Reconnaissance of Ground-Water Conditions in Maine

By GLENN C. PRESCOTT, JR.

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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ABSTRACT

The principal sources of ground water in Maine are glacial-outwash deposits and bedrock formations. Ground water in large quantities—enough for municipal and large-scale industrial use—is obtained chiefly from sand and gravel in the outwash. These deposits occupy many valleys and lowlands in the State and are especially widespread in the Coastal Lowlands and Central Uplands. Their specific location and water-bearing potentialities are generally unknown. Moderate to large quantities of water also are available locally from carbonate bedrock formations—limestone, marble, and calcareous slate and shale. These formations underlie most of the Aroostook Valley and the northern part of the Moosehead Plateau. Ground water in small quantities—commonly enough for ordinary household and rural use—may be obtained from the bedrock formations at most places throughout the State. Less commonly, enough water may be obtained from these formations for small public supplies and small-scale industrial use.

Water levels in Maine fluctuate seasonally. Records of water levels indicate no long-term trend of the water table, either up or down.

Ground water in Maine is generally of good chemical quality. There are, however, scattered localities throughout the State where the ground water contains excessive amounts of iron, and excessive hardness is associated with water from the carbonate bedrock formations.

There is a trend toward larger withdrawals of ground water for municipal and industrial use and a growing demand for larger supplies of water for the individual rural home and farm.

The current ground-water investigation has shown no immediate critical ground-water problems of appreciable magnitude. Rather, it has confirmed the lack of basic information that is essential to the wise use and orderly development of the water resources in Maine. Areas where additional ground-water information is needed include southwestern Maine, the lower Androscoggin River basin, the lower Kennebec River basin, the lower Penobscot River basin, and the Aroostook Valley.

INTRODUCTION

PURPOSE AND SCOPE

A program of ground-water investigations in Maine was begun in 1957 by the U.S. Geological Survey in cooperation with the Maine Public Utilities Commission. As a basic step in establishing an effective program, a preliminary reconnaissance of the State was made during the 1958–59 biennium. The reconnaissance had four main objectives: (1) to gather and analyze data on the geology and occurrence of ground water; (2) to identify current or foreseeable ground-water problems; (3) to determine the status of available information, including deficiencies in information; and (4) to form a basis for planning further investigations.

This report summarizes the technical findings of the study and briefly reviews pertinent hydrologic principles as they apply to ground water in Maine. It supersedes a preliminary summary released earlier (Prescott, 1959).

Fieldwork for the reconnaissance was begun in August 1957 and was carried on intermittently until September 1958. The geology and physical features that influence the occurrence of ground water were examined from place to place throughout the State. Officials of water districts and water companies, government agencies, private firms, college departments of geology and engineering, and well owners and drillers were interviewed regarding the use of ground water in Maine and the existing or potential water problems. Information on more than 1,500 wells and springs was obtained. Of these, about 100 were being used for public supply, about 100 for industrial purposes, about 60 by the military, and 1 for irrigation; more than 350 were test wells or abandoned wells, and most of the others were being used principally for domestic purposes. Chemical analyses of more than 100 water samples were assembled, and an inventory of pumpage from public-supply wells was made. Eight wells were selected to augment a small network of observation wells (pl. 1), which had been established in 1942 by the U.S. Geological Survey.

PREVIOUS REPORTS

For a complete listing of publications pertaining to the geology of Maine, the reader is referred to bibliographies by the Maine Geological Survey (1958, 1959). Though very few of the reports listed are concerned primarily with ground water, the geologic information contained in many of them is applicable to ground-water studies.

Several reports on the geology of Maine were published during the 19th century. Among the early geologists who worked in Maine were C. T. Jackson, C. H. Hitchcock, N. S. Shaler, and G. H. Stone. Jackson was the author of many reports concerned with the geological features of Maine (1837, 1838, 1839); these reports include his first, second, and third reports on the geology of Maine. One of Hitchcock's reports (1861) is a general report on the geology of Maine, and another (1862) contains a geologic map of northern Maine. One of the most pertinent of Shaler's many contributions to geological science is a report on changes in sea level on the coast of

Maine (Shaler, 1874). Stone (1899) described the glacial gravel and associated deposits, which form an important aquifer in some places.

During the early part of the 20th century, several geologic reports pertinent to ground water in Maine were published. Among these are geologic folios by Smith and others (1907), Bastin (1908), and Bastin and Williams (1914). These reports contain useful geologic maps and a few short paragraphs on ground water in the Penobscot Bay, Rockland, and Eastport areas, respectively. A report by Pressey (1902), describing water power in Maine, contains a brief summary of geology. Reports by Barrows (1907) and Barrows and Babb (1912), which describe in considerable detail the surface-water resources of the Kennebec and the Penobscot River basins, respectively, also contain sections on geology. Katz (1917) described the bedrock stratigraphy of southewestern Maine. A report by Toppan[1] outlines the geologic history and summarizes the bedrock and structural geology of the State according to county or region.

Since the publication of Stone's report a few papers dealing with glacial geology in Maine have been written. The most comprehensive of these is a bulletin by Leavitt and Perkins (1934a, b; 1935). This report, which is published in two volumes, includes a map of Maine showing the location of stratified glacial deposits, a preliminary map of the bedrock geology (Keith, 1933), and a discussion of the glacial history of Maine. In a previous report, Katz and Keith (1917) described the glacial deposits in an area in southwestern Maine. A U.S. Geological Survey report (Hanley, 1959) on the surficial geology of the Poland topographic quadrangle is a valuable aid in the study of the ground-water resources of that area. A report by Bloom (1960) contains a generalized map of the unconsolidated deposits of southwestern Maine and a comprehensive discussion of the glacial and postglacial history of the area.

Several early reports mention ground water in Maine. Among them, papers by Goodale (1861), Peale (1886 and 1894), Jackson (1905), and Skinner (1911) are concerned with water quality. In the early 1900's there was a flurry of interest in ground water in Maine and several reports were published during that time. Among these are reports by Smith (1905a, b) describing briefly the water resources of the Portsmouth-York area and water supply from glacial gravels near Augusta, respectively, and by Bayley (1905) summarizing the topography, geology, and water resources of Maine. Another report by Bayley (1904) contains data on wells and springs and chemical analyses of a few water samples. A report by Fuller and others (1905) describes wells drilled in the United States in 1904,

[1] Toppan, F. W., 1932, the Geology of Maine: unpublished M. S. thesis, Union College, Schenectady, N.Y., 141p., map.

including three in Maine. The most comprehensive paper dealing with ground water during this period was written by Clapp (1909) on the underground waters of southern Maine. This report describes the ground-water situation in southern Maine counties according to town; it includes a listing of 474 wells and 290 chemical analyses. Three other reports by Clapp (1911a, b, c) describe, respectively, the occurrence of ground water in slate in Maine and in granite in New England, and the composition of mineral springs in Maine.

Since the work by Clapp, there has been very little study of ground water in Maine. A report of the State Geologist for 1947–48 (Trefethen, 1949) contains notes on ground-water conditions, and his report for 1953–54 (Trefethen, 1955) includes an article on well finding. A series of reports by the New England-New York Interagency Committee (NENYIAC, 1945) contain brief summaries of the geology and ground-water resources of Maine's major drainage basins.

Since 1943, the water levels in several wells in Maine have been measured periodically in connection with a national observation-well program. These measurements and brief text are published in Geological Survey Water-Supply Papers entitled "Water Levels and Artesian Pressures in Observation Wells in the United States, Part 1, Northeastern States". The Water-Supply Papers containing water-level records for Maine from 1943–57 are:

Year	*Water-Supply Paper*	*Year*	*Water-Supply Paper*
1943	986	1950	1165
1944	1016	1951	1191
1945	1023	1952	1221
1946	1071	1953	1265
1947	1096	1954	1321
1948	1126	1955	1404
1949	1156	1956–57	1537

Two reports by the New England Water Works Association (1949; 1957) tabulate public-water systems in Maine that use ground water,

The only recent areal study of geology and the occurrence of ground water pertinent to Maine was made in adjacent coastal New Hampshire. Two reports have been issued as the result of that investigation (Bradley, 1955; Meyers and Bradley, 1960).

A preliminary report summarizing the principal findings of the present investigation was approved for the open file in 1959 (Prescott, 1959). In addition, a paper based on this investigation was published in 1960 by the Maine Water Utilities Association (Prescott, 1960).

GEOGRAPHY

The water situation and water problems can be assessed realistically only by considering the water resources in relation to man's activities and the general environment. For this reason a brief summary of some of the pertinent elements of the geography of Maine precedes the discussion of the ground-water conditions.

GEOGRAPHY BY AREAS

The State has an area of 32,562 square miles, of which about 1,447 square miles is inland water (Maine State Planning Board, 1936, p. 92). Maine lies in the New England physiographic province of the Appalachian Highlands and may be subdivided into the Moosehead Plateau, the Aroostook Valley, the Central Uplands, and the Coastal Lowlands (Toppan, 1935, p. 77). These units furnish the basis for a brief description of the geography of Maine by areas. Later in this report the same units serve as a basis for the discussion of ground-water conditions by area.

MOOSEHEAD PLATEAU

The Moosehead Plateau encompasses the northwestern third of the State. It lies west of a line running from the international boundary near the confluence of the Fish and St. John Rivers to the New Hampshire boundary and includes part of Oxford, Franklin, Somerset, Piscataquis, and Aroostook Counties (pl. 1). The region is hilly to mountainous and averages about 1,500 feet in altitude, though numerous mountains are higher. Baxter Peak on Mount Katahdin, the highest point in Maine, has an altitude of 5,257 feet. Many lakes, including Moosehead Lake, and the headwaters of four major river systems—the St. John, Penobscot, Kennebec, and Androscoggin—lie within this region.

The population is sparse, averaging only about 1 person per square mile. The most populous area, the town of Fort Kent, which is at the northeast edge of the region, had 4,761 residents at the time of the 1960 census. Greenville, the next largest town, had a population of 2,025 in 1960.

The economy of the Moosehead Plateau is relatively undeveloped, and most of the area is a wilderness. The forests provide the most valuable known natural resources of the region, and much of the population is in some way concerned with the lumbering business. Agriculture and industry are not important. However, in the vicinity of Fort Kent, potatoes are raised and there is some light industry, including starch factories at Fort Kent and a plywood mill at Greenville.

The Moosehead Plateau has several known mineral deposits of potential value. Many deposits such as sand, gravel, and limestone, and other rock materials are of no value currently because of their inaccessibility, though such materials are used where they occur near populated areas or transportation lines. Deposits of pyrrhotite, a mineral from which iron and sulphur can be derived, and asbestos occur, but as yet have not been mined. Very small amounts of gold have been found. Slate is mined at Monson.

AROOSTOOK VALLEY

The Aroostook Valley extends from the Moosehead Plateau eastward to Canada. Its southern border is just north of Danforth and Millinocket (pl. 1). The region is one of rolling topography and has an average altitude of about 700 feet. Swampy land is common. Though the western part of the region is heavily wooded, the eastern part is cleared and contains the famous Aroostook County potato-growing lands. The Aroostook River is the principal river, but the St. John River, which forms the northern boundary between the United States and Canada, is large and of considerable economic importance.

The density of population of the Aroostook Valley is about 30 to 40 persons per square mile. The principal urban areas are Presque Isle, which in 1960 had a population of 12,886; Caribou, 12,464; and Houlton, 8,289. Loring Air Force Base, the largest Strategic Air Command base in the East, is located at Limestone.

Agriculture is the most important economic pursuit in the Aroostook Valley. Aroostook County raises about 90 percent of Maine's and nearly 17 percent of the nation's potato crop. The production of pulp and paper, lumber and wood products, processed foods, and potato starch also are important to the economy of the area.

Aroostook Valley has no known mineral resources of great economic value. Limestone has been used locally as a source of road metal and agricultural lime. The occurrence of low grade manganese deposits in the area has been known for many years, and if an economical process of extracting the manganese can be discovered, these deposits may become valuable. There is some peat in this region, but little or none is produced commercially.

CENTRAL UPLANDS

The Central Uplands is a belt of gently rolling to moderately hilly country averaging about 40 miles in width. The region extends northeastward from New Hampshire to the northeast border of the State near Vanceboro, where it merges with the Coastal Lowlands. The Central Uplands are separated from the Moosehead Plateau by a fairly distinct escarpment but are separated from the Coastal Lowlands, which lie to the south, by a gentle slope, which becomes less distinct northeastward. The average altitude of the region is about 500 feet, although many hills rise above this general level. The region is crossed by the Penobscot, Kennebec and Androscoggin Rivers and contains many lakes, particularly in its eastern section.

The region has considerable wooded country, particularly on the east side, but contains numerous towns of economic importance and an appreciable amount of industry, including pulp and paper mills, shoe factories, tanneries, and canning plants. Among the larger towns are Lincoln, Millinocket, Old Town, Dover-Foxcroft, Skowhegan, Farmington, and Rumford, which in 1960 had populations of about 5,000 to 10,000.

Mineral deposits of the Central Uplands area include clay, peat, sand and gravel, slate, granite, and pegmatite minerals—feldspar, mica, and beryl. Some gold has been found in the gravel along the Swift River in Oxford County. A few years ago an unsuccessful test well for oil was drilled at Brookton, in northeastern Washington County.

COASTAL LOWLANDS

The Coastal Lowlands lie between the Central Uplands and the Atlantic Ocean (pl. 1). The Coastal Lowlands and the Central Uplands are separated by a gentle slope. The slope is distinct in York and Cumberland Counties, less distinct farther north, and dies out almost entirely in the Grand Lake region of Washington County (Toppan, 1935, p. 78). The topography is almost flat to gently rolling. Low mountains or mountain groups such as the Camden Hills, Mount Cadillac, Lead Mountain, and Blue Hill rise above the general level. The land generally slopes toward the sea, and the average altitude of the region is approximately 100 feet.

The characteristics of the coastline differ considerably from south to north. Southwest of Portland it is characterized by extensive sandy beaches backed by tidal marshes and nearly flat, low-lying country. Northeast of Portland the coastline is very irregular and is characterized by drowned river mouths separated by long rocky promontories and fringing islands.

The St. Croix River forms the eastern boundary of the Coastal Lowlands and the Salmon Falls (and Piscataqua) River borders the region on the southwest. The Penobscot, Kennebec, Androscoggin, and Saco Rivers flow through the lowlands to the sea. The Union, Machias, and Presumpscot Rivers, which lie almost entirely in the coastal region, also are relatively large. Lakes are common, particularly in Washington County.

The Coastal Lowlands is the most densely populated region in the State and contains most of the largest cities, though Washington County, particularly the section away from the coast, is sparsely populated. Twelve of the 13 urban areas in Maine listed in the census of 1960 as having populations of 10,000 or more are in this region They include Auburn, Augusta, Bangor, Bath, Biddeford, Lewiston, Portland, Saco, Sanford, South Portland, Waterville, and Westbrook. In 1960 these communities had an aggregate population of about 310,000—about one-third of the total population of the State. The Coastal Lowlands, particularly the southwestern third, also has more industry and better transportation facilities than other parts of the State.

Among the principal economic pursuits in the area are the manufacture of textiles, boots, shoes, machinery, and electronic products, the processing of food, and shipbuilding. Agriculture and the fishing industry are of secondary economic significance. Northeast of Penobscot Bay the blueberry crop provides most of the agricultural income. Southwest of Penobscot Bay dairy, poultry, fruit, and truck farming are the principal agricultural pursuits. Also of economic importance are the many resort and recreational facilities in the coastal region.

The Coastal Lowlands has many mineral deposits—both metallic and nonmetallic. Clay, the most widespread of these deposits, is used in its natural state in the manufacture of bricks and pottery, but it might be adaptable to other uses that require a purer grade of clay. Limestone occurs extensively in the vicinity of Rockland and Thomaston, and the only cement plant in New England is at Thomaston. At many places, granite is quarried for building stone, curbstones, riprap, and monuments; it is also used for crushed rock in highway construction. Deposits of sand and gravel are common. A small amount of peat for agricultural and horticultural purposes is dug from bogs, principally in Hancock and Washington Counties. A few pegmatite deposits are being worked for feldspar in Sagadahoc and Cumberland Counties, but production is not very great. Mica and beryl have been recovered from pegmatite mines.

Metallic minerals in the region include ores of copper, nickel, lead, zinc, manganese, molybdenum, and iron, and sulphur. Interest in these minerals has increased recently, and investigations of some of these deposits are currently being made by private companies.

CLIMATE

Maine has a humid microthermal climate: four well-defined seasons and precipitation distributed fairly evenly during the year. The climate is varied owing to differences of latitude and altitude, the influence of the Atlantic Ocean, and the location of the State in relation to storm paths and prevailing winds.

Northern Maine, which includes the Moosehead Plateau and the Aroostook Valley, usually has more severe winters (higher snowfalls and lower temperatures) and shorter growing seasons than other parts of the State (Fobes, 1946, p. 5, 6). The average annual snowfall for the region is more than 100 inches, and, because of low winter temperatures, accumulations of snow are great. The water stored as snow is a significant source of runoff and ground-water recharge each spring. The climate of this region is little affected by coastal storms that sweep inland from the ocean, and the St. Lawrence Valley disturbances, which pass just north of the area, are commonly almost dry by the time they reach northern Maine. As a result, the average precipitation is generally less than in other regions of the State. Mean annual precipitation in northern Maine is about 40 inches, though mean annual precipitation at individual stations in the region ranges from 44.71 inches at Brassua Dam to 35.88 inches at Caribou. The mean annual temperature for the region is about 41° F. According to published records of the Weather Bureau, through 1958 the lowest mean annual temperature for any reporting station in the State is 37.2° F at Houlton.

The climate of the coastal area, which is a strip of land 12 miles wide parallel to and adjacent to the shoreline (Fobes, 1946, p. 16), is distinguished by fog, land-sea breezes, and lesser extremes of temperature than that of other parts of the State. The mean annual temperature ranges from 42.3° F at Eastport to 45.4° F at Belfast. The mean annual precipitation ranges from a high of 48.95 inches at Machias to a low of 35.98 inches at Eastport. The mean annual precipitation at Portland is 41.78 inches. The long-term mean precipitation for the region is about 45 inches. Figure 1 shows the average distribution of precipitation by months at Portland.

The region between the coastal area and northern Maine is characterized by relatively high temperatures during the summer. Temperatures as high as 105°F have been recorded at Gardiner and North Bridgton. Precipitation during the summer frequently occurs as thundershowers. The mean annual precipitation and temperature at stations in this area vary, but representative mean annual temperatures are 43.5°F at Orono, 45.0°F at Gardiner, and 43.8°F at Rumford. The mean annual precipitation at these same stations is 37.44, 43.16, and 39.63 inches, respectively.

Long winters, fog, and occasional local floods are undesirable features of Maine climate, but the State on the whole benefits from the lack of the prolonged droughts, dust storms, tornadoes, and widespread floods which plague some parts of the United States.

GEOLOGIC HISTORY

The geologic history of Maine includes invasions and retreats of the sea, deposition of sediments, erosion of land masses, mountain building and volcanism, and glaciation. The rocks of Maine and the configuration of the land surface are a result of these processes. The character, distribution, and structure of the rocks determine the occurrence of ground water in the State.

The oldest known rocks in Maine are of Precambrian age and are more than 600 million years old. They consist of gneiss and schist

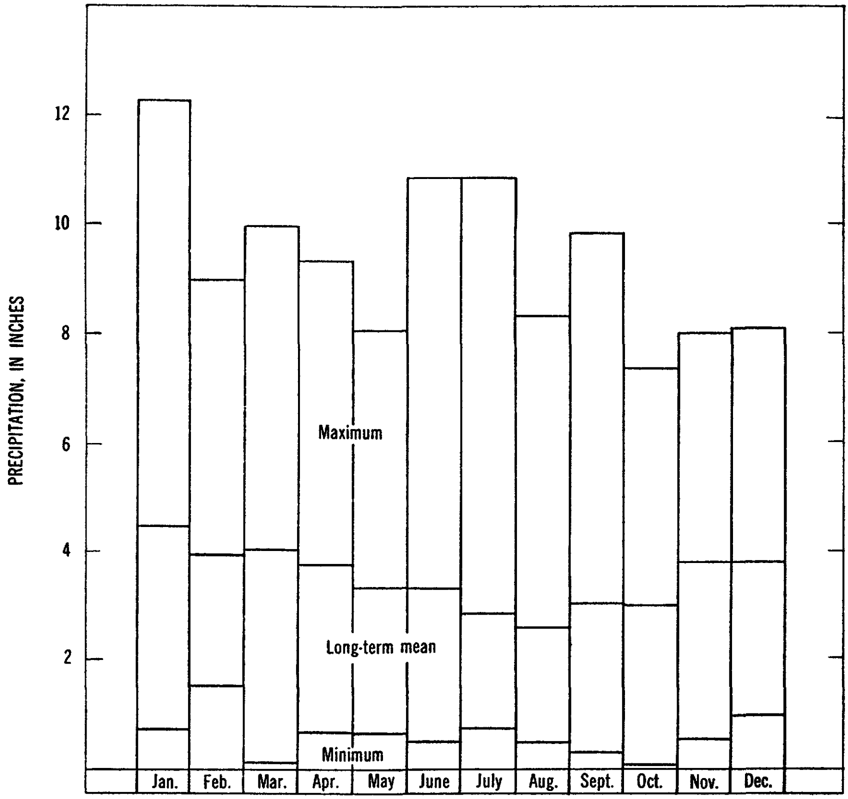

FIGURE 1.—Monthly maximum, minimum, and long-term mean precipitation at Portland.

and some slate and recrystallized limestone that represent sedimentary rocks highly altered by heat and pressure. Precambrian formations in Maine also include some igneous rocks, mostly granite (Leavitt and Perkins, 1935, p. 6).

Rocks ranging in age from Cambrian to Mississippian (about 600 to 300 million years old) also are primarily former sedimentary deposits, which were laid down under marine conditions. After deposition the formations became lithified through compaction and cementation; beds of sand became sandstone; clay became shale; silt became siltstone; and calcareous deposits became limestone.

These bedrock formations were uplifted, folded, and metamorphosed to some degree by heat, pressure, and hydrothermal action. Much of the sandstone was converted to quartzite; shale and siltstone were altered to argillite, slate, phyllite, or schist; and limestone was altered to marble. The heat and pressure of numerous igneous intrusions of granitic and other coarsely crystalline rocks and the hydrothermal solutions associated with these intrusions caused much of the metamorphism. Volcanism resulted in flows of rhyolitic and diabasic lava. Basalt dikes pentrated consolidated rocks of all ages, particularly in the coastal region.

From Mississippian time to the beginning of the Pleistocene epoch (about 1 million years ago), erosion was the dominant geologic process, and any sediments that previously might have been deposited during temporary advances of the sea were removed. At the beginning of the Tertiary period, about 60 to 70 million years before the Pleistocene glaciation, the land surface of Maine ranged from nearly flat to gently undulating (Leavitt and Perkins, 1935, p. 10–11). The monotony of the surface was interrupted at places by low hills, such as Mount Katahdin, of resistant rock. During the Tertiary period the land was uplifted and tilted southeastward. Drainage systems were rejuvenated and the present main lines of drainage were established throughout the State. Uplift was intermittent and reached a climax shortly before the end of the Tertiary. The land surface then was much higher relative to sea level than it is now; for example, in the vicinity of Eastport, a channel that must have been at or above sea level during the Tertiary is now 400 feet below sea level (Upson, 1954, p. 294).

Although many of the State's major topographic features were formed during the Tertiary period, they, along with the drainage pattern, were modified during the succeeding Pleistocene epoch. Four major ice advances have been recorded in North America since the beginning of the Pleistocene epoch, but deposits of glacial origin in Maine are usually attributed to the last major advance and retreat of the ice (Leavitt and Perkins, 1935, p. 178). However, sediments at New Sharon represent an older stage of glaciation (Caldwell, 1959, p. 22, 23). During the last advance, the entire State, including high points such as Mount Katahdin, was covered by ice that moved down from the north. The maximum thickness of the ice may have been as much as 10,000 feet.

As the ice slowly advanced, it picked up loose soil and rock and planed off the tops of hills. The material so picked up was sometimes carried for great distances. Some of the material later was deposited directly from the ice as till, an unstratified mixture of sand, gravel, clay, and rock fragments. Till is widespread in Maine and occurs as a sheet of variable thickness that covers the bedrock in much of the State; it is exposed at numerous places in the upland areas, but it is concealed by younger deposits at most places in the valleys.

As the glaciers melted back, streams were formed by the melt water. These streams picked up and transported large amounts of sediments derived from the soil and rock materials in the ice. The sediments in turn were deposited generally in layers by the melt-water streams in channels in or beneath the ice, between the ice and adjacent valley walls, at places where the streams issued from the glacier, and in the ice-free valleys and lowlands beyond the glacier terminus. The deposits of these streams have distinctive landforms, which include eskers (the familiar snakelike ridges of gravel often referred to in Maine as "horsebacks"), crevasse fillings, kames (irregular hills of sand and gravel), kame terraces, deltas, and outwash plains. Many of these landforms are favorable places for wells. In this report all stratified (layered) materials deposited by glacial streams will be termed "outwash."

End moraines, ridges formed of sediments deposited at the terminus of the ice sheet, also are found in Maine. Where the ice ended in standing water, the deposits forming end moraines may be stratified and deltaic in structure, but where the ice did not terminate in water the morainic deposits may be composed predominantly of till. The end moraines in Maine do not represent the maximum extent of the glacial advance but, rather, halts in the recession of the ice front.

Some preglacial drainageways were blocked by glacial debris, and postglacial streams had to find new routes. For example, the preglacial Androscoggin River did not flow between the towns of Brunswick and Topsham over solid rock as does the present Androscoggin; the preglacial river probably flowed more directly to the sea through a channel now buried. Many of Maine's present lakes were formed by the damming of preglacial valleys.

Because of the great weight of the ice, the land underneath subsided. The subsidence amounted to several hundred feet. When the ice melted and the released water flowed to the sea, the land rose again. However, for a time the sea rose at a faster rate than the land surface, and much of the present coast was submerged. Deposits of late-glacial or postglacial marine clay occur in the seacoast area, in the Kennebec Valley as far north as Bingham, and in the Penobscot Valley as far north as Lincoln. At Moscow, about 6 miles north of Bingham, the surface of a delta formed where a glacial stream flowed into the sea is now 460 feet above mean sea level (Leavitt and Perkins, 1935, p. 200). This fact indicates that a net movement—presumably mostly uplift of the land—of 460 feet has occurred in this area since the retreat of the ice. In southwestern Maine and perhaps in other coastal areas, the ice readvanced after the withdrawal of the sea and outwash from the glacier front was deposited above the marine clay.

Since the postglacial uplift of Maine the cycle of erosion has continued as rivers and streams have been lowering their valleys toward new base levels. Some streams, which flow partly in valleys filled with glacial and marine deposits, such as the Saco near Fryeburg and the Little Androscoggin near South Paris, have reached their grades and are now swinging in meanders and terracing their valley sides. Others which flow over bedrock are still incising. In local areas the wind is active and sand dunes or sand plains are being formed. The sea is actively eroding in some places and depositing in others. Deposits of peat and muck are being formed in some of the swamps.

GROUND WATER

SOURCE AND OCCURRENCE

For practical purposes the source of all moisture is water from the oceans. The amount of water in the ocean may change from time to time, as when vast amounts were stored in the great glaciers that covered a large fraction of the earth's land surface during the Pleistocent epoch. However, the net amount of water available for use by man generally can be considered to be about constant. Through a complex pattern of evaporation, precipitation, and runoff, the same water is used again and again. The natural cycle by which water is circulated, purified, and made available for reuse is commonly known as the hydrologic cycle.

In the course of the hydrologic cycle, which is illustrated diagrammatically in figure 2, water is evaporated from the ocean and other

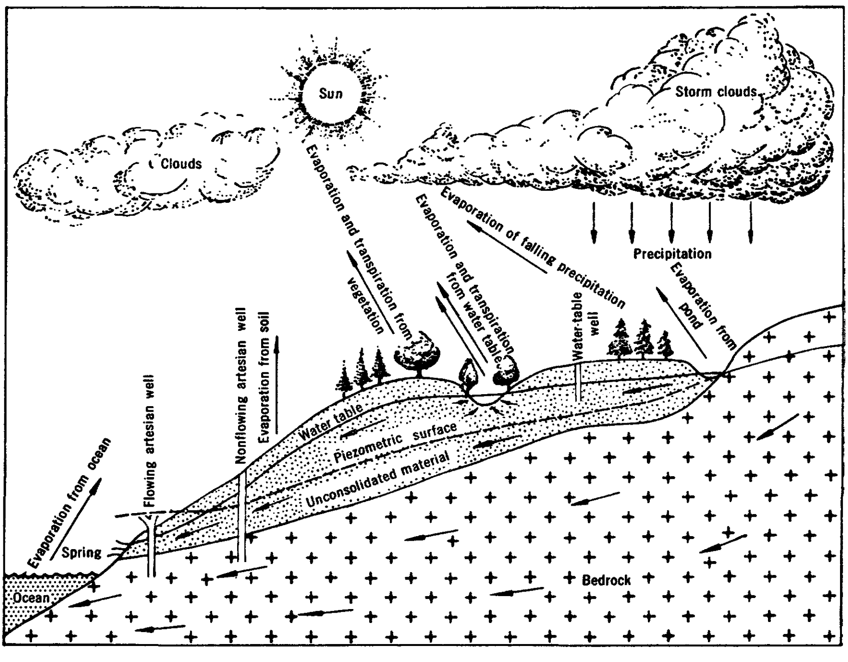

FIGURE 2.—The hydrologic cycle.

water bodies and from the land and vegetation. The water is carried upward into the atmosphere as vapor and is later returned to the earth as some form of precipitation. Of the rain falling to earth, part falls on bodies of water, part runs off immediately in streams, part soon returns to the atmosphere by evaporation, and the remainder seeps into the soil. Of the fraction seeping into the soil, some may evaporate, some may be consumed by plants in the growth process and either be retained or returned to the atmosphere by the process known as transpiration, and some may percolate through the soil and underlying formations to the zone of saturation—the zone below which all permeable rocks are saturated with water under hydrostatic pressure—to become ground water. Of the ground water, some may be pumped out, some may issue as springs, some may be consumed by growing vegetation or may evaporate in areas where the water table is near the land surface, and some may flow into streams or ponds or into the sea. The ground water that seeps into stream channels sustains the flow of streams during periods of low rainfall.

During the winter, most of the precipitation in Maine is in the form of snow, and moisture is stored until spring when the snow melts; the released water runs off, sinks into the ground, or returns to the atmosphere as water vapor.

All water below the surface of the ground is called subsurface water (Meinzer, 1923, p. 38). Suspended subsurface water is held in the soil or underlying materials by capillarity or adhesion or is moving downward toward the zone of saturation. Ground water is the part of subsurface water which is in the zone of saturation and which is recoverable from wells or springs.

Ground water may occur under either water-table or artesian conditions. Under water-table conditions the top of the zone of saturation (the water table) is at atmospheric pressure, and water generally will not rise in a well above the level at which the water is reached. Artesian conditions prevail when the ground water is confined under pressure by an overlying impermeable body. Under artesian conditions, water will rise in a well above the level at which the water is reached but a well tapping such an aquifer need not flow to be termed an "artesian" well. Where the water in an artesian aquifer is confined by overlying impervious or relatively impervious beds, there is no free water surface or water table; instead there is postulated an imaginary surface called the piezometric surface, which coincides with the level to which the confined ground water would rise in wells. Figure 3 illustrates conditions favorable for the development of artesian wells.

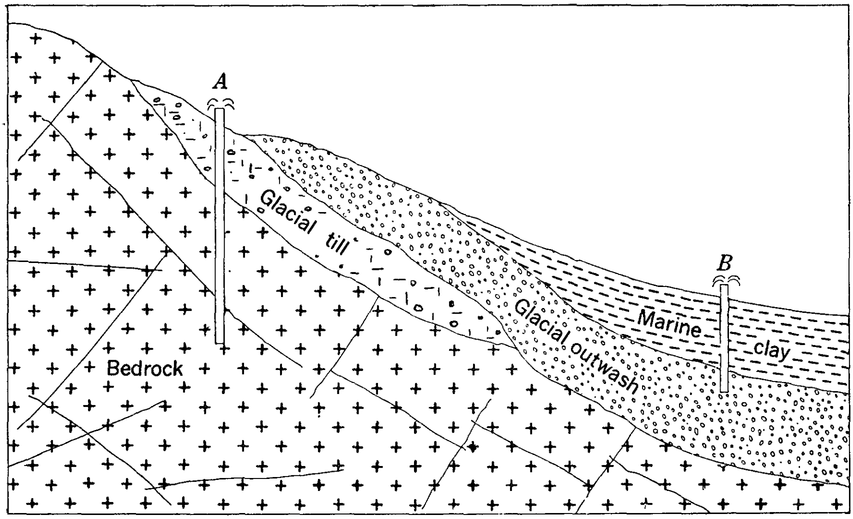

FIGURE 3.—Diagram illustrating conditions favorable for the development of artesian wells. In well *A*, water is obtained from cracks in bedrock. In well *B*, water is obtained from sand and gravel and is confined above by marine clay and below by bedrock. In both wells the intake area of the water is at a higher altitude than the land surface at the well, so the well flows.

Ground water in Maine occurs in the bedrock formations and unconsolidated deposits. The unconsolidated deposits of glacial outwash are the source of the largest volumes of ground water in the State.

GROUND WATER IN BEDROCK

The bedrock formations in Maine principally consist of igneous and metamorphic rocks, but they include some virtually unaltered sedimentary rocks. The igneous and metamorphic rocks are granite, pegmatite, rhyolite, diabase, gneiss, schist, phyllite, argillite, slate, quartzite, and marble. The sedimentary rocks include limestone, sandstone, conglomerate, and shale. Figure 4 shows general outcrop areas of the different ages and types of bedrock.

The consolidated rocks (bedrock) are dense and store little water compared to their total volume. They generally contain recoverable ground water only in secondary openings such as fractures, cracks, bedding planes, and solution openings. These secondary openings are neither uniformly spaced nor of uniform size. As a result, the capacity of the rock to store and transmit water differs from place to place. Therefore it is virtually impossible to predict accurately the depth at which water-bearing fractures will be found and how much water will be available (fig. 5). During the present study, information was collected on approximately 1,200 wells drilled in bedrock. Of these about 90 percent obtained sufficient water for farm or rural home use within a depth of 200 feet. The depth of the wells ranges from less than 50 to about 1,000 feet. (This depth was recorded for an unsuccessful well.)

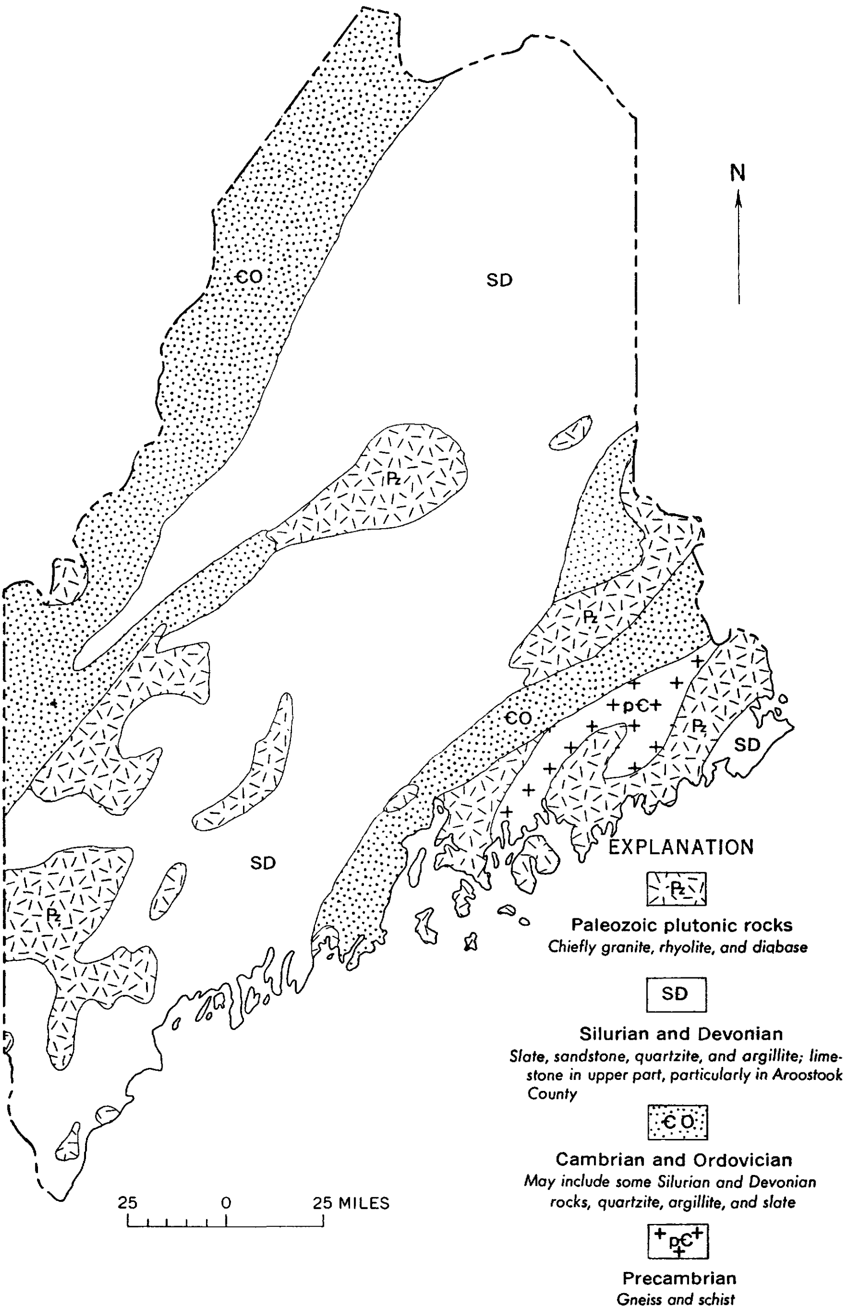

FIGURE 4.—Generalized geologic map of the bedrock formations in Maine. (After Billings, 1956, fig. 1.)

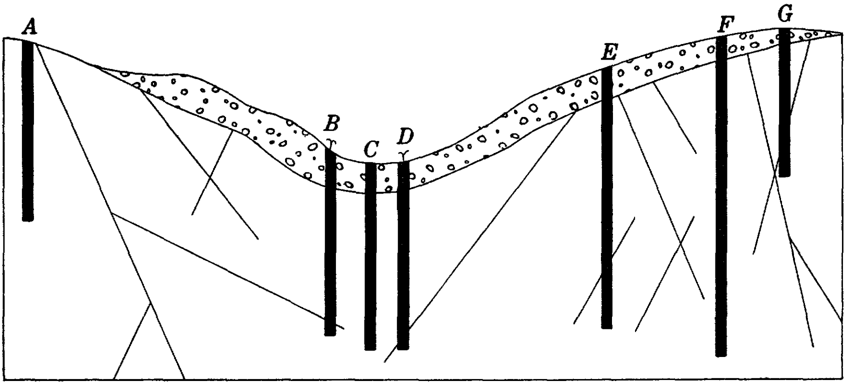

FIGURE 5.—Diagram illustrating how a well in jointed rock such as granite may meet or miss water-bearing zones. Wells *A*, *C*, and *F* penetrated no water-bearing cracks and produced no water. Well *E* penetrated a crack that was dry and produced no water. Wells *B* and *D* struck water under sufficient head (pressure) to flow at the surface. Well *G* obtained water that, though under artesian head, did not flow.

According to a study by Clapp (1911b, p. 44) the chances of drilling a successful well in granite in Maine decrease greatly below 200 feet, because rock fractures tend to be smaller and fewer in number with increasing depth. In general this relation holds true for all types of dense, hard rock but, for different types of rock, there will be a variance in the depth at which it is more economical to move to another site than to continue to greater depth in a given hole. Many wells deeper than 200 feet obtained abundant supplies from slate and schist (Clapp, 1911a, p. 34).

In the limestone areas of Aroostook County, the success or failure of a well apparently has little relation to its depth. At least two wells drilled at Loring Air Force Base obtained substantial amounts of water below 500 feet but several wells deeper than 700 feet were considered failures. The largest reported yield of any bedrock well for which information was obtained during this study was 560 gallons per minute (gpm) from a well only 300 feet deep at Loring Air Force Base. Probably in the limestone, as in other types of bedrock, there is a depth (perhaps of about 500 feet) beyond which further drilling would be less economical than drilling at a different site.

The ground-water potential differs considerably from one rock type to another. The beds of limestone in Aroostook County yield more water than other bedrock aquifers in the State. They are thin bedded and shaley and contain many openings that have been enlarged by the dissolving action of water. More than 500 gpm has been obtained from individual wells in limestone in Aroostook County, although yields of that magnitude are exceptional and 50 gpm or less is typical. The limestone beds of the Rockland-Thomaston area, on the other hand, have been recrystallized by metamorphism, and many of the original openings have been closed; hence, yields from wells in limestone in that area are smaller than those in Aroostook County.

Yields from wells in other bedrock types range from less than 1 to as much as 100 gpm, depending on the number and size of the water-filled fractures intercepted by the wells. Wells that yield as much as 100 gpm are rare, but wells that yield no water also are relatively rare. The yield of about 20 percent of the nearly 1,200 wells for which information was collected was 10 gpm or more. The yield of few wells was less than 3 gpm.

Water in bedrock in Maine generally is under artesian conditions, except perhaps in recharge areas where the water is at shallow depth. In many wells that are virtually dry after drilling has proceeded 100 feet or more, when water-bearing fractures or strata are at last penetrated, water may rise to within a few feet of the surface or may even flow at the surface.

GROUND WATER IN UNCONSOLIDATED DEPOSITS

The unconsolidated deposits that overlie the bedrock in Maine consist principally of glacial drift, which includes till and outwash, and marine clay. Other less extensive deposits are alluvium in the channels of some of the streams, peat and muck in swamps, and beach deposits and dune sand in coastal areas.

Ground water in unconsolidated deposits occurs in openings between the constituent grains. Permeability, a measure of the capacity of a material to transmit water, and porosity, a measure of its capacity to store water, are determined chiefly by grain size, sorting, and packing; permeability and porosity vary considerably according to the type of material. In general, the permeability of coarse-grained materials such as sand and gravel is large, especially if the materials are well sorted. In contrast, the permeability of fine-grained materials, such as silt or clay, is small, even though they may be very porous. As a consequence of these differences in permeability, the water-bearing characteristics of unconsolidated deposits in Maine differ widely.

Till is a poor aquifer. Although till may be fairly porous, the poor sorting and usual high percentage of fine materials render it rather impermeable, and water moves through it very slowly. Many shallow dug wells obtain water from till, but their yields are small and usually inadequate. Failures caused by declining water levels during dry periods are common.

Marine clay also is a poor aquifer. Although clay may be saturated, it yields little or no water to wells because of the smallness of its pores. Where it contains interbedded layers of sand, it may yield moderate quantities of water from them. At some places, clay overlies beds of sand and gravel and tends to confine the water contained in them under artesian pressure.

The best unconsolidated aquifers in Maine are coarse-grained deposits of glacial outwash. Normally these deposits have a high permeability; they yield as much as 1,250 gpm to gravel-packed wells. However, individual aquifers of sand and gravel in Maine are of small areal extent, and unless they are in contact with a source of recharge, such as a river or other body of surface water, the sustained yield may be substantially less than the short-period yield. The general location of the principal deposits of outwash are shown in figure 6. The outcrop areas of these deposits are favorable sites in which to explore for large supplies of ground water.

Alluvium, swamp deposits, dune sand, and beach deposits generally are thin and overlie bedrock, glacial drift, or marine clay. Locally they may yield small quantities of water to wells, but they are not major sources of ground water.

RECHARGE, MOVEMENT, AND DISCHARGE

Ground-water recharge is the addition of water to the ground-water resorvoir. All ground water available to wells and springs in Maine is derived from precipitation, principally within the State and to a lesser extent in nearby areas of New Hampshire and the Provinces of New Brunswick and Québec. As already indicated (p. 14), the total precipitation is not available for ground-water recharge because of evaporation, transpiration, and surface runoff. Surface runoff occurs where rain falls on solidly frozen ground or on solid rock; it also takes place where an aquifer is fully saturated and cannot accept additional recharge or when the infiltration capacity of the soil is exceeded. Steep slopes increase the rate of surface runoff, and clayey soils permit more runoff than do sandy soils. A suitable vegetative cover reduces the velocity of surface runoff and affords a better opportunity for water to penetrate the soil. However, reducing the rate of runoff may result in increased evapotranspiration losses and no real gain to ground-water recharge.

All water that enters the soil does not find its way to the zone of saturation. Soil-moisture deficiencies first must be overcome. These deficiencies are caused by the evaporation of water from the soil and by the absorption of water by plants and its subsequent discharge to the atmosphere by transpiration. According to Paul W. Bean, Chief Engineer for the Union Water Power Co., more than 60 percent of precipitation in Maine is lost during the summer through evapotranspiration (oral communication, June 1958). A report by Thornthwaite and others (1958) indicates that summer evapotranspiration may be even higher. When the amount of water in the soil exceeds the amount being used by evapotranspiration and exceeds the amount that can be held by the capillary forces opposing the pull

FIGURE 6.—Map of Maine showing the general location of the principal deposits of glacial outwash. (Based on "Glacial Map of the United States East of the Rocky Mountains", published in 1959 by the Geological Society of America.)

of gravity, the excess water moves downward toward the saturated zone. Rains that would produce no recharge during the growing season will produce recharge and cause a rise of the water table during the fall when vegetation is dormant. In Maine the water table commonly declines during the summer and rises again in the fall at the end of the growing season.

Ground water moves laterally through small openings in rocks from high points of the water-table or piezometric surface to low points. In artesian aquifers the direction of flow may be upward in some places in the same manner as water is forced upward through pipes under pressure, but the flow is always in the direction of hydraulic gradient.

In a humid area, such as Maine, the water table in unconsolidated deposits normally slopes toward bodies of surface water; hence, ground water continually moves toward and discharges into bodies of surface water. An exception occurs when high stream levels cause local reversal in ground-water flow; surface water then moves into the materials bordering a stream to be stored temporarily. A considerable amount of temporary or "bank" storage occurs along the Saco River in the vicinity of Fryeburg during periods of high river level.

The reversal of the normal ground-water movement may be significant where a well obtains water from sand and gravel deposits adjacent to a body of surface water. When the well is pumped, some of the ground water moving toward the stream will be intercepted. If pumping is continuous and the yield of the well sufficiently large, the cone of depression caused by the pumping may extend to the stream; if such a depression occurs, the normal movement of ground water is reversed thereby and some water then moves from the stream into the aquifer (fig. 7). In recent years wells for public supply in Maine have been drilled in sand and gravel deposits adjacent to bodies of surface water to take advantage of a permanent and dependable source of recharge.

Bodies of surface water also may serve as sources of recharge to bedrock aquifers, particularly where a stream flows over fractured bedrock. Water entering the openings in the rock may move downward or laterally, under the influence of gravity and following the lines of least resistance, until it reaches the saturated zone. Thence it will move in the direction of the hydraulic gradient toward areas of discharge. Obviously, if the pressure of water in the fractures is greater than the pressure of water in the stream, water will move into the stream, rather than conversely.

Ground water is discharged naturally by evaporation and transpiration, by seepage into streams and other bodies of surface water, by

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movement into other aquifers, by springs and seeps, and by wells and other works of man.

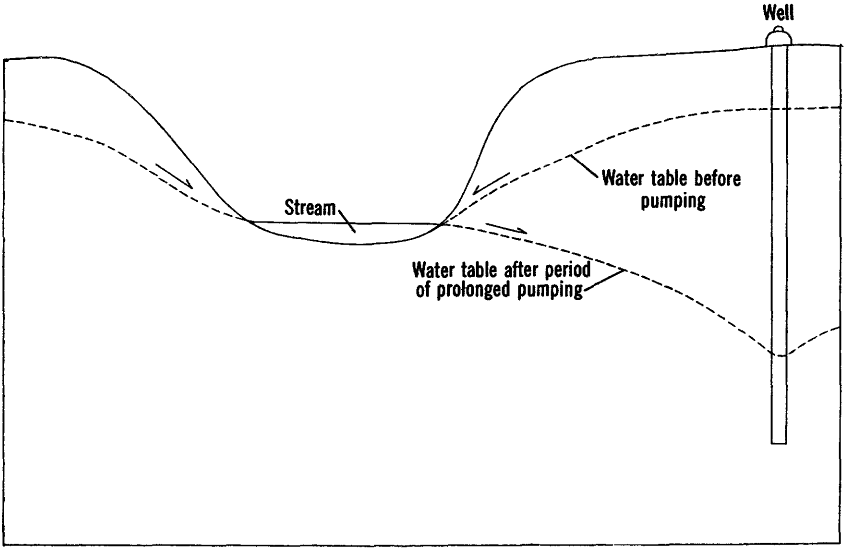

FIGURE 7.—Diagram showing how recharge may be induced from a stream by a well near the stream.

The discharge of ground water by evaporation and transpiration is large in areas where the water table is close to the surface, as it is in many places in Maine. The roots of vegetation extend to the water table or to the capillary zone overlying the water table and may withdraw large amounts of water. Where the water table is shallow, water will be lifted by capillarity so that it can evaporate directly from the soil.

Ground water is discharged by springs and seeps where the water table intersects the land surface. Seeps usually form marshy or swampy areas, commonly at a break in the slope of the land surface. Springs are similar to seeps, but generally are points of concentrated discharge of ground water. The flow from a seep may be increased by excavation to concentrate the flow. The flow of some springs and seeps is so small that during the summer the water is consumed almost entirely by evapotranspiration; the presence of the springs and seeps may go undetected until the end of the growing season when the entire flow cannot be evaporated or transpired and wet spots or pools of water may appear. The flow of springs in Maine ranges from less than one to more than a hundred gallons per minute. Springs are used extensively for farms and rural homes and for public-water supplies, particularly in some of the smaller communities.

A considerable amount of ground water in Maine is discharged into lakes, streams, and the ocean. During dry weather the flow of unregulated streams is maintained almost entirely by ground-water discharge. Points of concentrated discharge into ponds are easily detected by swimmers because of the coldness of the issuing ground water.

Some ground water is discharged from bedrock aquifers to unconsolidated deposits or from unconsolidated deposits to bedrock aquifers. Discharge from bedrock to unconsolidated deposits would occur where, for example, precipitation on a hilltop filtered into the soil and underlying rock and percolated downward and laterally until it was near the level of the valley below. If permeable beds of glacial gravel lay next to the bedrock hill, ground water issuing from cracks in the rock might enter the gravel.

In many places, where water-bearing unconsolidated materials overlie fractured bedrock, ground water may discharge from the unconsolidated aquifer into the underlying bedrock.

Ground water also is discharged by wells and other works of man, as from the mines and quarries at Monson and Thomaston where excess ground water must be drained to permit continued operation. In some construction activities, dewatering must be done. The base underlying the asphalt or concrete of roads should consist of permeable materials that will allow water to drain out if freezing of the water and subsequent heaving or cracking of the road are to be averted. Drainage works for agricultural purposes also discharge excess ground water.

FLUCTUATIONS OF WATER LEVEL IN WELLS

The water level in most wells fluctuates almost continually. Among the common causes of fluctuation are changes in the ratio of recharge to discharge and changes of atmospheric pressure. Under certain conditions, ocean tides, earth tides, earthquakes, or the movement of railroad trains also may produce fluctuations of water levels.

Changes in the ratio of ground-water recharge to discharge are reflected by changes in water levels in wells. Recharge by precipitation is intermittent, whereas discharge is continuous, though varying. When recharge exceeds discharge, the water stored in an aquifer increases. This increase is reflected by a rise in water level and eventually by an increase in discharge. When discharge exceeds recharge, the water level declines and discharge eventually decreases.

Figure 8, which shows graphically the long-term record of the water level in three observation wells in Maine, indicates no long-term trend of the water level, either up or down, in areas of little or no pumping; in these areas storage has remained relatively constant during the period of record.

The typical seasonal fluctuations of the water table in five wells are shown in figure 9. The highest water levels, which indicate maxi-

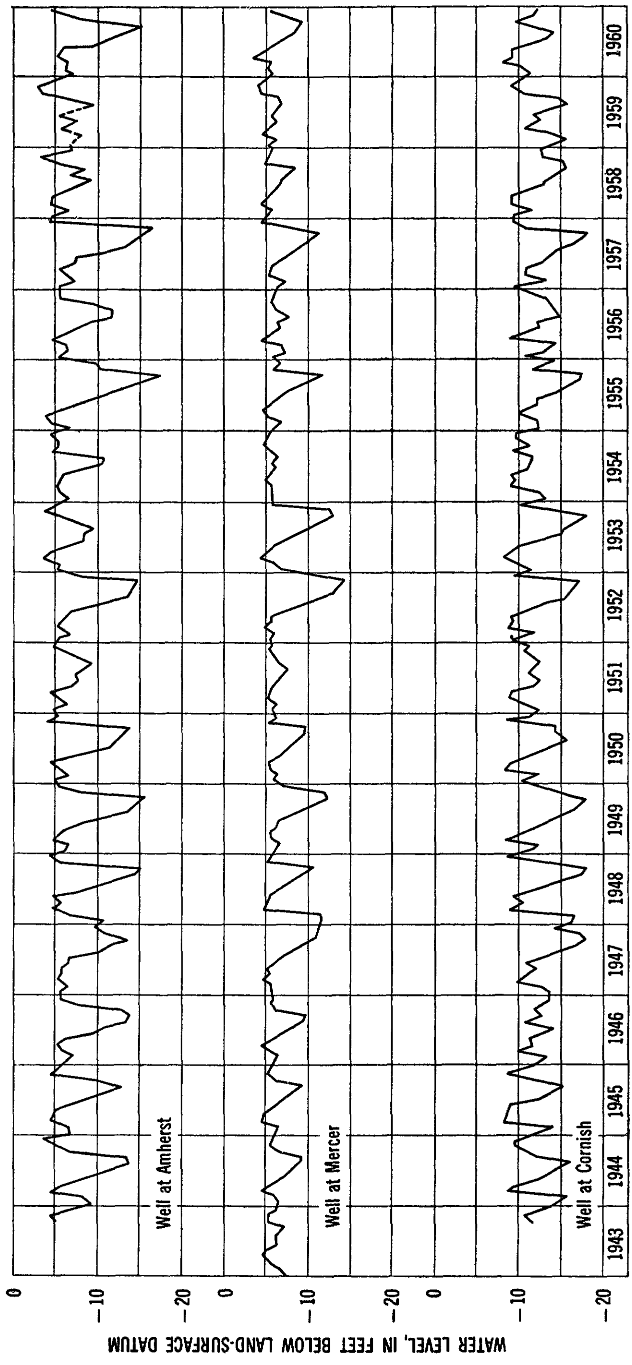

FIGURE 8.—Representative hydrographs showing water-level fluctuations in Maine.

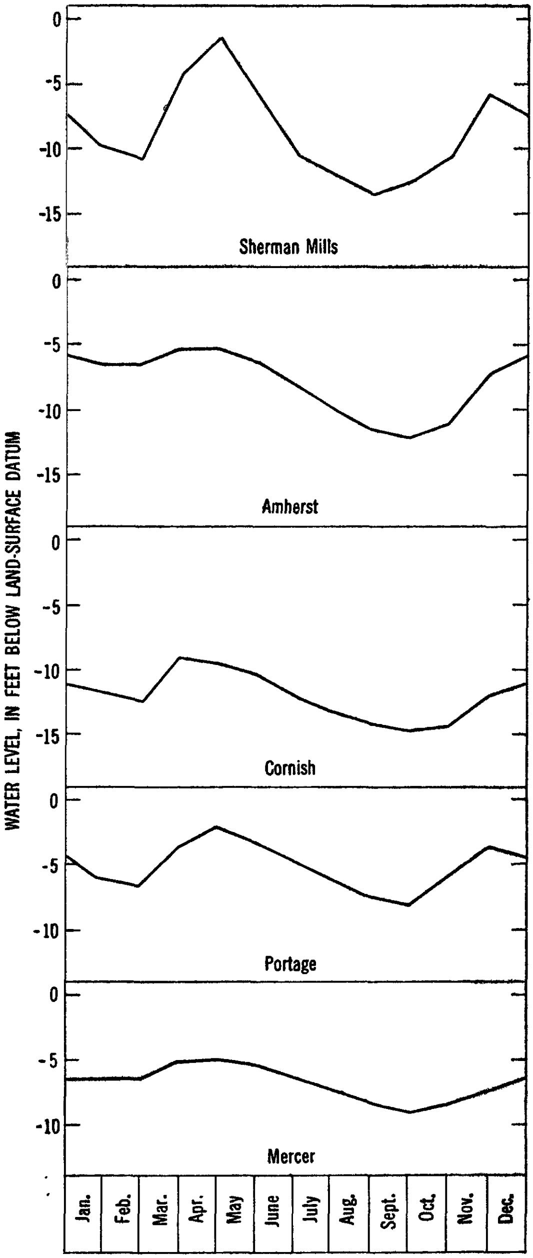

FIGURE 9.—Diagram showing average month-end water levels in five key observation wells for the period 1943–58.

mum storage, are reached in the spring as the result of recharge from snowmelt and spring rains. Storage decreases from late spring to early fall, when most of the precipitation is evaporated or used by growing vegetation. During the late fall, at the conclusion of the growing season, recharge again exceeds discharge; consequently, water in storage increases and water levels rise. During the winter, when the ground is generally frozen and precipitation is snow, ground-water storage again decreases.

RECOVERY OF GROUND WATER

SPRINGS

The use of springs for domestic and public water supplies is fairly common in Maine. Of the 79 public-water systems using ground water that reported to the Public Utilities Commission in 1957, 19 used springs for the entire supply and 14 obtained part of the supply from springs. The springs used for public supply are generally in wooded areas away from sources of contamination. They are dug out and enlarged to provide storage space, lined with concrete or rocks, and covered. Some of these springs are situated advantageously with respect to the towns they serve, in that the water flows by gravity directly from the source to the points of use; others flow by gravity and siphonic action; still others, which lie at a lower elevation than the points of use, must be pumped.

Most of the small springs used for domestic purposes have been improved by being lined with cement or rocks and covered, but many are uncovered and are subject to contamination.

Springs occur under a variety of geologic conditions. Some issue from bedrock, some from till, and others from outwash. One of the most productive springs seen during the study, "Boiling Spring" in the town of Dayton, issued from outwash sand where an overlying layer of clay, which confined the water under pressure, was breached.

WELLS

Principles of recovery—When water is standing in a well, equilibrium exists between the pressure of water within the well and the pressure of water outside the well. When water is pumped, the pressure inside the well is reduced and water flows into the well from the surrounding aquifer. Continued withdrawal results in the formation of a cone of depression in either the water table or the piezometric surface; the apex of the cone is at the well. The radius and depth (drawdown) of this cone is determined by the rate of pumping, the length of time the well is pumped, and the capacity of the formation to store and transmit water. If, during pumping, enough water is not diverted from previous points of discharge to supply the well, the water level continues to drop until the pump ceases to operate effectively and the rate of pumping is reduced. When pumping ceases, the cone of depression gradually fills until equilibrium is again reached and the water is at approximately the original level.

The capacity of a well is defined as the maximum rate at which the well will yield water after the pumping water level becomes approximately stabilized, and is generally expressed in gallons per minute. The specific capacity of a well (its rate of yield per unit of drawdown) is determined by dividing the capacity in gallons per minute by the drawdown in feet. The specific capacity of wells in Maine ranges from much less than 1 gpm per foot for some of the rock wells to more than 250 gpm per foot for some of the large-diameter gravel-packed wells used for public supply.

Dug wells.—Dug wells are wells that have been excavated, usually with pick and shovel, but in some instances by power machinery. The wells are ordinarily 3 to 4 feet in diameter and are cased with stone, concrete, tile, iron, or steel. Dug wells in Maine obtain water from unconsolidated deposits, particularly till, or from the top few feet of bedrock. Usually they are not deep because the water table is close to the land surface and because it is difficult to deepen them once water is struck. Dug wells that tap only a few feet of poorly permeable water-bearing material frequently go dry by late summer.

Driven wells.—Driven wells are constructed by driving a pipe, usually equipped with a screened drive point at the bottom, below the water table. This type of well is effective where the water level is not deep and where the aquifer is sandy.

Jetted wells.—Some shallow wells in unconsolidated materials in Maine are constructed by the jetting or washing method. This method employs a stream of water under pressure to wash a hole in the ground; the hole is then cased with 2- to 2½-inch pipe. A cutting bit may be used to help in getting through hard layers, but bedrock or boulders cannot be penetrated. For best results, a perforated section of pipe or screen is installed opposite the best water-bearing material. In a variation of this method, a casing equipped with a drive shoe is driven into the ground and at intervals of about 5 feet the materials penetrated are washed out. Several water districts have jetted wells. The jetting method is also used by some of the well-drilling companies in testing for favorable sites for gravel-packed wells.

Drilled wells.—Drilled wells are used where it is impossible or economically infeasible to obtain the desired quantity of water from other types of wells, or where water available from unconsolidated deposits to shallow dug wells is of inferior quality. Most of the drilled wells in Maine have been constructed by the cable-tool method, though since 1958 several drillers have purchased rotary equipment.

In the cable-tool or percussion method, a portable truck or trailer-mounted machine is used. Drilling is done by the alternate lifting and dropping of a heavy bit to produce a cutting action at the bottom of the hole. The crushed material is mixed with water, which must be added during the drilling until ground water is reached, and removed by a bailer. In rock wells, casing is inserted and driven a few feet into bedrock and sometimes cemented to effect a tight seal. This action prevents water from the overlying unconsolidated deposits entering the well, and may prevent the infiltration of contaminated surface water. However, casing off the unconsolidated deposits may also prevent the entrance of large amounts of good ground water, particularly where there is permeable sand and gravel lying below the water table. A screen is sometimes set at the appropriate depth to admit such water.

Most large-diameter gravel-packed or gravel-developed wells in Maine, the type generally used for public supply purposes, also are drilled with cable-tool rigs. Ordinarily the drilling of a large-diameter well is preceded by the drilling and pumping of test wells to determine the best site for the well and to determine the depths and thicknesses of the best water-bearing zones. In one method of drilling a gravel-packed well, a blank casing is inserted to the bottom of the hole during the process of drilling. If the final casing is to be 18 inches in diameter, then the blank casing will be 24 inches or more in diameter. Next, a well screen or perforated casing is centered opposite the principal water-bearing beds, and enough plain casing to reach the surface is added. The space between the two casings is filled at least to above the top of the screen with sorted gravel of a grain size slightly larger than the openings in the screen or perforated casing and also slightly larger than the grain size of the water-bearing material. The outer casing is then withdrawn to uncover the screen and to allow the flow of water from the water-bearing material through the gravel pack. The envelope of gravel around the screen increases the effective diameter of the well and decreases the velocity of water leaving the formation. The reduction in velocity reduces the movement of fine sand into the well. The friction of water entering the well is also reduced, as are the drawdown and consequently the cost of pumping. If the formation contains sufficient coarse material, the addition of a gravel pack may not be necessary. In this event, after the well is drilled it is pumped, surged, and backwashed or otherwise developed. The development procedures bring in from the adjacent formation the fine materials, which are then pumped out; the coarse materials surrounding the screen form a natural gravel pack. A well of this type is commonly known as a gravel-developed well.

In the rotary method a cutting bit on the end of a hollow drill stem is rotated in the hole. Cuttings are removed by water circulated under high pressure down through the drill stem and up through the annular space between the stem and the sides of the hole. Because the straight rotary action is relatively ineffective in drilling in the hard rocks of Maine, rotary drills provide an additional cutting action using a system whereby compressed air rapidly raises and lowers the bit in a jack hammer fashion. In this method, cuttings may be ejected from the hole by air pressure.

Bennison (1947), Gordon (1958) and War Department Technical Manual 5-297 (1943) give additional details on the drilling and development of wells.

Methods of Lift.—Many different pumps or methods of lift of water from wells are used in Maine. The rope and bucket method, well sweeps, and endless-chain and bucket arrangements are still used in some places. Pitcher pumps may be used when water levels are within suction lift; hand- or windmill-operated cylindrical pumps are sometimes used to extract water where the depth to water exceeds the suction lift. Many domestic wells are now equipped with electrically driven pumps of the jet, centrifugal, or cylindrical variety. Most of the gravel-packed wells used for public supply or industrial purposes are equipped with deep-well turbine pumps and powered by electricity. Some deep drilled rock wells used for public supply employ cylindrical pumps. Batteries of driven well points may be connected to one common vacuum-type pump. Some of the older industrial wells have air-lift pumps.

QUALITY OF WATER

As water sinks into the ground, percolates to the zone of saturation, and travels slowly in the direction of decreasing head, it dissolves some of the minerals with which it comes in contact. The nature and quantity of dissolved solids in the water depend principally upon the chemical character of the infiltrating water, the geologic formations through which the water passes, and the rate of movement of the water in the aquifer.

The kind and quantity of soluble mineral constituents in water determine its suitability for use. The tolerance limits for various types of chemical constituents vary according to the use of the water. The limits of tolerance for different uses are described in Publication 3 of the California State Water Pollution Control Board (1957).

During the current investigation, more than 100 chemical analyses of ground water in Maine were assembled. Sixteen of these analyses are listed in table 1, and 10 analyses are shown graphically in figure 10. The major chemical constituents of the ground water in Maine are

TABLE 1.—*Chemical analyses of*

[Analytical results in parts per

Owner	Location	Aquifer	Depth of well (feet)	Date of collection	Temperature (° F)	Silica (SiO_2)	Total iron (Fe)
Androscoggin County							
Mrs. Arthur French	Turner	Sand	23	Feb. 17, 1954	41	8.7	0.22
Aroostook County							
U.S. Air Force	Presque Isle	Limestone	309	May 13, 1958	44	8.5	1.3
Do	Limestone	do	275	Aug. 2, 1957	46	13	.97
Do	do	do	650	Jan. 24, 1956	44	7.9	.04
Cumberland County							
Dielectric Company	Raymond	Granite and pegmatite.	594	Aug. 4, 1958	----	16	0.04
Portland Water District.	North Windham	Sand	18	Aug. 4, 1958	45	16	.03
Kennebec County							
Augusta Water District	Augusta	Sand and gravel	89	Mar. 27, 1957	47	13	0.02
Kennebec Motel	Vassalboro	Schist	250	Mar. 28, 1957	51	13	.09
Oxford County							
Davis Florists	Rumford	Sand and gravel	66	Apr. 9, 1953	52	12	0.06
Penobscot County							
U.S. Air Force	Charleston	Slate or schist	236	Dec. 6, 1957	----	8.4	0.04
Linden Heal	Newport	Schist or limestone	120	Apr. 9, 1953	49	8.5	.03
Piscataquis County							
Monson Spring Water Co.	Monson	Slate	272–315	Apr. 1953	----	----	[1] 1.2
Waldo County							
Brooks Water Co	Brooks			Apr. 1953	----	----	[1] 0.9
Washington County							
U.S. Air Force	Bucks Harbor	Tuff or rhyolite	170	July 30, 1958	52	14	0.05
York County							
C. W. Fernald	Eliot	Clay and sand	18	Feb. 17, 1954	45	11	0.10
L. R. Boston	North Berwick	Schist	275	Apr. 10, 1953	49	13	.06

[1] Combined values for iron (Fe) and manganese (Mn).

water from selected wells in Maine

million except as indicated]

Total manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (Residue on evaporation at 180° C)	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25° C)	pH	Remarks
Androscoggin County																
0.00	3.7	1.4	2.5	0.9	19	0	2.2	3.0	0.0	0.2	31	19	2	45	6.8	
Aroostook County																
0.08	74	14	6.0	0.5	235	0	39	13	0.0	8.8	284	242	50	467	7.0	Free CO_2, 37; Al, 0.4.
.75	85	16	18		360	0	12	7.0	.0	.2	322	278	0	550	7.6	Free CO_2, 14.
.00	41	7.6	13		148	0	22	11	.0	2.8	213	134	12	338	----	Free CO_2, 3.7.
Cumberland County																
0.00	27	4.6	8.4	0.6	91	0	12	9.0	1.4	0.0	125	86	12	198	7.8	Uraniuum (μg/1) 960±96; Al, 0.0; PO_4, 0.00. Radium 226 (μμc/1) 57±2.
.00	6.8	2.2	3.8	1.0	31	0	2.7	4.5	.1	1.4	55	27	1	70	6.6	Uranium (μg/1) 1.0±0.1; Al, 0.1; PO_4, 0.00.
Kenebec County																
0.02	45	1.6	5.5	3.6	134	2.0	12	6.2	0.0	0.7	160	119	9	258	8.4	Al, 0.0; Li, 0.2; Cu, 0.00; PO_4, 0.00; Zn, 0.00.
.00	29	9.7	35	3.6	183	.0	28	7.9	1.1	.0	225	0	112	344	8.0	Al, 0.0; Li, 0.2; Cu, 0.00; Zn, 0.12; PO_4, 0.00.
Oxford County																
0.00	10	2.0	5.0	3.8	30	0	12	6.6	0.0	4.8	79	33	9	106	6.6	Al, 0.3; Zn, 0.00; Cu, 0.00; Li, 0.0; PO_4, 0.00.
Penobscot County																
0.00	26	9.5	1.6		102	0	10	8.5	0.1	1.1	118	104	21	213	6.3	Free CO_2, 81.
.00	73	7.0	23	5	118	0	25	68	.1	57	328	211	114	586	6.9	Al, 0.2; Zn, 0.00; Cu, 0.00; Li, 0.0; PO_4, 0.3.
Piscataquis County																
(2)	4.8	1.6	3.7	1.4	----	----	5.8	Trace	Trace	Trace	46	20	----	----	6.8	Analysis by U.S. Public Health Service.
Waldo County																
(2)	7.4	1.5	5	3.6	----	----	8.0	2	Trace	0.35	48	33	----	----	6.7	Do.
Washington County																
0.08	35	3.8	20		102	0	15	32	0.1	3.0	175	108	20	287	6.8	Free CO_2, 26.
York County																
0.00	7.2	2.0	3.9	0.8	20	0	12	8.8	0.0	0.4	52	29	12	79	6.5	Al, 0.2; Cu, 0.14; Zn, 0.67; Li, 0.0; PO_4, 0.00.
.05	23	3.1	8.2	3.1	75	0	17	15	.1	1.1	129	70	9	211	7.2	Al, 1.1; Zn, 1.2; Cu, 0.00; Li, 0.0; PO_4, 0.10.

[2] See total iron (Fe) column.

described in the following paragraphs. This discussion is based on reports of the Geological Survey, especially Water-Supply Paper 1473 (Hem, 1959).

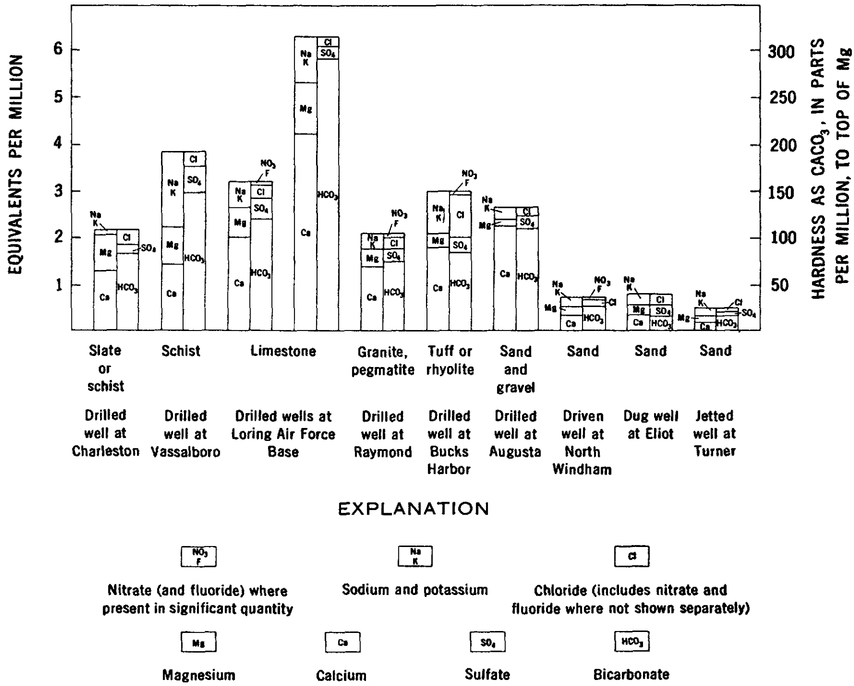

FIGURE 10.—Diagram showing chemical character of 10 samples of ground water from Maine.

The Geological Survey commonly reports water analyses in parts per million (ppm) by weight. One part per million represents 1 milligram of solute in 1 kilogram of solution. However, to help describe the composition of water and the relationships among the ions in solution another method of expressing analysis is desirable. A commonly used system is in terms of equivalents per million (epm). Parts per million may be converted to equivalents per million by multiplying the concentration of each ion in parts per million by the reciprocal of the combining weight of that ion. (The combining weight is the atomic or molecular weight of the substance.) The analyses in figure 10 are in equivalents per million.

The following table gives the conversion factors for changing from parts per million to equivalents per million for the principal ions in ground water in Maine.

Conversion factors: Parts per million to equivalents per million

Ion	Multiply by	Ion	Multiply by
Bicarbonate (HCO_3^{-1})	0.01639	Nitrate (NO_3^{-1})	0.01613
Calcium (Ca^{+2})	.04990	Sodium (Na^{+1})	.04350
Carbonate (CO_3^{-2})	.03333	Potassium (K^{+1})	.02558
Chloride (Cl^{-1})	.02820	Sulfate (SO_4^{-2})	.02082
Magnesium (Mg^{+2})	.08224		

DISSOLVED SOLIDS

When water is evaporated, the residue consists principally of mineral constituents that were in solution in the water. Water with less than 500 ppm of dissolved solids is generally satisfactory for domestic use, except for difficulties resulting from hardness, excessive iron content, or corrosiveness. Of the more than 100 water sample analyses assembled during this study, none reported a dissolved-solids content in excess of 500 ppm. The highest reported dissolved-solids content was 472 ppm in water from a limestone aquifer tapped by a deep well at Loring Air Force Base. The lowest reported dissolved-solids content was 31 ppm in water from sand tapped by a shallow driven well at Turner in Androscoggin County.

HARDNESS

Hardness of water is a characteristic commonly recognized by the increase in the quantity of soap required to produce a lather. Calcium and magnesium salts cause practically all the hardness of water, and they also are the active agents in the formation of the greater part of the scale in steam boilers and other vessels in which water is heated or evaporated. Carbonate hardness, sometimes called temporary hardness, is caused by calcium and magnesium bicarbonate and can be removed by boiling. Noncarbonate or permanent hardness is caused by sulfates, chlorides, and nitrates of calcium and magnesium, and it cannot be removed by boiling.

In water to be used for ordinary domestic purposes, hardness does not become particularly objectionable until it reaches the level of about 100 ppm. Hardness greater than this causes increased consumption of soap and incrustation of utensils. The acceptable limit of hardness for some industrial purposes is much lower than 100 ppm.

Ground water in Maine is ordinarily soft except where the aquifer consists of limestone or calcareous shale, as it does in much of Aroostook County where the water is very hard. Hardness values of water samples ranged from 8 ppm from a spring at North New Portland to 338 ppm from a deep well at Loring Air Force Base. The water at Loring Air Force Base is softened before use.

IRON

If ground water contains more than 0.3 ppm of iron, the excess generally will separate out and settle as a red precipitate when exposed to the air. Excessive iron may give a disagreeable taste and may stain cooking utensils, laundry, and bathroom fixtures. It generally can be removed from water by aeration and filtration, but some water requires additional treatment to eliminate iron.

The iron content of ground water in Maine varies considerably, and at places it is excessive. One sample of water analyzed by a private company contained 15 ppm. Many water samples contained no iron. Excessive iron in water from wells or in water in public ground-water supplies may not necessarily be characteristic of the ground water but may result from corrosion of well screens, casings, or distribution pipes. Water may be corrosive if it has a high hydrogen-ion content (pH much less than 7), excessive carbon dioxide, excess oxygen, or very low hardness. Ground water in unconsolidated deposits in Maine is generally slightly acid (pH less than 7). Water from wells tapping bedrock formations is commonly alkaline (pH greater than 7).

FLUORIDE

Fluoride is generally present in ground water in very small concentrations. Water that contains more than 1.5 ppm of fluoride may cause the mottling of the enamel of children's teeth. However, most dental authorities are now convinced that water containing about 1 ppm of fluoride will aid in the prevention of dental decay among children.

Ground water in Maine contains only small amounts of fluoride. Samples from drilled rock wells at Raymond and Vassalboro contained 1.4 and 1.1 ppm of fluoride, respectively, but most samples contained much less than this and many contained no fluoride.

The public water supplies of a number of towns in Maine are now treated with fluoride.

NITRATE

Nitrate normally occurs in ground water only in small amounts. Where high concentrations occur, the nitrate probably is being derived from the soil, fertilizer, plants, or animal wastes, and is being carried into the well either by direct flow of surface water or by percolation through the soil and rocks and into the well in the subsurface. Because cesspools, barnyards, and privies are a source of organic nitrogen, a large amount of nitrate in a well may also indicate the presence of harmful bacteria.

Aside from the possibilities of accompanying bacterial pollution, high nitrate concentrations are also undesirable because, according to a report by Comly (1945, p. 112-116), water containing more than 45 ppm of nitrate (as NO_3), if used in the feeding of infants, may cause cyanosis. In this disease, the baby becomes drowsy and listless and the skin takes on a blue color. Death may result if the water supply is not changed in time. High nitrate concentrations may also cause digestive disorders in adults.

Water from wells in the potato-farming country of Aroostook County tends to be somewhat higher in nitrate on the average than water from elsewhere in the State. The source of the nitrate is thought to be the fertilizer that is applied to the farm land. In general, the water from shallow dug wells, which may not be adequately cased and sealed, is more subject to contamination and accompanying high concentration of nitrate than water from deeper, drilled wells. However, high concentrations of nitrate in water from several deep wells suggest that at some places the water may convey the nitrate a considerable distance downward from its source.

Concentrations of nitrate in analyses obtained during this study ranged from 0.0 to 70 ppm.

RADIOACTIVITY

The ground water in an area around Panther Pond in the town of Raymond in Cumberland County is abnormally radioactive, as shown by analyses of samples collected in the winter of 1958–59. Samples of water from more than 50 wells were collected and analyzed by the Maine Department of Health, Division of Sanitary Engineering. The most highly radioactive water was from a 594-foot well at the Dielectric Co. This water contained a total activity of radon plus daughters (which are decay products of radioactive nuclides) of 583,000 micromicrocuries per liter. Subsequent samples from the same well contained 64, 57, and 45 micromicrocuries per liter of radium, respectively, which exceed the presently accepted maximum permissible concentration for occupational hazard of 40 micromicrocuries per liter set by international committee. The maximum permissible concentration of radium in water used by the general public is 4 micromicrocuries per liter. The source of the radioactivity apparently is radioactive pegmatite minerals. Uranium-bearing minerals identified from the pegmatite area that stretches from the Rangeley Lakes south to the coastal area of Sagadahoc and Cumberland Counties include uranite, autunite, monazite, and samarskite (Chandler and others, 1959, p. 19).

CHLORIDE

Ground water in Maine generally contains a few parts per million of chloride. According to a report by Jackson (1905) chloride contents are highest near the sea and decrease uniformly away from the sea, and contour lines showing equal chloride concentration are parallel to the coast. However, a recent study by MacDonald (1954) indicated that, although higher average chloride concentrations are found on the coast than in the central interior of Maine, the highest average chloride values are now found in the ground waters of Aroostook County, where the median value of a number of samples from public supplies was 9 ppm in contrast to 6 ppm for the coastal area. According to MacDonald (1954, p. 208), chloride quantities in private supplies run much higher than in public supplies. During the present study the minimum chloride value observed was 1 ppm and the maximum was 160 ppm. This high value is almost certainly the result of pollution. The high chloride concentrations in Aroostook County are probably derived from fertilizer, although they may be in part due to chlorite schist (MacDonald, 1954, p. 207). High chloride contents in Aroostook County are not necessarily accompanied by high bacterial counts, especially in deep wells, though in some places this may be so. High chloride contents do indicate that some of the surficial water is dissolving chloride from the soil zone and is percolating down to the water table. In many cases the water may have traveled sufficiently far to have become purified of bacterial contamination.

Water containing as much as 1,000 ppm of chloride may be used safely for drinking purposes, although the U.S. Public Health Service recommends that chloride not exceed 250 ppm. For some industrial purposes tolerances are much less than 250 ppm, and water having chloride in the 20-100 range may be corrosive.

If chloride contents increase with pumping in the coastal regions, it probably means that salt water is being drawn toward the well. A few occurrences of this sort have been reported for Maine. For example, in the summer of 1957, which was very dry, the chloride content of the water in a well of Northern Chemical Industries, Inc. at Searsport increased from about 6.0 ppm to 60 ppm, and it was necessary to reduce the rate of pumping to prevent the further deterioration of the quality of the water.

THE CURRENT GROUND-WATER SITUATION IN MAINE

GROUND-WATER CONDITIONS BY AREAS

The four physiographic provinces into which Maine may be divided were discussed earlier in this report; they are the Moosehead Plateau, the Aroostook Valley, the Central Uplands, and the Coastal Lowlands (pl. 1). These units are based upon geologic and topographic considerations and form a logical basis for a discussion of ground-water conditions by areas.

MOOSEHEAD PLATEAU

GEOLOGY

Only the general outlines of the geology of the Moosehead Plateau are known because of the inaccessibility of much of the area. The bedrock in the northern part is largely of sedimentary origin and consists chiefly of beds of shale, limestone, and sandstone of Paleozoic age. These formations almost everywhere are folded and in many places are metamorphosed into slate, phyllite, marble, or quartzite. Some igneous rocks, including rhyolite, granite, and diabase, crop out in this area.

In the northern part of Oxford and Franklin Counties and the adjacent part of Somerset County, igneous and metamorphic rocks, consisting predominantly of granite, gneiss, schist, diabase, and pegmatite, are most common. The entire region has been glaciated, and the bedrock is obscured in many places either by till or outwash—the till is on the hills and the outwash is in the valleys.

AVAILABILITY AND USE OF GROUND WATER

Ground water has not been developed to any great extent in the Moosehead Plateau because much of the region is uninhabited. However, where wells for domestic purposes have been drilled in bedrock, they have almost always been successful. Relatively large yields for industrial or municipal use may be obtained from some bedrock aquifers, especially limestone, and to a lesser extent, slate. Under favorable conditions, as much as 300 gpm may be obtained from wells in limestone but yields from slate probably will not exceed 100 gpm and normally will be much less. Till yields small amounts of water to dug wells in this region. No large supplies have been obtained from glacial outwash, although large amounts of water are contained in such deposits throughout the Moosehead Plateau. An indication of the potential yield from outwash is given by a well owned by the water district at Bingham, which is just below the southern border of the Moosehead Plateau. This well is pumped at the rate of 750 gpm and was initially tested at 1,200 gpm and a drawdown of only about 9 feet.

The Moosehead Plateau has few public water supplies. The only ones using ground water are at Monson, where water is obtained from two deep drilled wells in slate, at Stratton and Jackman, where part of the water comes from springs, and at Greenville, where a few houses are served by two small water companies, one having a spring, and the other a dug well as the source of water.

The only industrial well that was inventoried in the Moosehead Plateau during the course of the study—although there may be others—was at Fort Kent at the northeastern extremity of the region.

This well is reported to pump 300 gpm from a limestone aquifer; the water is used by a potato starch factory.

QUALITY OF GROUND WATER

The quality of ground water in the Moosehead Plateau varies, depending on the geologic source of the water. The water is excessively hard in the limestone areas and generally moderately soft to very soft elsewhere. The following table contains data from partial chemical analyses made by the State Department of Health, Division of Sanitation, of water from representative wells and springs in the region.

Location	Samples	Constituent	Range (ppm)	Median (ppm)
Fort Kent	16	Hardness	36 -195	111
		Chloride	1.0- 50	10.6
		Nitrate [1] (NO_3)	.1- 22	4.7
Rangeley	8	Hardness	18 - 80	40
		Chloride	1.0- 3.0	1
		Nitrate [1] (NO_3)	.0- 1.8	.26
Greenville	12	Hardness	8 -285	29
		Chloride	1.0-145	1
		Nitrate [1] (NO_3)	.1- 8.9	.18

[1] Nitrate concentrations in analyses made by the State Department of Health are in terms of elemental nitrogen (N). To convert to nitrate (NO_3), nitrate values reported by the State have been multiplied by a factor of 4.4266.

Fort Kent is in a potato-farming area and the abnormally high nitrate and chloride concentrations in the ground water probably are derived from fertilizer. The maximum values of hardness and chloride from the Greenville area were in water from a single badly polluted well.

A sample of water from a public-supply well at Monson (The Monson Spring Water Co.), which derives its water from slate, had a hardness of only 20 ppm. However, the combined iron and manganese content was 1.20 ppm, which is considerably higher than the desirable amount for domestic use and many industrial uses. Undesirably high iron contents are found in ground water in some other scattered localities in the Moosehead Plateau.

AROOSTOOK VALLEY

GEOLOGY

More is known about the geology of the Aroostook Valley than about the Moosehead Plateau because more of the county is open, there are more roads, and the low-grade manganese deposits and associated rocks have been studied from time to time. The bedrock consists principally of slate or shale, limestone, and sandstone of Silurian age. The rocks have been folded, fractured, and metamorphosed, as in the area to the west. Igneous and metamorphic rocks including granite, rhyolite, diabase, and schist crop out in places.

Glacial deposits of till and outwash occur, though outwash is perhaps less widespread here than in adjacent regions.

AVAILABILITY AND USE OF GROUND WATER

Large amounts of water—as much as 550 gpm—can be obtained from beds of limestone or calcareous shale in the Aroostook Valley, although average yields are considerably smaller, and 50 gpm or less is more typical. Wells tapping igneous rocks generally yield substantially less water than wells in limestone, but they yield enough water for household use. Outwash yields large quantities of water to a few wells and till yields small quantities to many dug wells.

More ground water is used in the Aroostook Valley than in the Moosehead Plateau. Though most of the public-water systems use surface water, four use ground water. Three—Patten, Washburn, and Fort Fairfield—depend entirely upon ground-water sources, and the fourth, Houlton, uses about 50 percent ground water. Washburn, Fort Fairfield, and Houlton derive water from sand and gravel; Patten, a smaller town whose requirements are less, obtains water from a deep rock well.

Ground water is also used to some extent for industrial purposes, principally starch factories.

During the course of the investigation, only one irrigation well was inventoried. This well, which is near Presque Isle, was reported to be capable of producing about 400 gpm from a limestone aquifer.

Until some time in 1960, when it converted to a surface-water supply, Loring Air Force Base at Limestone pumped more than 1 million gallons per day (mgd) from deep wells in limestone formations. Many of the base's subsidiary installations continue to use ground water.

QUALITY OF GROUND WATER

Ground water in the Aroostook Valley is generally more highly mineralized than in other parts of the State, and on the average it is much harder. Calcium and magnesium, the principal elements causing hardness of water, are readily dissolved from the limestone beds that underlie the region, and they are in high concentration in ground water. Bicarbonate sulfate, nitrate, and chloride are also present in relatively high concentrations. Iron and manganese locally occur in objectionable amounts.

Chemical analyses of several samples of ground water from public and military water supplies in the region show a dissolved-solids content ranging from 163 to 472 ppm. Hardness ranges from 119 to 338 ppm, and chloride content ranges from 2.0 to 103 ppm; all extreme values are for water samples from wells at Loring Air

Force Base. Few wells contained less than 10 ppm of chloride. A similar range in values for hardness and chloride is indicated by the following table (data from partial analyses of samples of domestic water made for the State Department of Health, Division of Sanitation).

Location	Samples	Constituent	Range (ppm)	Median (ppm)
Houlton	21	Hardness	56 -434	201
		Chloride	1.0-140	13
		Nitrate [1] (NO_3)	.1-199	8.9
Sherman	12	Hardness	63 -371	186
		Chloride	2.0-210	26
		Nitrate [1] (NO_3)	.0- 18	6.1
Caribou	9	Hardness	106 -350	321
		Chloride	12 -275	18
		Nitrate [1] (NO_3)	.7- 31	6.6

[1] Nitrate concentrations in analyses made by the State Department of Health are in terms of elemental nitrogen (N). To convert to nitrate (NO_3), nitrate values reported by the State have been multiplied by a factor of 4.4266.

Nitrate concentrations in water from wells in the Aroostook Valley were higher than elsewhere in the State. The nitrate probably is derived from fertilizer on the potato fields and from organic matter. The range in nitrate for 42 samples of water from wells in the Aroostook Valley was from about 0.04 to 200 ppm. For the sake of comparison, the range in nitrate in 11 representative wells in the Gardiner area in the Coastal Lowlands was from a trace to 5.5 ppm. At Dover-Foxcroft in the Central Uplands the nitrate range of 12 samples was from a trace to 11 ppm; the median was 0.13 ppm.

CENTRAL UPLANDS

GEOLOGY

The geology of the Central Uplands is diverse, and the age of formations ranges from Precambrian to Recent. The bedrock includes sedimentary, igneous, and metamorphic rocks. Slate, shale, quartzite, and argillite predominate in the eastern half of the region; granite, gneiss, schist, and pegmatite are more common in the western part. Glacial deposits, particularly outwash, are more widespread in the Central Uplands than in the Aroostook Valley region. In some areas, particularly in the major river valleys, marine clay mantles bedrock or glacial deposits. Marine clay occurs in the Kennebec Valley as far north as Bingham and in the Penobscot Valley at least as far north as Lincoln.

AVAILABILITY AND USE OF GROUND WATER

Ground water is available in small amounts from bedrock everywhere in the Central Uplands. Most wells in bedrock produce less than 10 gpm, but yields of as much as 100 gpm have been reported for some wells. Large supplies of ground water may be obtained from wells that tap beds of sand and gravel in outwash deposits, particularly where adjacent streams or other bodies of surface water furnish a dependable source of recharge. As in the other regions, small amounts of water can be obtained from wells dug in till.

This region contains more towns than do those regions previously discussed and it has more public-water supplies, many of which are obtained from ground water. Most towns obtain water from sand and gravel, but a few small towns obtain all or part of their water from deep bedrock wells. A few towns use springs. Ground water is used by industries including paper mills, tanneries, dairies, canning factories, and chemical plants.

QUALITY OF GROUND WATER

The quality of ground water in the Central Uplands differs from place to place because of the variety of geologic formations in the region, but in general the water is softer and less mineralized than that from the Aroostook Valley. For samples of ground water from 11 water companies or water districts, the range in hardness in October 1958 (analyses by the State Department of Health, Division of Sanitation) was from 12 ppm at Fryeburg to 80 ppm at Danforth. The median hardness was 44 ppm. Chloride contents ranged from 1 ppm at Danforth, East Millinocket, Bingham, New Sharon, and Farmington Falls to 29 ppm at Pittsfield; the median value was 3 ppm. Nitrate values were uniformly low. The water from Pittsfield had an iron content of 0.45 ppm, which is high enough to cause some staining of laundry and plumbing fixtures.

A sampling of partial analyses of water from some representative wells and springs used for domestic supply was obtained from the Division of Sanitation. A summary of the results of these analyses is contained in the following table.

Location	Samples	Constituent	Range (ppm)	Median (ppm)
Livermore	8	Hardness	10 -134	30
		Chloride	1.0- 41	3
		Nitrate [1] (NO_3)	.0- 66	.93
Farmington	12	Hardness	16 -149	38
		Chloride	1.0- 11	1.5
		Nitrate [1] (NO_3)	.1- 22	.89
Fryeburg	13	Hardness	6 - 70	37
		Chloride	1.0- 22	1
		Nitrate [1] (NO_3)	.0- 22	.11
Passadumkeag	11	Hardness	26 -169	48
		Chloride	1.0- 61	6
		Nitrate [1] (NO_3)	.0- 4.4	2.2
Millinocket	12	Hardness	2 - 89	18
		Chloride	1.0- 8.0	1
		Nitrate [1] (NO_3)	.0- 35	.20

[1] Nitrate concentrations in analyses made by the State Department of Health are in terms of elemental nitrogen (N). To convert to nitrate (NO_3), nitrate values reported by the State have been multiplied by a factor of 4.4266.

At Fryeburg the highest concentration of hardness, chloride, and nitrate was in water from a single polluted well, hence that sample is not representative of ground water in its natural state.

COASTAL LOWLANDS

GEOLOGY

The geology of parts of the Coastal Lowlands is well known as a result of several detailed areal studies that were made by the U.S. Geological Survey many years ago (the latest published in 1917). This region has more igneous and metamorphic rocks, consisting largely of granite, gneiss, schist, and pegmatite, and less slate and shale than the other regions of the State. A small basin consisting of sedimentary rocks (sandstone and conglomerate) interbedded with lavas exists near Perry in extreme eastern Washington County, and beds of limestone or marble occur in the Rockland-Thomaston area. Glacial deposits consisting of till in the uplands and of outwash at the lower elevations are widespread. Marine clay covers the lowlands and valley areas, in places being underneath or merging with outwash.

AVAILABILITY AND USE OF GROUND WATER

Sufficient ground water for domestic use is generally available from bedrock in this region, though some instances of failure have been noted, particularly in the shore areas. These failures may be due either to lack of water or to contamination by salt water. Yields of as much as 100 gpm have been reported, though the higher yields are exceptional. The yields from slate, schist, and limestone generally exceed those from granite or gneiss.

Large quantities of ground water are available in many areas from glacial deposits of stratified sand and gravel, and small quantities are available from till.

Ground water is used to a considerable extent for public supply purposes in the Coastal Lowlands. Several small towns, including Kezar Falls, Waldoboro, Port Clyde, and Warren, are supplied at least in part by ground water from rock wells. Many towns, including Sanford, Augusta, Gardiner, Belfast, Lubec, and Calais, derive large amounts of water from wells in sand and gravel deposits. Several small towns such as Cherryfield, Gray, Searsmont, and Harrington obtain water from springs. Kittery obtains some of its water from a spring.

Ground water is used also for industrial purposes in this region. In many places additional supplies in large quantity are available from deposits of sand and gravel, and smaller supplies ranging from 50 to 75 gpm are available from bedrock. The Eastern Corp. in Brewer, which is reported to pump about a million gallons per day from five wells in bedrock and two wells in sand and gravel during the peak of the season, is one of the largest industrial users of ground water in this region. Northern Chemical Industries, Inc., at Searsport, pumps about a quarter of a million gallons daily from five or six rock wells.

QUALITY OF GROUND WATER

Ground water in the Coastal Lowlands region is generally soft and of good quality. Locally, however, water may be very hard or may contain excessive iron. Brackish or salty water is occasionally tapped during the drilling of wells on offshore islands and in areas adjacent to the sea, or it may be induced by continuous pumping from wells in such areas. Highly radioactive ground water occurs in the town of Raymond in Cumberland County. It is possible that the water in other areas, particularly where pegmatitic rocks occur, is excessively radioactive.

Partial chemical analyses made in October 1958 by the State Department of Health of water from public-water supplies derived from ground water were examined. Hardness ranged from 10 ppm for water from the spring that supplies Searsmont Village to 70 ppm for water from the drilled well of the Belfast Water District. The median hardness was 32 ppm. Chloride content ranged from 1 ppm at Brunswick, Cornish, and Calais to 20 ppm at Port Clyde; the median was 6 ppm. Iron content from a sample from the Alfred Water Co. was 1.3 ppm, which is excessive. Nitrate content ranged from 0.04 ppm at Warren to 13 ppm at Gray; the median was 0.40 ppm.

Partial chemical analyses made by the State Department of Health, Division of Sanitation, of samples of water from domestic supplies were also examined and are summarized in the following table.

Location	Samples	Constituent	Range (ppm)	Median (ppm)
Alfred	8	Hardness	8 - 82	25
		Chloride	1.0- 8.0	4
		Nitrate [1] (NO_3)	.0- 6.6	.06
Freeport	13	Hardness	24 -285	62
		Chloride	4.0-165	15
		Nitrate [1] (NO_3)	.0- 5.5	.35
Machias	13	Hardness	18 -321	55
		Chloride	3.0-370	14
		Nitrate [1] (NO_3)	.0- 35	.22

[1] Nitrate concentrations in analyses made by the State Department of Health are in terms of elemental nitrogen (N). To convert to nitrate (NO_3), nitrate values reported by the State have been multiplied by a factor of 4.4266.

The maximum chloride content, nitrate content, and hardness of water at Freeport were from the same well, which apparently was contaminated.

USE OF GROUND WATER

No accurate figures are available on the quantity of ground water used in Maine. In 1955 the Geological Survey estimated that about

21 mgd was being withdrawn for all purposes (MacKichan, 1955, p. 13). The Geological Survey estimate for 1960 was 32 mgd (MacKichan and Kammerer, 1961, p. 34).

Perhaps more significant than figures on actual use are trends of current use. These trends are discussed in the following paragraphs in relation to withdrawals for rural, municipal, industrial, and military use.

RURAL SUPPLIES

In rural sections where most farms and homes furnish their own water from privately owned wells, the demand for larger individual water supplies is increasing. A common sign of this trend is the gradual replacement of shallow dug wells, which once satisfied the needs in many rural areas, by drilled wells, which generally have a larger capacity and are more dependable. The increasing demand for larger supplies is due partly to the higher standard of living made possible by rural electrification. With the advent of electricity, it has become possible to replace hand pumps by electric pumps and to modernize kitchens, bathrooms, and laundries. The demand is also due partly to the changing pattern of agriculture. For example, large modern dairy and poultry farms require far more water than the farms that preceded them.

As farmers in Maine become aware of the benefits of irrigation, the demand for large supplies of water in the rural areas should increase. According to Mr. W. B. Oliver, formerly State Soil Conservationist, U.S. Department of Agriculture, Soil Conservation Service (oral communication, June 1958), rainfall during the growing season is deficient about 5 out of 10 years, and during those dry periods supplemental irrigation water would measurably improve crop yields. According to Mr. Oliver, the 250 irrigation systems in Maine are capable, at present, of irrigating 6,500 acres. Mr. Oliver also said that irrigation is just now in the formative stage and should increase in the future. Most of the water now used for irrigation is from surface-water sources; only one irrigation well was noted during the investigation.

According to MacKichan and Kammerer (1961, p. 9), 8.1 mgd of ground water was used in rural areas in 1960. Of this, 6.7 mgd was for domestic purposes and 1.4 mgd was for livestock. A negligible quantity was used for irrigation.

MUNICIPAL SUPPLIES

The amount of water withdrawn for municipal use in Maine is increasing owing principally to a shift in population from rural to urban areas, the extension of water mains from cities to suburbs, the increasing use of modern household devices such as dishwashers and automatic washing machines, and the formation of new water districts. Many water districts have had to supplement their old supplies, often by drilling wells. Other water districts have drilled wells to replace polluted or otherwise unsatisfactory surface-water supplies. As a result, the amount of ground water withdrawn for municipal supply has increased by more than 75 percent during the past decade. An inventory of pumpage indicated that in 1957 approximately 11 mgd of ground water was supplied by public-water systems. The distribution of municipalities using ground water for public supply is shown in plate 1.

INDUSTRIAL SUPPLIES

The use of ground water by industry is increasing also, although an inventory of pumpage for industrial use from privately owned wells has not been completed. Among the industries now using appreciable amounts of ground water either for cooling, washing, or processing are starch factories, chemical industries, canneries, tanneries, dairies, poultry-processing plants, bottling plants, paper mills, and power stations. MacKichan and Kammerer (1961, p. 21) have estimated that the quantity of ground water withdrawn in 1960 by industries for their own uses was 12 mgd.

MILITARY SUPPLIES

A substantial quantity of ground water is withdrawn for use at military installations in Maine. Although some military installations purchase water from the local water districts, others have their own wells. Loring Air Force Base, formerly the largest military installation in Maine using ground water, changed to a surface-water supply in 1960.

CONCLUSIONS

In terms of immediacy, Maine has no specific critical ground-water problems of appreciable magnitude. However, it does have numerous local problems, such as the need for new and supplemental water supplies by municipalities, by industries, and by individual homeowners in the many parts of the State not served by municipal water-supply systems. Separately these problems are significant principally to the localities and the individuals involved, but in aggregate they form an important facet of the overall water problem confronting the State. This problem, in its broadest sense, involves satisfying the varied and changing, but generally increasing, needs of the public for water, by developing and managing the water resources in the most economical and effective manner possible.

For example, if the economy of the seacoast region between New Hampshire and Portland, Maine, were to expand appreciably and the population were to grow accordingly, which is a likely prospect, towns in that area ultimately would require new or supplemental water supplies. What new sources are available? What is the ground-water potential? What is the surface-water potential? Are sources equally accessible? Can they be developed and managed most effectively on a town-by-town basis or on a regional basis? What are the possible consequences of development? In short, what alternatives are available and which would best satisfy the requirements of the area and produce the fewest undesirable consequences?

Questions of this nature typify the ground-water problem in Maine, particularly in terms of the future. The resolving of this problem is basically a matter of decisions whose soundness depends largely on their foundation in facts. The current investigation shows that, in general, data in Maine are inadequate regarding: (1) location of available ground water of suitable quality for various uses, (2) quantity of available ground water, and (3) the interrelationships between surface water and ground water.

The current investigation suggests that the need for ground-water information is greatest in the following general areas:

1. Southwestern Maine.—This area includes the southwestern part of the coastal area from the New Hampshire border to and including Portland, and other parts of the Presumpscot and Saco River basins.
2. Lower Androscoggin River basin.—This area includes the downstream part of the Androscoggin River basin and adjoining areas, particulraly the vicinities of Brunswick and Lewiston-Auburn.
3. Lower Kennebec River basin.—This area includes the downstream part of the Kennebec River basin between and including the Bath and Waterville areas.
4. Lower Penobscot River basin.—This area includes the part of the Penobscot River basin in the vicinity of Bangor and downstream to Penobscot Bay.
5. The Aroostook River Valley.—This area includes the eastern part of Aroostook County.

The first four areas listed contain most of Maine's population, its larger cities and towns, and most of its industry. The economic base in these areas promises to expand, and water requirements are likely to increase accordingly. Any future industrial growth will be accompanied by increased demands for water for both industrial and public supplies. Ground-water information will be of assistance in locating these additional supplies. Aquifers in the unconsolidated deposits should be explored as a possible source of these supplies.

The economy of the Aroostook Valley—the last area listed above—is founded on agriculture. A principal need for ground-water information is to furnish a basis for determining the feasibility of obtaining sufficient ground water for irrigation. Aquifers in the bedrock formations and the unconsolidated deposits have potentialities that need quantitative evaluation.

The need for ground-water information elsewhere in Maine appears to be less urgent at the present time. In general, much of the rest of the State is sparsely populated and relatively undeveloped. However, in some areas ground-water information soon may be needed. These areas include the southern sections of Oxford, Franklin, Somerset, and Piscataquis Counties, where several towns of small to medium size and a number of locally important industries depend on ground-water supplies; and parts of Lincoln, Knox, and Waldo Counties, which are sufficiently close to the larger centers of population in the region to the west to share in future industrial developments there. In addition, there may be an increasing need for ground-water information in the coastal sections of Washington and Hancock Counties, where several small towns depend on ground-water supplies and where blueberry crops are irrigated to some extent. In settled parts of the State where there are no municipal water-supply systems, information on the occurrence of ground water is needed in sufficient detail to assist homeowners in locating sites for wells.

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