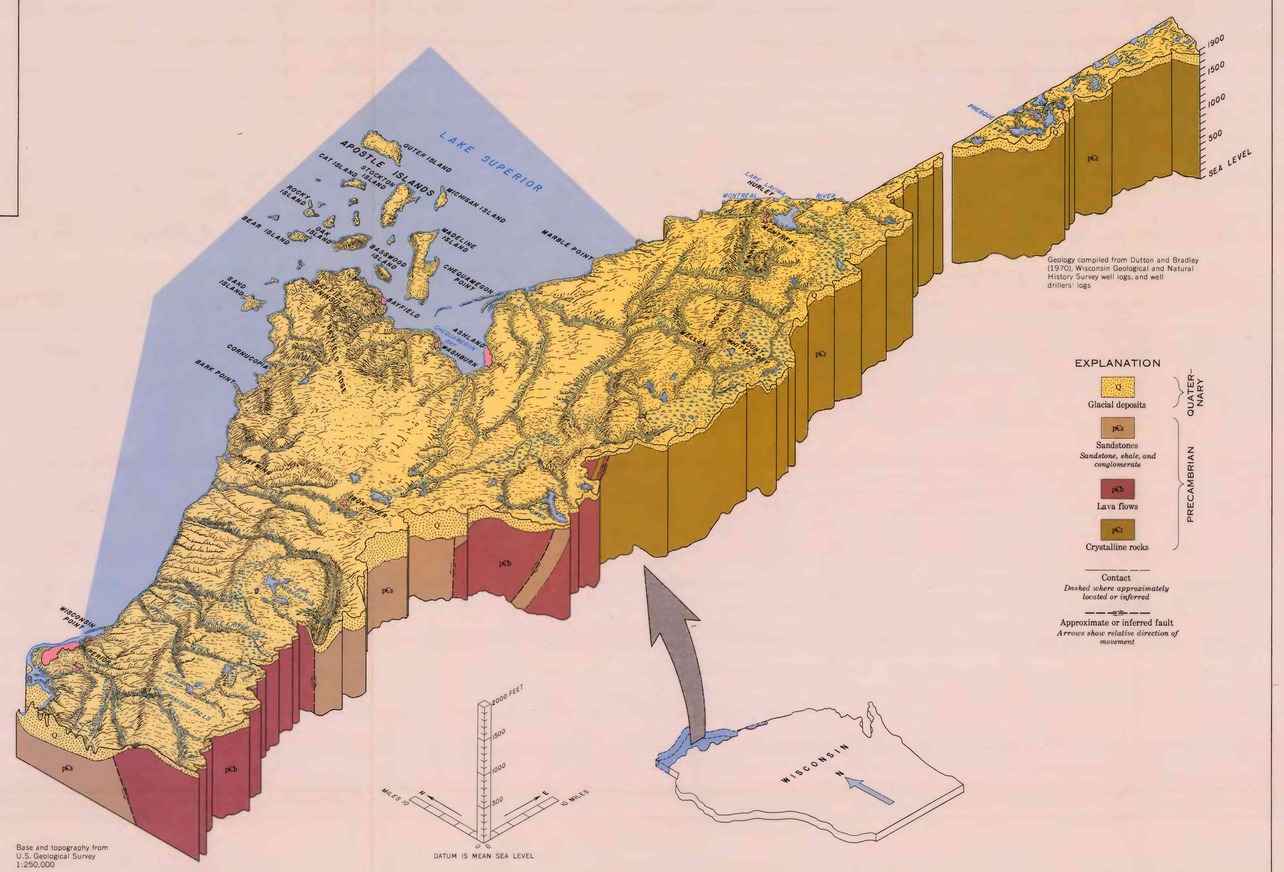
INTRODUCTION

This report describes, in general terms, the physical environment, availability, distribution, movement, quality, and use of water in the Lake Superior basin of Wisconsin. It will aid in planning the management of water resources in the basin. Detailed studies of individual areas may be necessary when specific information is needed.

The basin includes all the area in Wisconsin that drains to Lake Superior, an area of 2,885 square miles as computed from the most recent topographic maps. It constitutes 5.2 percent of the State and includes parts of Douglas, Bayfield, Ashland, Iron, and Vilas Counties. From west to east, the major streams are the St. Louis, Nemadji, Amnicon, Bois Brule, White, Marengo, Bad, Tyler Forks, Potato, and Montreal Rivers. Only 63 of 3,647 square miles of the St. Louis River basin, 162 of 424 square miles of the Nemadji River basin, and 160 of 263 square miles of the Montreal River basin are in Wisconsin. The small part of the basin on the extreme east is separated from the main basin by a small area of the Chippewa River basin to the south, which crosses the Michigan line. Drainage from this separate area of 95 square miles is to the Presque Isle and Ontonagon Rivers in Michigan. The Apostle Islands, off the Bayfield Peninsula, are part of the basin, but few data are available for them, and they are not included in most areal analyses in this report.

Many organizations and persons assisted the study by providing data. Among the contributors were the Wisconsin Department of Natural Resources; the Public Service Commission of Wisconsin; the U.S. Bureau of Commercial Fisheries; and the U.S. Lake Survey Center. Municipal water officials furnished water-supply information and well records. Many individuals and companies allowed access to their wells for water-level measurements and collection of water samples for chemical analysis.

PHYSICAL SETTING



Base and topography from U.S. Geological Survey 1:250,000

Geology compiled from Dutton and Bradley (1970), Wisconsin Geological and Natural History Survey well logs, and well drillers' logs

EXPLANATION

- Q — Glacial deposits — QUATERNARY
- pC3 — Sandstones. *Sandstone, shale, and conglomerate*
- pCb — Lava flows
- pC2 — Crystalline rocks
- PRECAMBRIAN

Contact. *Dashed where approximately located or inferred*

Approximate or inferred fault. *Arrows show relative direction of movement*

BLOCK DIAGRAM OF THE LAKE SUPERIOR BASIN

The block diagram shows three distinct types of topography as well as the subsurface rock strata and structural relations. Two types of topography are of glacial origin, and the third is bedrock controlled.

A nearly flat but deeply dissected lake plain adjoins Lake Superior between the Minnesota line and Fort Wing, and between North Fish Creek and the Montreal River. The plain is formed on thick deposits of red lake clay, which were deposited during the close of the glacial period, when Lake Superior was at higher stages. The lower edge of the plain is mostly 20–50 feet higher than the lake because of wave-cut bluffs along the present shore. The bottom of Lake Superior adjacent to the plain also is underlain by the clay deposits. Streams on the plain are generally short and youthful, have few tributaries, and flow in narrow, straight valleys to the lake. Gullying is active on the youthful elevated plain. The major streams cut deep valleys when the stage of Lake Superior dropped to almost 150 feet below the present stage (Farrand, 1969, p. 194); a subsequent rise in lake level has drowned the drainage pattern along the shore. Drowned valley mouths of several streams have since filled with sediment, as their courses became aggraded to the present lake level. The lake plain increases in altitude from 620 to 650 feet at Lake Superior to about 1,100 feet along its upper edge.

Rugged knob-and-kettle topography, formed by thick end moraines and pitted outwash, constitutes the massive Bayfield Ridge of the Bayfield Peninsula. Similar topography is prominent along the southern basin boundary east of the Bois Brule River to Lake Owen, and in the detached eastern extremity of the basin. The surfaces of these areas are characterized by a lack of surficial drainage and by an abundance of deep, dry depressions in the Bayfield Peninsula and by kettle lakes in the area southeast of Iron River to Lake Owen and in the detached part of the basin. These areas are fairly uniform in altitude, ranging from 1,150 to 1,350 feet.

Bedrock controls the topography in several parts of the basin. Prominent bedrock ridges with little or no drift cover, such as the Gogebic Range, occur where the rock is resistant to erosion. Mt. Whittlesey, near the west end of the Gogebic Range, is the highest point in the basin at 1,872 feet above mean sea level. Stream courses in the Gogebic Range area generally are aligned in one of two principal directions. Northeast-southwest trending streams are developed in the outcrop of the least resistant layers of the steeply dipping rocks forming the Gogebic Range. Northwest-southeast stream segments cut through the ridges of resistant rock where transverse faults caused zones of weakness. The escarpment along the south edge of the lake plain between the Nemadji and Iron Rivers is a result of resistant lava flows comprising the upthrown side of the Douglas Thrust Fault. Prominent water falls occur along this escarpment on the Black and Amnicon Rivers. In the central part of the basin resistant basalt also forms Copper Falls and other nearby falls on the Bad River and on Tyler Forks River at its junction with the Bad. The Apostle Islands are glaciated remnants of sandstone and are separated from the Bayfield Peninsula by deep, preglacial valleys.

The deep and wide valley containing the upper reach of the Bois Brule River is a prominent and historically important geomorphic feature. Indians and early explorers used the Bois Brule and St. Croix Rivers as a "water highway" between Lake Superior and the Mississippi River. The divide between the St. Croix and Bois Brule Rivers crosses the valley in a swamp only 425 feet above the level of Lake Superior. This valley was a southern outlet of the large glacial lakes that occupied the Lake Superior basin.

WATER USE

WITHDRAWAL USE OF WATER IN 1970
[Million gallons per day]

Use	Source and type of supply						Total
	Ground water			Surface water			
	Public supply		Private supply	Public supply		Private supply	
	Municipal	Other		Municipal	Other		
Domestic	0.5	0.1	1.4	1.4	0.0	0.0	3.4
Industrial and commercial (excluding fuel-electric power)	.8	<.1	.3	1.9	0	3.1	6.1
Fuel-electric power	0	0	0	0	0	57.8	57.8
Irrigation	<.1	<.1	<.1	.1	0	.2	.3
Stock	0	0	.1	0	0	.5	.6
Other	.6	.2	.5	1.3	0	0	2.6
Subtotal	1.9	.3	2.3	4.7	0	61.6	70.8
Total	4.5			66.3			70.8

Almost 71 mgd (million gallons per day) of water was withdrawn for use within the Lake Superior basin in 1970. About 93 percent of this water was withdrawn from and returned to Lake Superior, whereas only 6 percent was withdrawn from ground-water sources. The remaining 1 percent was from other surface-water sources. The 71 mgd is equivalent to 110 cfs (cubic feet per second), which is about 4 percent of the average runoff from the basin.

The largest withdrawal use of water was 57.8 mgd for cooling condensers in two fuel-electric power generating plants at Ashland and Superior. This use was 87 percent of the surface water withdrawn. Consumption is small because the water is circulated in closed systems and is returned to the lake.

The second largest use of water in 1970 was 6.1 mgd by industry and commerce. The water was primarily from Lake Superior and accounted for 9 percent of the surface water used.

The only other significant withdrawal of water was 3.4 mgd for domestic use, 89 percent of which was ground water. In 1970, about 51,300 people (73 percent of the population) were served by public water supplies, and the remaining 19,100 people were served by privately owned supplies from ground water. Consumption is low because most of the withdrawn water is discharged into streams or Lake Superior through sewage-treatment plants or to the ground through septic tanks.

The miscellaneous "Other" use of 2.6 mgd includes losses from distribution systems, street washing, main flushing, and use in schools, institutions, and other public buildings. Consumption of water is low, and most of the water is discharged to streams or Lake Superior through storm drains or is returned to the ground.

Irrigation is not significant in the basin. In general, soils in the basin are not suitable for crop irrigation; thus, irrigation is common only on golf courses and lawns. Wild rice production on the Bad River Indian Reservation used 0.2 mgd of surface water in 1970, which is included on the table as irrigation.

COMMUNITY WATER USE IN 1970
[Pumpage and use data from Public Service Commission of Wisconsin]

Community	County	Population (1970)	Average daily pumpage (mgd)	Maximum daily pumpage (mgd)	Use (million gallons per year)				Source of water[1]
					Domestic	Industrial and commercial	Public	Other	
Ashland	Ashland	9,615	1.12	1.69	147	114	15.9	133	LS,G
Bayfield	Bayfield	874	.128	.194	12.6	14.5	8.1	11.6	S
Drummond	Bayfield	180	[2].009	.....	1.6	.8	1	1.7	G
Harley	Iron	2,418	.232	.388	27.9	13.3	2.4	41.3	Lake Lavina
Iron Belt	Iron	[2]300	.019	.053	2.8	.4	.3	3.5	G (spring)
Iron River	Bayfield	650	.048	.085	5.1	6.5	.6	12.2	S
Marengo	Ashland	110	[2].004	.....	1.1	.4	.....	.....	S
Mellen	Ashland	1,168	.122	.304	10.8	16.3	4.1	13.5	G
Montreal	Iron	877	.141	.186	13	10	8	20	G
Oliver	Douglas	210	.007	.021	1.2	.6	.....	.7	G
Pence	Iron	[2]220	.016	.....	5.6	.2	.....	.....	G (springs)
Superior[3]	Douglas	32,713	4.58	6.08	457	812	77.5	327	LS,G
Washburn	Bayfield	1,957	.184	.310	25.5	13.0	4.5	43.0	LS
Total		51,292	6.610		711.2	1,002.0	121.5	606.5	

G, glacial sand and gravel; S, sandstone; LS, Lake Superior
[1]Estimated
[2]Includes Village of Superior, population 476

Although most communities in the basin used ground water in 1970, almost 80 percent of the 2.4 billion gallons used was surface water. Of the 13 community supplies, six were from glacial sand and gravel, three from sandstones, three from Lake Superior (but with supplemental supplies for two from glacial sand and gravel), and one from a small inland lake. Superior and Ashland withdrew 1.5 billion gallons from Lake Superior and 0.6 billion gallons from ground water. In 1970, Washburn developed a ground-water supply from the sandstones and now uses Lake Superior only as a standby source.

Based on data from Wisconsin Department of Natural Resources; Public Service Commission of Wisconsin, and miscellaneous sources

DISTRIBUTION OF USE

Water is used in many ways. Some uses require its removal from the ground or from surface storage, but others do not. Thus, uses are categorized as withdrawal or nonwithdrawal. Withdrawal use of water is concentrated primarily at Superior and Ashland. Most is self-supplied surface water for fuel-electric power. (See withdrawal-use table above.) Elsewhere very small amounts of ground water are withdrawn, mainly for rural homes and municipal supplies.

Among nonwithdrawal uses of water are hydroelectric power generation, waste disposal and assimilation, fish and wildlife habitat, recreation, and transportation. Five hydroelectric plants used about 670 mgd in 1970 to generate 32.1 million kilowatt-hours of electricity. Some streams transport wastes and sediment from many sources, and Lake Superior receives treated effluent from several municipalities and industries along its shore.

Lake Superior, many interior lakes, and numerous streams draw people for year-round outdoor recreation and sports. Fish and wildlife habitat and closely associated water-based or water-related recreation are important to the basin's tourist industry. Several State and county parks and forests, more than 400 square miles of the Chequamegon National Forest, and the new Apostle Islands National Lakeshore provide recreational opportunities. The cool water necessary for trout in the summer is maintained in many streams by natural ground-water discharge. Several streams also are used by migratory trout from Lake Superior. The fishery of Lake Superior includes coho and chinook salmon; lake, brook, brown, and rainbow trout; and other game fish. Warm-water fisheries in inland lakes and streams also are significant.

Duluth-Superior (fifth largest port in tonnage in the United States) and Ashland are major ports for shipping on the Great Lakes and St. Lawrence Seaway. Almost 34 million tons of materials, of which 87 percent was iron ore from Minnesota and 12 percent was farm products, was shipped from the Duluth-Superior Harbor in 1968. About 2 million tons of products, of which 92 percent was coal, was received in the same port. Most shipping is domestic, but, of 4 million tons of farm products outgoing, 2.4 million tons was exported (Great Lakes Basin Commission, written commun., 1972).

Recreational boating is popular, but its potential capacity is far from being reached (Great Lakes Basin Commission, written commun., 1970). Both inland waters and Lake Superior provide abundant resources for canoeing, sailing, fishing, and cruising. Use of Lake Superior water by small craft is limited primarily to short distances (generally within 4 miles) from the harbors at Superior, Port Wing, Cornucopia, and Saxon and to the sheltered waters of the Apostle Islands and Chequamegon Bay. The average length of the boating season is about 120 days. Sheltered waters are estimated to be usable for 90 days and open waters only 60 days of this season.

GEOLOGY AND SOILS

Bedrock in the basin is wholly Precambrian in age and consists of three major groups of rock types in three general areas of outcrop (Dutton and Bradley, 1970). They are, from oldest to youngest: 1) various crystalline rocks in the southeastern part of the basin; 2) lava flows, mainly in the southwestern part; and 3) sandstone, shale, and conglomerate in the central and northwestern parts.

The crystalline rocks are primarily granite, gneiss, greenstone, and quartzite of intrusive igneous and metamorphic origins. These rocks form the bedrock surface in the eastern part of the basin and also the basement complex under the younger lava flows and sedimentary rocks. Steeply dipping and complexly faulted layers of slate, iron formation, and dolomitic marble strike northeast along the Gogebic Range.

The lava flows are possibly as thick as 30,000 feet and may contain as many as 700 separate sheet flows, each averaging more than 40 feet in thickness (White, 1966, p. 2). The flows are composed primarily of basalt and andesite. A few layers of sedimentary rock are interbedded with the flows, mainly near the top of the sequence. The flows dip 40–60° SSE away from the Douglas Thrust Fault. Where not uplifted by faulting, they underlie the sedimentary rocks.

Thwaites (1912) described in detail the sedimentary rocks in the basin and classified them into several formations within an older Oronto Group and a younger Bayfield Group. These rocks are referred to collectively as sandstones in this report. The regional correlation of these groups is uncertain, and the age (Precambrian or Cambrian) of the Bayfield Group is controversial among several investigators (Ostrom, 1967). The Oronto Group is 60 percent shale and 40 percent arkosic sandstone, whereas the Bayfield Group is 99 percent quartzose sandstone (Thiel, 1956, p. 1088). The younger Bayfield Group is generally absent south of the Douglas Fault but overlies the Oronto Group north of the Fault. Estimates of maximum thickness of the sedimentary rocks range from more than 15,000 feet to more than 25,000 feet. Although their thickness is uncertain, it is greatest north of the Douglas Fault.

An iron-bearing district, the Gogebic Iron Range, extends from Michigan southwestward through Hurley to a point about 8 miles south of Grand View. From 1886 until production ceased in 1965, 71 million tons of iron ore was produced from this district in Wisconsin (Dutton and Bradley, 1970, p. 7).

Geology after Dutton and Bradley (1970)

BEDROCK GEOLOGY

Glacial drift forms an almost continuous cover as thick as 600 feet over the bedrock. The drift is thickest in preglacial bedrock valleys, such as beneath the St. Louis River valley near Superior, and in the areas of end moraine and pitted outwash. It is thin to absent in wide areas along the Gogebic Range and on the uplifted side of the Douglas Fault and locally where streams have cut through the drift cover. Glacial deposits in the basin consist of, in order of decreasing abundance, lake deposits, end moraine, outwash, and ground moraine.

Sediments from glacial melt waters were deposited in the Lake Superior depression when widespread lakes stood as much as 500 feet higher than the present Lake Superior (Leverett, 1929, p. 54–60). Half of the basin is covered by these lake deposits, primarily red clay that locally contains small amounts of silt and sand in thin, discontinuous layers. Some lake deposits, mainly on the Apostle Islands, are largely sand.

End moraine is extensive along the southern basin boundary and in the Bayfield Ridge. A broad east-west belt of moderately hummocky end moraine, composed of red sandy to clayey till and stratified deposits of sand and gravel, forms most of the basin divide. Interlobate end moraine forms the core of the Bayfield Ridge, extending southward to the east-west moraine, but most of the interlobate moraine is buried either by lake clay or by the pitted outwash capping the ridge. The large deposit of outwash on the Bayfield Ridge is the most extensive in the basin. An extension of this deposit in the headwaters of the Bois Brule River continues uninterrupted as far as St. Croix Falls, 80 miles to the southwest. Because it is high topographically, this outwash has a deep water table; thus, most water in the drift in the Bayfield Ridge is in the moraine core. Only minor amounts of outwash are associated with the major east-west end moraine.

Ground moraine is not extensive as a surficial deposit except along and north of the Gogebic Range, where it occurs in relatively thin deposits. Extensive deposits of older ground moraine, partly reworked by the glacial lakes, underlie much of the lake clay. They generally consist of silty to sandy clay till containing some gravel and cobbles. Sand and gravel deposits are common beneath the older drift, especially near Superior (Mengel, 1971, p. 60–61).

Geology, except drift thickness, after Thwaites (1956) and Leverett (1929)

GLACIAL GEOLOGY

Soil permeability is the capacity of the soil to transmit water under given conditions and is a factor in infiltration, recharge to ground water, and surface runoff. The map shows areas of estimated permeability rates of the least permeable soil horizon. Areas are generalized, and each includes several soil types and soil associations. Soil-moisture content, vegetal cover, land slope, depth to the water table, soil thickness, and frequency and duration of precipitation are additional factors that affect infiltration through soils.

Soils with high permeability, greater than 2.5 inches per hour, cover 28 percent of the basin. These soils are loamy sands, sands, and sandy loams formed largely on outwash and end moraine on and southwest of the Bayfield Ridge and on thin ground and end moraine along the Gogebic Range.

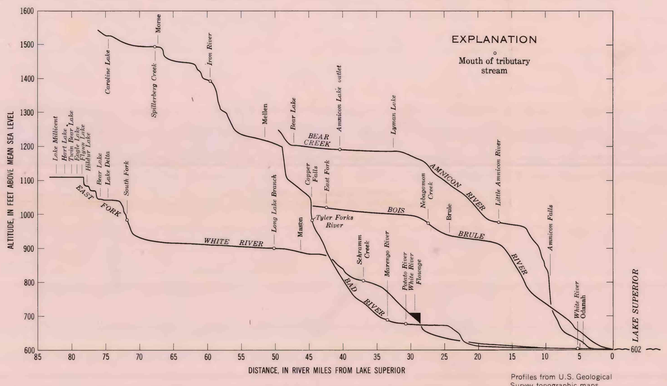
Soils with moderate permeability of 0.8–2.5 inches per hour cover 34 percent of the basin and consist mainly of loams. These soils lie primarily on the major east-west trending end moraine.

Soils with low permeability, less than 0.8 inch per hour, cover 38 percent of the basin and are mainly silty clay loams and loams developed on the glacial lake clay.

Compiled from Hole and others (1968) and U.S. Soil Conservation Service (1964)

SOIL PERMEABILITY

DRAINAGE



Profiles from U.S. Geological Survey topographic maps

RIVER PROFILES

Lake Superior is the base level for all streams in the basin; however, most stream profiles result from the conformance of drainage to the postglacial land surface. Gradients commonly are erratic, changing abruptly from flat to steep. Very flat reaches, with gradients of 0.2–1.8 feet per mile, occur on plains formed by glacial lakes and ground moraine and where stream courses have lengthened to adapt to bedrock structure or glacial landforms. Wetlands are common on some flat reaches in headwater areas and near Lake Superior. Gradients are steep, 30–60 feet per mile, on bedrock escarpments and on the end-moraine border. Rapids and falls are common, especially on the middle and upper reaches of the Bad River.

WATER SYSTEM

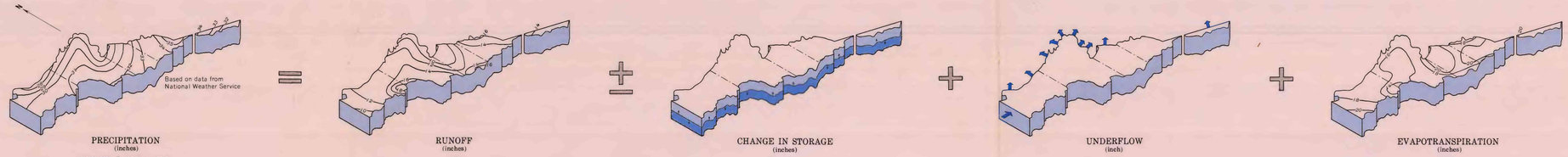
HYDROLOGIC BUDGET

The source of all water in the basin is precipitation. Some water runs rapidly off the land surface to nearby streams and lakes (surface runoff); some evaporates (evaporation); some reaches the ground-water reservoir (recharge), which supplies base flow to streams (ground-water runoff); and some returns to the atmosphere through plants (transpiration). This circulation of water constitutes the hydrologic cycle.

The hydrologic budget for the basin is a simplified equation of the average annual components of the hydrologic cycle. Water input to the basin equals water output plus or minus changes in storage. Input is primarily precipitation on the basin, but it includes runoff and ground-water underflow from the Minnesota part of the Nemadji and Pokegama River basins. Although available in the basin as stream-flow, this runoff from Minnesota is not included in the calculation of the hydrologic budget. Water output includes runoff, ground-water underflow, evapotranspiration (sum of evaporation and transpiration), and consumptive use by man. Major changes in the budget from year to year occur only in precipitation, runoff, and evapotranspiration, although small changes in storage occur.

Man's effect on the budget items is negligible in the Lake Superior basin. The small amount of ground water withdrawn does not lower the water table permanently, because recharge is more than adequate to balance the system. Most ground water withdrawn is returned to the ground or discharged to streams; thus, average runoff is not altered appreciably. A large part of the water withdrawn for lawn and stock watering is consumed. However, these uses account for only 1 percent of the water withdrawn. The rate of evaporation from surface reservoirs is probably about equivalent to the rate of evapotranspiration.

Average annual conditions and budget quantities during 1931–60 are shown on the budget diagrams. Also shown are budgets for a dry year (1963) and for a wet year (1951).



PRECIPITATION (inches)

DRY YEAR (1963)	21.8
AVERAGE (1931–60)	31.0
WET YEAR (1951)	44.4

Average annual precipitation on the basin is 31 inches, ranging from less than 28 inches near Superior to more than 35 inches at Hurley. Precipitation increases to the south and east from Lake Superior (general direction of movement of prevailing winds aloft) due to temperature differences between the lake and land and to the roughness and higher altitude of the uplands. Annual precipitation on the basin was 9.2 inches below average in 1963 and 13.4 inches above average in 1951.

Average annual snowfall is 20–35 percent of the annual precipitation and ranges from about 50 inches at the Minnesota-Wisconsin line to 120 inches at Hurley. A belt of heavy snowfall extends eastward from Mellen along the Gogebic Range.

RUNOFF (inches)

	8.8
	12.8
	24.7

An average of about 2,700 cfs of water (12.8 inches per year) is estimated to run off the basin to Lake Superior. This does not include about 150–200 cfs that enters Wisconsin from Minnesota in the Nemadji and Pokegama Rivers and flows to Lake Superior. Average runoff generally increases away from Lake Superior in direct relation to precipitation and topographic relief. Almost half the average runoff is from the Bad-White River basin, at an average rate of 1.0 cfs per sq mi (13.6 inches per year). The rugged Bayfield Ridge has little runoff. In the dry year, runoff from the basin was only 4 inches below average, but in the wet year it was about 12 inches above average.

CHANGE IN STORAGE (inches)

Loss	1.1
	0.0
Gain	0.6

Water is stored in the basin as ground water and surface water, as soil moisture, and in winter as snow. The major part is ground water, and its long-term net change in quantity is negligible. Annual gains or losses of water, as interpreted from ground-water hydrographs, nearly balance over a long-term period.

UNDERFLOW (inches)

	0.5
	0.5
	0.5

Underflow in and out of the basin is small, and changes during years of extremes in precipitation are negligible. An insignificant amount of inflow comes from Minnesota on the western border. Outflow is to Lake Superior along its 115-mile shoreline within the basin and into Michigan from the detached part of the basin. The only significant underflow is that out of the Bayfield Peninsula between the mouth of the Iron River (west of Port Wing) and the head of Chequamegon Bay. Much recharge through the permeable glacial deposits of the high Bayfield Ridge results in much ground-water underflow. Most of the remaining shoreline borders the flat lake plain of thick clay that contributes negligible underflow to Lake Superior.

EVAPOTRANSPIRATION (inches)

	13.6
	17.7
	18.6

Evapotranspiration annually returns an average of 17.7 inches of water to the atmosphere. It is computed here as precipitation minus the sum of runoff, changes in storage, and underflow. The small consumptive use by man also is included. The major part is transpiration because the basin is almost entirely forested. The highest rate of evapotranspiration is in wetlands. The amount of water evaporated from open-water surfaces is small because there are few inland lakes. Annual evaporation from the surface of Lake Superior averages about 18 inches (Richards and Irbe, 1969, p. 485).

Evapotranspiration generally is indirectly proportional to runoff and directly proportional to precipitation. The main exceptions are on the Bayfield Ridge and its southwestern extension, where deep water tables and permeable soils decrease the amount of water available for transpiration.

Base from U.S. Geological Survey
1:500,000

WATER RESOURCES OF WISCONSIN–LAKE SUPERIOR BASIN

By
H. L. Young and E. L. Skinner

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