Ground-Water Contamination and Legal Controls in Michigan

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1691

Ground-Water Contamination and Legal Controls in Michigan

By MORRIS DEUTSCH

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1691

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library has cataloged this publication as follows:

Deutsch, Morris, 1925–

Ground-water contamination and legal controls in Michigan. Washington, U.S. Govt. Print. Off., 1963.

v, 79 p. maps, diagrs. 24 cm. (U.S. Geological Survey. Water-supply paper 1691)

Bibliography: p. 72–75.

1. Water—Pollution—Michigan. 2. Water—Laws and legislation—Michigan. I. Title. (Series)

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

CONTENTS

ILLUSTRATIONS

GROUND-WATER CONTAMINATION AND LEGAL CONTROLS IN MICHIGAN

By Morris Deutsch

ABSTRACT

The great importance of the fresh ground-water resources of Michigan is evident because 90 percent of the rural and about 70 percent of the total population of the State exclusive of the Detroit metropolitan area are supplied from underground sources. The water-supply and public-health problems that have been caused by some cases of ground-water contamination in the State illustrate the necessity of protecting this vital resource.

Manmade and natural contaminants, including many types of chemical and organic matter, have entered many of the numerous aquifers of the State. Aquifers have been contaminated by waste-laden liquids percolating from the surface or from the zone of aeration and by direct injection to the aquifer itself. Industrial and domestic wastes, septic tanks, leaking sewers, flood waters or other poor quality surface waters, mine waters, solids stored or spread at the surface, and even airborne wastes all have been sources of ground-water contamination in Michigan. In addition, naturally occurring saline waters have been induced into other aquifers by overpumping or unrestricted flow from artesian wells, possibly by dewatering operations, and by the deepening of surface stream channels. Vertical migration of saline waters through open holes from formations underlying various important aquifers also has spoiled some of the fresh ground waters in the State. In spite of the contamination that has occurred, however, the total amount of ground water that has been spoiled is only a small part of the total resource. Neither is the contamination so widespread as that of the surface streams of Michigan.

Overall legal authority to control most types of ground-water contamination in the State has been assigned by the Michigan Legislature to the Water Resources Commission, although the Department of Conservation and the Health Department also exercise important water-pollution control functions. The Michigan Supreme Court, in an important case upholding the power of the Water Resources Commission to control pollution of ground water, in effect has introduced the doctrine of reasonable use into the law of the State. Excluding controls administered by the Department of Conservation on activities of the oil and gas industry, however, legal controls have not been used to abate intrusion of natural saline waters into fresh-water aquifers in response to pumping and other manmade changes in the hydrologic regimen.

INTRODUCTION

Michigan's fresh-water resources are enormous. Vast supplies of surface water are available in 4 of the 5 Great Lakes, more than

11,000 inland lakes, and many thousands of miles of rivers and streams. In addition, the State has an abundant resource of ground water. The ground-water resources are particularly valuable because they provide a readily available source of supply in a large part of the State. Excluding the Detroit Metropolitan area, about 90 percent of the rural and 70 percent of the total population of the State are supplied with water from underground sources (MacKichan, 1957).

Despite the abundance of the ground water in Michigan, many problems face those concerned with the development and management of this resource. One of the most serious of these problems—and the one with which this paper deals—is that of contamination. Numerous instances of ground-water contamination have been observed in many areas of the State. The overall extent of contamination probably is not unusual for a highly populated industrial State and is only a small part of the total resource. In some places, notably in the Saginaw Bay and Grand Rapids areas, irreparable damage has been caused by the encroachment of saline water into fresh-water aquifers.

Pollution of rivers and streams, especially in southern Michigan, has placed many communities and other water users in the ironic position of having available adequate quantities of surface water, but of a quality unfit for most uses. Similar pollution of ground water must be avoided. Ground-water resources can be developed at relatively low cost in many areas of the State. If this widespread source of supply should become contaminated the importation of water to water-rich areas would follow. Also, ground-water contamination is more serious than similar contamination of surface water for several reasons: (1) It is longer lasting because of the slow movement of ground water; (2) it may not be detected until after a considerable part of an aquifer is affected; and (3) reclamation of the aquifer is difficult and time consuming, if possible at all.

The purposes of this paper are: (1) To review the various ways in which the quality of water in aquifers in Michigan has been impaired; (2) to cite briefly cases of actual or suspected ground-water contamination and thus point out practices that may result in contamination; (3) to point out hydraulic principles involved in the migration of contaminants to fresh ground-water reservoirs; (4) to mention the decisions of the Michigan Supreme Court and acts of the Michigan Legislature pertinent to the subject of ground-water contamination and to examine the legal safeguards designed to abate further contamination. The discussion of the many cases cited herein may increase awareness of hazards to ground-water supplies and lead indirectly to the curtailment of ground-water contamination in the future. The drawings that show migration of contaminants through aquifers are schematic and illustrate principles; they are not based on actual field data.

PREVIOUS INVESTIGATIONS

Problems concerning the contamination of ground-water supplies throughout Michigan have been studied by a number of State, Federal, and local governmental units although no comprehensive tabulation of all types of contamination in the State had previously been prepared. Many cases of contamination of public water supplies referred to herein were investigated by State agencies and described in the "Michigan Water Works News," published by the Michigan Department of Health. Since 1949 the Michigan Water Resources Commission has been active in controlling contamination of the surface and ground waters of the State. An informal report issued by the Commission, the "Quarterly Bulletin," is also a source of some of the material contained in this report.

The U.S. Public Health Service (Stiles and others, 1927) conducted an elaborate series of experiments at Fort Caswell, N.C., to study the movement, velocity, and duration of chemical and bacterial pollutants in the ground, especially as affected by ground-water movement and water-level fluctuations.

A significant advance in the understanding of principles involved in ground-water contamination was made by Fiedler (1936) who described the general geologic and hydrologic controls governing the migration of contaminants in various types of aquifers. Faust (1937) described methods of safeguarding various types of wells from contamination by properly locating, constructing, and equipping wells of each type. Ferris (1951) discussed the roles that aquifers might play as waste-disposal reservoirs and outlined the basic hydrologic problems. The problems involved in subsurface waste disposal are mainly the same as those involved in aquifer contamination.

Adams (1944) made a plea for the abatement of water pollution in Michigan and cited hazards, annoyances, damages, and economic losses caused by polluting the water resources of the State. Problems caused by ground-water pollution were summarized by Billings (1950), who cited the need for detailed geologic, hydrologic, and hydraulic data to analyze individual problems. He noted also that legal restrictions included in the State's oil and gas laws safeguard not only the public at large, but also the oil and gas industry.

An informative pamphlet covering various aspects of ground-water pollution was prepared for general public use by Slaughter and Campbell (1952).

The 1955 "Yearbook of Agriculture" entitled "Water" included several papers concerned with the protection of water resources:

681-387 O - 63 - 2

Parker (1955, p. 615–635) discussed the enroachment of saline waters into fresh-water aquifers of Michigan; Schwab (1955, p. 636–643) wrote on the growing national problems of water pollution; Fuhrman (1955, p. 644–649) discussed treatment of waste waters for cities and industries; Garver (1955a and b, p. 655–665) wrote on ways by which rural water supplies may be contaminated and of protective measures that may be taken and also on methods of safe disposal of sanitary wastes for rural homes.

Results of detailed quantitative work concerning the pollution of ground waters have been published by the California Water Pollution Control Board (1953; 1954a; 1954b). These reports also contain comprehensive bibliographies on pollution and contamination.

The American Water Works Association (1957) is concerned with various phases of underground waste disposal and control and organized a task group to study the problems involved and to report on its findings. The World Health Organization (1957) also has considered the general problem of ground-water pollution and the impact of pollution on the water economy of an area.

The present report contains no discussion of the possibility of future contamination of the State's ground-water resources by radioactive substances. A separate paper prepared by the author (Deutsch, 1956) discusses the effects of dissemination of radioactive materials on water resources and lists numerous pertinent reference.

The relation of law to water resources has received considerable attention in recent years. The Legislative Research Center of the University of Michigan Law School (Pierce, 1958) published contributions prepared for the 10th Annual Summer Institute of the Law School. An especially valuable contribution for those interested in the legal aspects of the contamination of water supplies is discussed by Lauer and others (1958). Piper and Thomas (1958) described the inappropriateness of common law in defining rights to water because of the complexities of the hydrologic cycle and the difficulty of adapting statutory law to "the realities of applied hydrology."

ACKNOWLEDGMENTS

Sincere thanks are due Mr. N. F. Billings, Chief, and other personnel of the Hydrology Division, Michigan Water Resources Commission, and to Mr. T. L. VanderVelde, Chief of the Water Supply Section, Michigan Department of Health, who made available pertinent data contained in the files of their respective organizations. Mr. J. G. Rulison and personnel of the Water Resources Section of the Michigan Geological Survey provided the author with valuable information concerning geologic aspects of cases of aquifer contamination. Mr. A. E. Slaughter, also of the Michigan Geological Survey, provided further pertinent data on contamination cases in the Northern Peninsula. Mr. E. M. Burt of Williams and Works, consulting engineers, Grand Rapids, contributed information and technical assistance in regard to instances of ground-water contamination in the Grand Rapids area. Appreciation is expressed also to Mr. J. G. Ferris of the U.S. Geological Survey who permitted use of pertinent unpublished file data and illustrative matter prepared by him

This report was prepared by the Geological Survey as part of a program of support for university research projects of direct interest to the Government. An earlier version was used by the author as a graduate school thesis. The graduate work was done at Michigan State University, East Lansing, under the guidance of Dr. C. R. Humphrys, Professor, Department of Resource Development.

SUMMARY OF GROUND-WATER OCCURRENCE IN MICHIGAN

Fresh ground water can be obtained in most of Michigan by wells drilled into one or more of the numerous aquifers of the State. The water-bearing rock formations of the State are commonly classified into two broad categories of aquifers—bedrock and glacial drift. The bedrock or consolidated-rock aquifers include (1) the igneous, metamorphic, and sedimentary rocks of Precambrian age which form the bedrock surface in much of the western half of the Northern Peninsula and (2) the sedimentary rocks of Paleozoic age, which overlie the Precambrian rocks elsewhere in the State (fig. 1).

The Precambrian rocks commonly are dense and their permeability is low. However, where the rock is fractured and connected with a source of recharge, water may circulate through these secondary openings and be intercepted by wells. Where mines penetrate such permeable zones, dewatering operations may be necessary.

Paleozoic rocks underlie all of the State except parts of the western section of the Northern Peninsula where the Precambrian rocks form the bedrock surface. The Paleozoic rocks consist of limestone, dolomite, shale, sandstone, and breccia. Some of these rocks are interbedded with layers of evaporites such as rock salt or gypsum. These rocks were deposited in the shallow seas which covered the Michigan basin during most of the Paleozoic Era. They were laid down in nearly horizontal layers, but their gradual subsidence and compaction which were contemporaneous and greatest in the center of the basin, produced a bowl-shaped structure (fig. 1). The youngest beds are exposed at the surface in the central part of the basin and the formations crop out in roughly concentric bands.

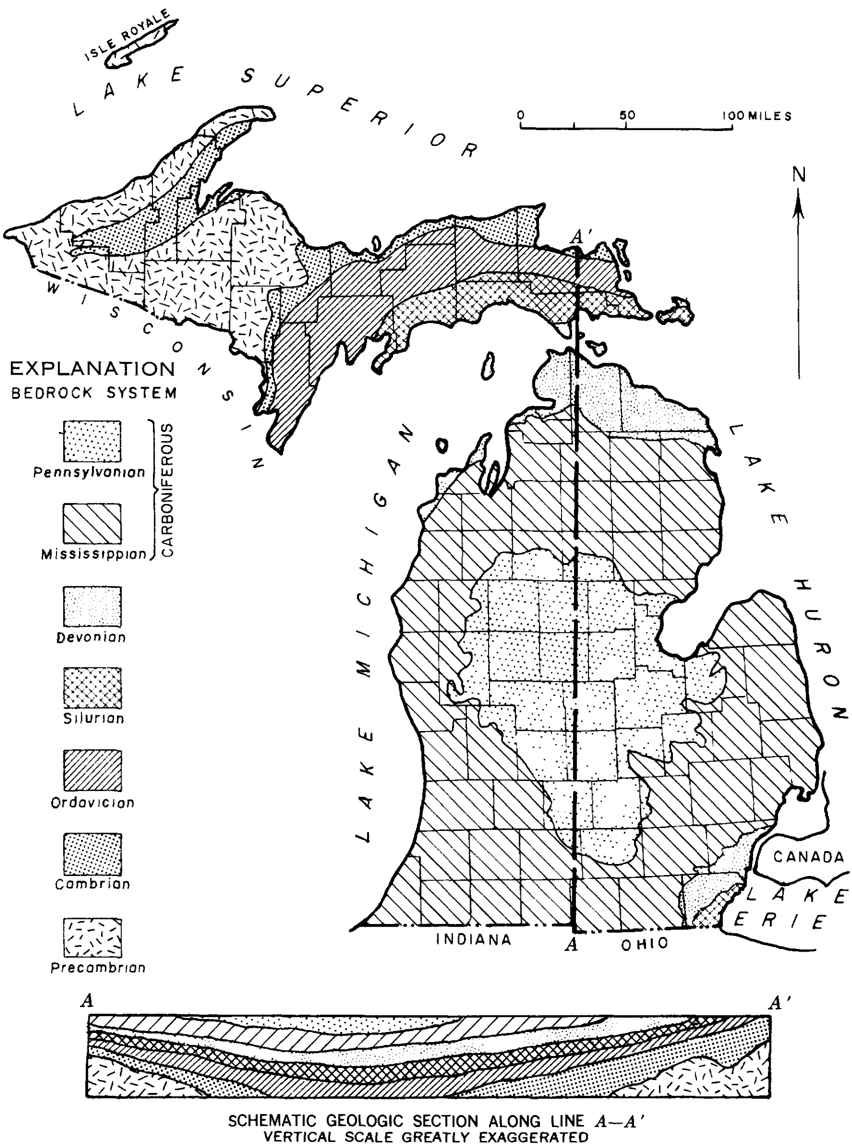

FIGURE 1.—Geologic map and section of the bedrock systems of Michigan.

The chief sedimentary rock aquifers are composed primarily of sandstone, limestone, or dolomite. In a sandstone aquifer water moves through interstices between individual sand grains and also along fractures and bedding planes. Movement of water in limestone and dolomite aquifers is predominantly through permeable zones, which were developed by weathering and solution. Layers of shale are of low permeability and yield little water to wells. Shale beds, however, are significant in the hydrologic system because they impede vertical movement of ground water and hence act as confining beds in artesian systems and retard solution in underlying soluble deposits.

Most of the fresh water in the sedimentary rock aquifers is in the outcrop areas of the formations—areas where the formation forms the land surface or is mantled only by glacial drift. Where the aquifers are buried beneath younger Paleozoic formations, they generally contain saline water. For example, the Marshall Formation of Mississippian age is the principal source of fresh ground water at Battle Creek, Calhoun County, in southwestern Michigan. In Calhoun County, the Marshall Formation forms the buried surface below the glacial deposits. In Ingham County, 40 miles to the northeast, however, where the Marshall Formation is overlain by younger Paleozoic strata, it yields saline water. Similarly, the Trenton and Black River Limestones of Middle Ordovician age are an important source of fresh water in Delta County in the Northern Peninsula, but in the Southern Peninsula, these formation are at great depth and locally produce gas, oil, and brine.

Fresh water is available, however, in some formations in areas where they are overlain by younger sedimentary rocks. In parts of Delta and Schoolcraft Counties, sandstone formations of Cambrian and Ordovician age yield fresh water 20 to 30 miles south of the outcrop area, although the salinity of the water tends to increase with depth and distance from the outcrop area.

A long period of erosion occurred after the deposition of the Paleozic rocks and before the deposition of glacial deposits. During this erosional interval much consolidated rock was removed and some of the major physiographic features of Michigan were formed, including large valleys, which are now part of the Great Lakes. The Pleistocene deposits, which consist of a heterogeneous mixture of unconsolidated rock debris known collectively as glacial drift, are the most important and accessible aquifers in many areas of the State. The drift material was deposited on the eroded bedrock surface of Precambrian and Paleozoic rocks by ice, meltwater streams, lakes, and wind action during the glacial epoch. The Pleistocene deposits are about a thousand feet in maximum thickness and mantle the bedrock over all but about 2 or 3 percent of the entire land area of the State.

The most permeable deposits, and hence those that form the best aquifers, are the stream-laid outwash deposits composed of moderately well sorted sand and gravel. On the other hand, ice-laid deposits of till are of low permeability and are not important as aquifers in most of the State. However, in the Lake Superior area and in the northern part of the Southern Peninsula where the deposits are composed largely of sand, till is locally an important aquifer. Also included within the glacial-drift mantle are large quantities of clay, silt, and fine sand deposited in the water of the numerous glacial lakes that existed during and after the Pleistocene Epoch. Most of these deposits are rather poor aquifers in Michigan except locally where they are composed chiefly of sand and will yield small to moderate amounts of water to wells. The extensive dunes in several areas of the State, especially along the Great Lakes shorelines, are not important as aquifers because they generally lie above the regional water table.

The principal hydrologic properties of aquifers—their permeability and porosity—are determined basically by the character of the interstices between grains or of the open spaces within the rocks forming

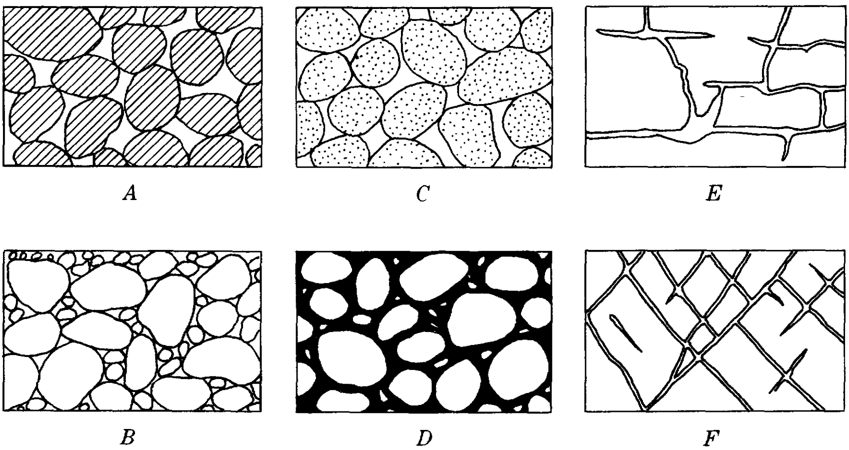

FIGURE 2.—Diagram showing several types of rock interstices and the relation of rock texture to porosity (after Meinzer, 1923). *A*, well-sorted sedimentary deposit having high porosity; *B*, poorly sorted sedimentary deposit having low porosity; *C*, well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; *D*, well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; *E*, rock rendered porous by solution; *F*, rock rendered porous by fracturing.

the aquifers (fig. 2). Interstices in rocks can be grouped into two main classes—the original or primary interstices, formed when the rocks came into existence; and the secondary interstices, joints, fissures, and solution passages, which were developed later.

Many areas of Michigan are underlain by two or more aquifers in which water levels differ considerably, and some natural seepage or leakage occurs between them. Figure 3 illustrates principles involved in natural leakage between aquifers. The water surface in well 1 coincides with the top of the zone of saturation and hence aquifer *A* is termed water table or nonartesian. Aquifers *B* and *C*

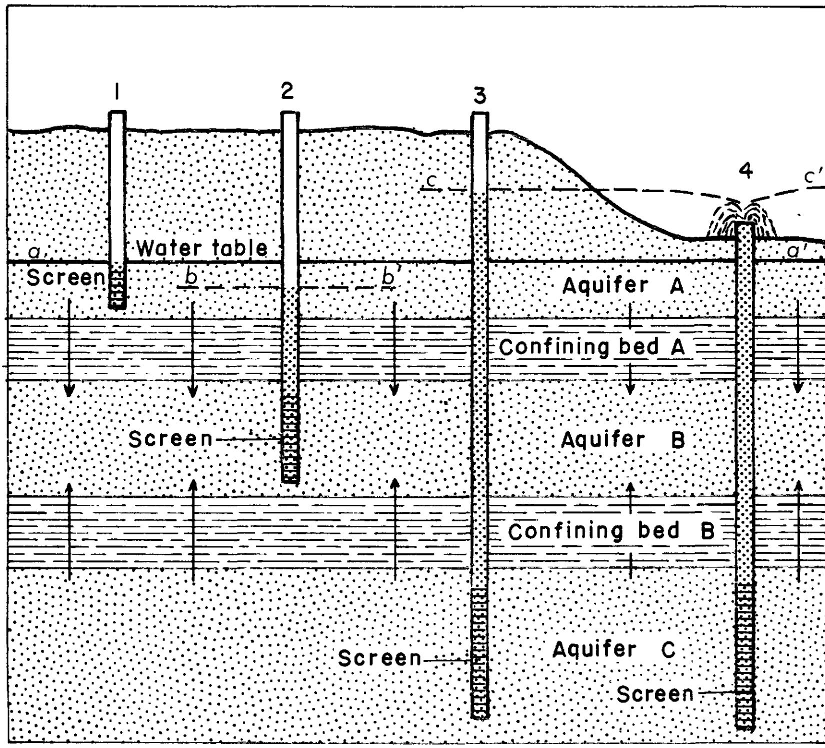

FIGURE 3.—Diagrammatic section showing hydrogeologic conditions of water table and artesian aquifers (after Ferris and others, 1954). Line *a–a'* is the water table in aquifer A and well 1 is a water table well. Line *b–b'* is the piezometric surface in aquifer B and well 2 is an artesian well. Line *c–c'* is the piezometric surface in aquifer C and wells 3 and 4 are artesian wells; well 4 is in an area of artesian flow. The arrows indicate the direction of cross-bed leakage.

and wells 2, 3, and 4 are artesian. The lower artesian pressure in aquifer *B* indicates that water may be moving into this formation from aquifers *A* or *C*, either through distant breaks in the aquicludes or by vertical seepage through the aquicludes themselves.

The direction of natural interformational leakage may be reversed by pumping (fig. 4). Under natural conditions the water level (head) in aquifer *A* is higher than the piezometric surface of aquifer *B* and water leaks from *A* to *B*. When the water level in aquifer *A* is lowered to a level below the piezometric surface of aquifer *B* by pumping, water leaks from *B* to *A*.

GROUND-WATER CONTAMINATION IN MICHIGAN

Natural and manmade contaminants may come in contact with water at any point in the hydrologic cycle. Figure 5 is a schematic

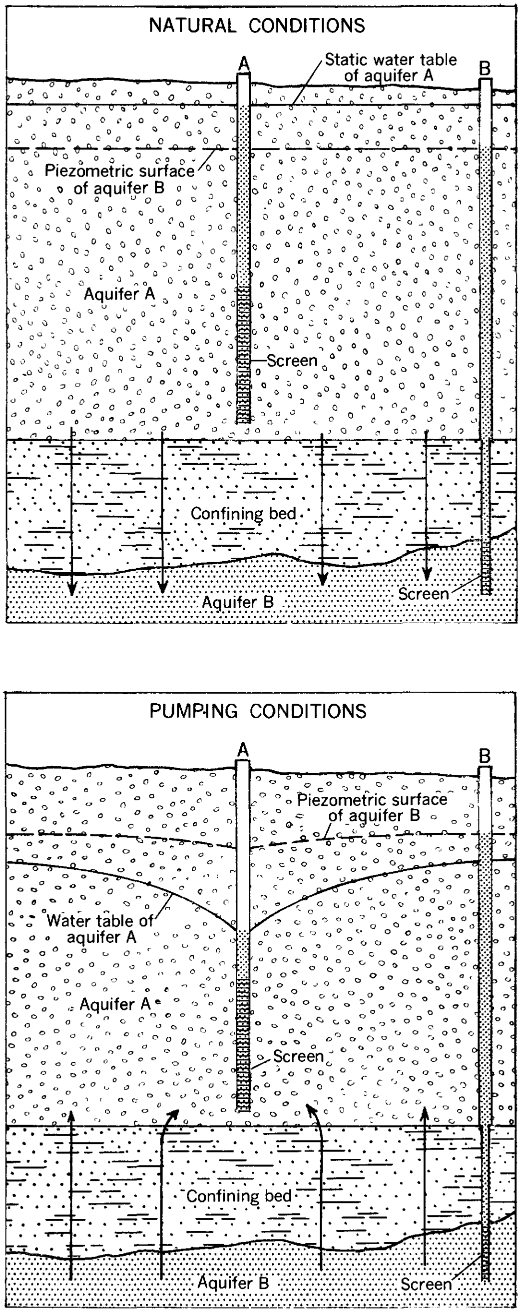

FIGURE 4.—Diagrams showing reversal of interformational leakage by pumping.

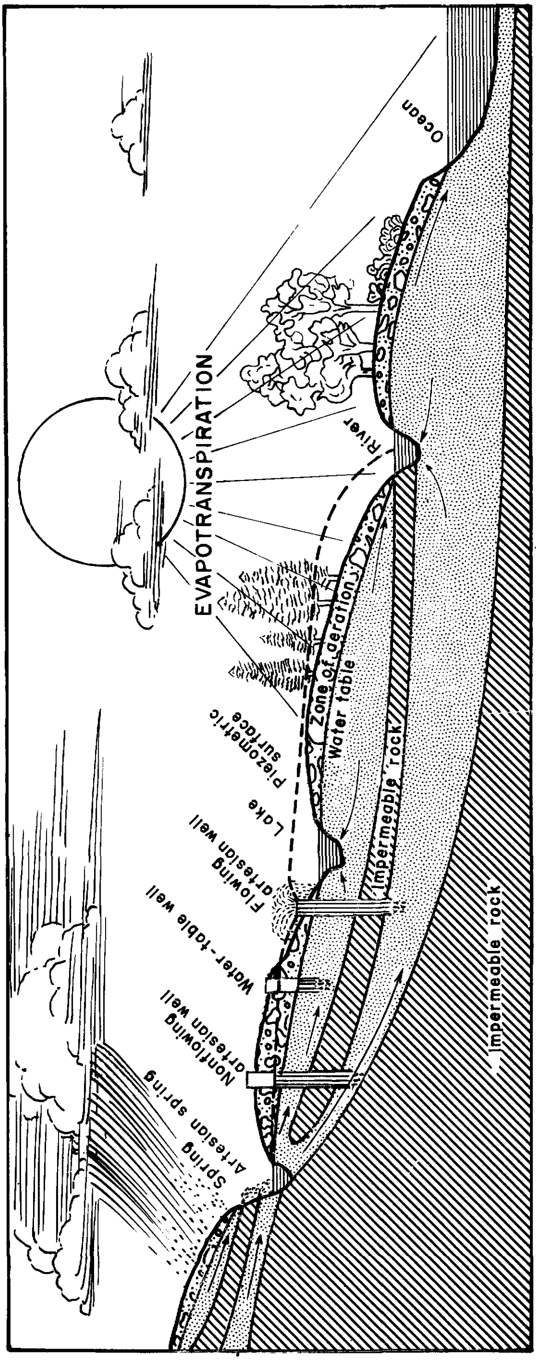

FIGURE 5.—Diagrammatic section showing water-table and artesian aquifers as part of the hydrologic cycle. (After Sayre, 1950.)

681-387 O - 63 - 3

section showing water-table and artesian aquifers as part of the hydrologic cycle. Contaminants may be introduced into aquifers in many ways. These are illustrated by the instances of contamination in Michigan described in this report.

Fresh water is arbitrarily defined as water containing less than 1,000 parts per million (ppm) of dissolved minerals. This concentration represents the maximum that should be permitted in drinking water, according to the U.S. Public Health Service (1946) and the Michigan Department of Health (1948). The dissolved-solids content of water of preferred chemical quality should not exceed 500 ppm. Natural ground water containing more than 1,000 ppm of dissolved solids, not limited to sodium chloride, is referred to herein as saline or mineralized.

For the purpose of this report, a fresh-water aquifer is termed contaminated if it has been impaired in quality—directly or indirectly by man's activities—to such a degree that the U.S. Public Health Service would not recommend it for drinking water. The impairment may be caused by the addition of excessive concentrations of one or more minerals; by the introduction of biological substances that may cause deleterious physiological effects; or by physical agents that impart objectionable taste, odor, color, or increases in temperature.

The extent of contamination of the fresh ground water in Michigan has not been determined. Furthermore, it is unlikely that such a determination could be made. However, widespread contamination of important aquifers in the Saginaw Lowlands and in the Grand Rapids area is known to have occurred. In other areas, serious but much more localized contamination has occurred. Some occurrences of ground-water contamination in Michigan are shown in figure 6.

CONTAMINANTS INTRODUCED FROM THE SURFACE

A wide variety of deleterious substances have been introduced in numerous ways from the surface to many of the aquifers of the State. These substances include salt, hexavalent chromium, phenols, picric acid, gasoline, fuel oil, brines, domestic and farm sanitary wastes, polluted surface waters, nitrates, fertilizer, and a variety of other industrial, municipal, and domestic wastes. Harmful substances may enter ground-water supplies by direct injection through wells; by percolation from dry wells, pits, underground storage tanks, and septic tanks; by percolation of liquids spilled at the surface or leached from soluble solids at the surface by precipitation; by leaking or broken sewers; and by infiltration of polluted surface water into the ground. Windblown wastes are suspected to have contaminated ground-water supplies in one locality.

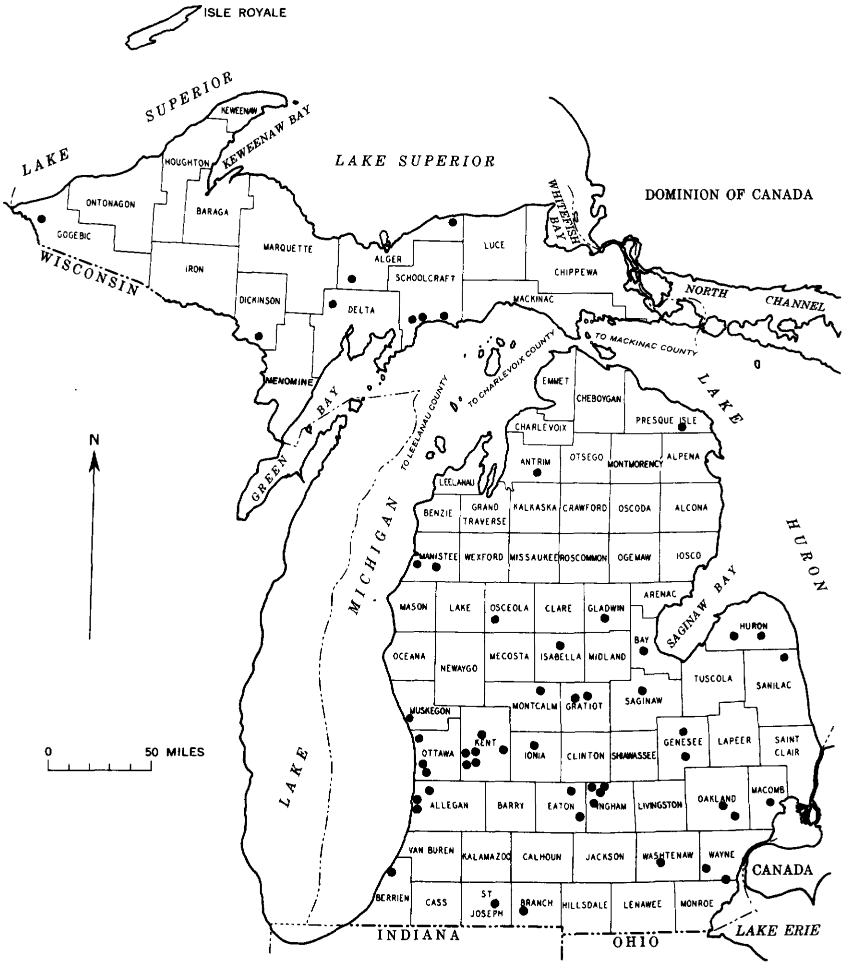

FIGURE 6.—Generalized distribution of actual or suspected cases of ground-water contamination in Michigan described in this report.

INJECTION INTO AQUIFERS

The most direct method by which aquifers in Michigan have become contaminated has been by the discharge of waste water directly into wells that tap fresh-water aquifers. Waste water will flow into an aquifer if its head is above water table or piezometric surface (fig. 7). The water that enters the well will flow radially from the well into the aquifer. Ultimately, the direction of flow away from the well to a point of discharge is controlled by the natural hydraulic gradient in the aquifer or by gradients created by nearby pumping wells. For practical purposes, this means that nearly all wells, except those that are plugged or flowing, provide a possible avenue of entry of liquid contaminants from the surface to an aquifer.

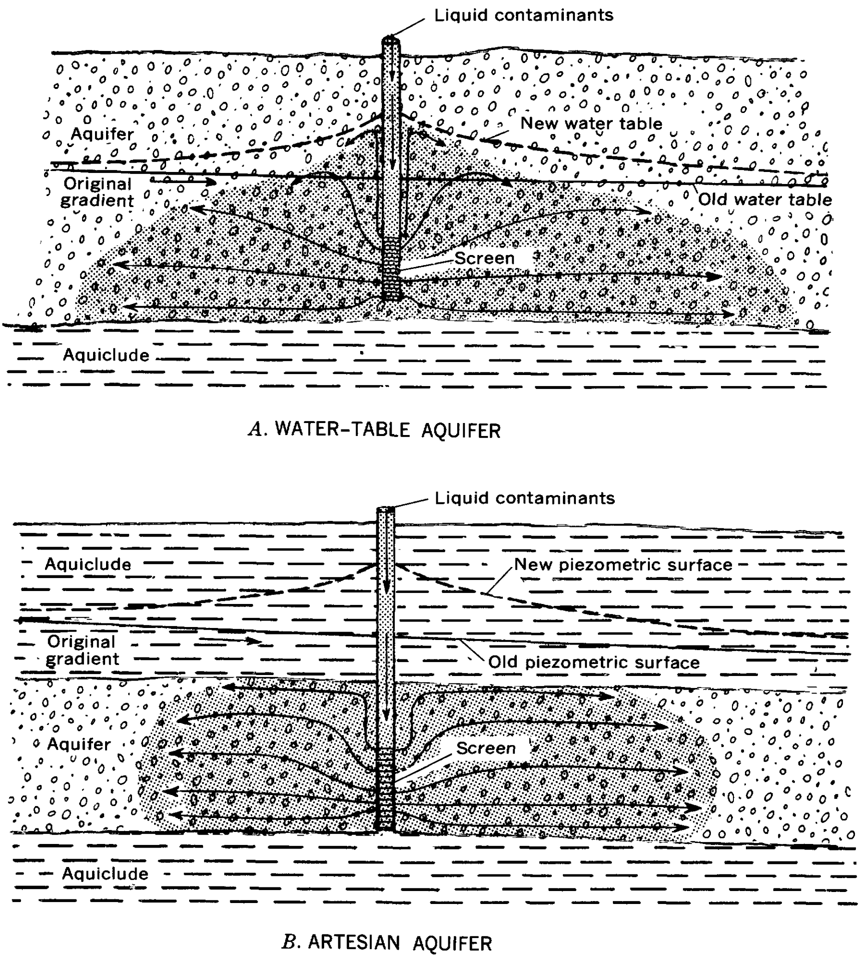

FIGURE 7.—Diagrams showing spread of contaminants injected through wells into water-table and artesian aquifers.

In some places, the injection of wastes has been resorted to because of the ease and lack of expense involved. In others, the injection was accidental or the deleterious effects of the injection were unanticipated.

SANITARY WASTES AT ELKTON

At Elkton, Huron County, during the summer of 1945, the municipal well, which taps the sandstone and limestone of the Marshall Formation, yielded water contaminated with sanitary and domestic wastes. At the request of the Elkton Village Council, the State Health Department, assisted by the Michigan Geological Survey, made an investigation that showed that abandoned domestic wells were used to drain basements, laundry and kitchen wastes, and septic tanks. This practice was widespread in the area owing to poor surface-drainage conditions. These abandoned wells tapped the Marshall Formation, and the aquifer, which was the village's main source of supply, was being polluted directly. Plugging of all so-called leak wells was impractical because of their large number—between 50–75—and because many of them could not be located. The village solved the problem of contamination by constructing a new well outside of town and remote from the contaminated part of the aquifer.

FUEL OIL AT HOLT

An occurrence of fresh-water contamination at Holt, Ingham County, illustrates how an accident can ruin a potable ground-water supply. In 1953, a home owner ordered a supply of fuel oil from a local distributor. The delivery man, who had not previously serviced the house, found an intake pipe and proceeded to pump the ordered quantity of fuel oil into the pipe. When an automatic shutoff device failed to operate and the pumping continued after the fuel tank should have been filled, the delivery man investigated. To the consternation of all concerned, the oil had been pumped into a well equipped with the same diameter and type of casing as the fuel oil intake pipe on the other side of the house. Needless to say, it became necessary for the home owner to obtain his water supply from other sources, as the aquifer in the immediate vicinity was contaminated with fuel oil.

WELL RECONDITIONING AT MOUNT MORRIS

The city of Mount Morris, Genesee County, has two wells within 35 feet of each other. In 1948, the west well was reconditioned by pulling the screen and installing a new gravelpack. During this operation, bacterial contamination of water pumped from the east well was noted. Apparently, bacterial contaminants entered the west well while it was being repaired. When the east well was pumped, a cone of depression resulted in a gradient from the east well to the west well, and water moving toward the pumping well carried with it the contaminants from the west well (fig. 8). The possibility of this and similar types of accidents was pointed out by Garver (1955a, p. 656), who recommended that newly developed water-supply systems and those repaired or extended be disinfected by chlorination.

AIR-CONDITIONING RETURN OR RECHARGE WELLS

The widespread use of ground water as a coolant in air conditioning presents a potential hazard to the ground-water resources of the State because it is common practice to return the circulated cooling water to the ground. The water generally is returned to the ground to avoid

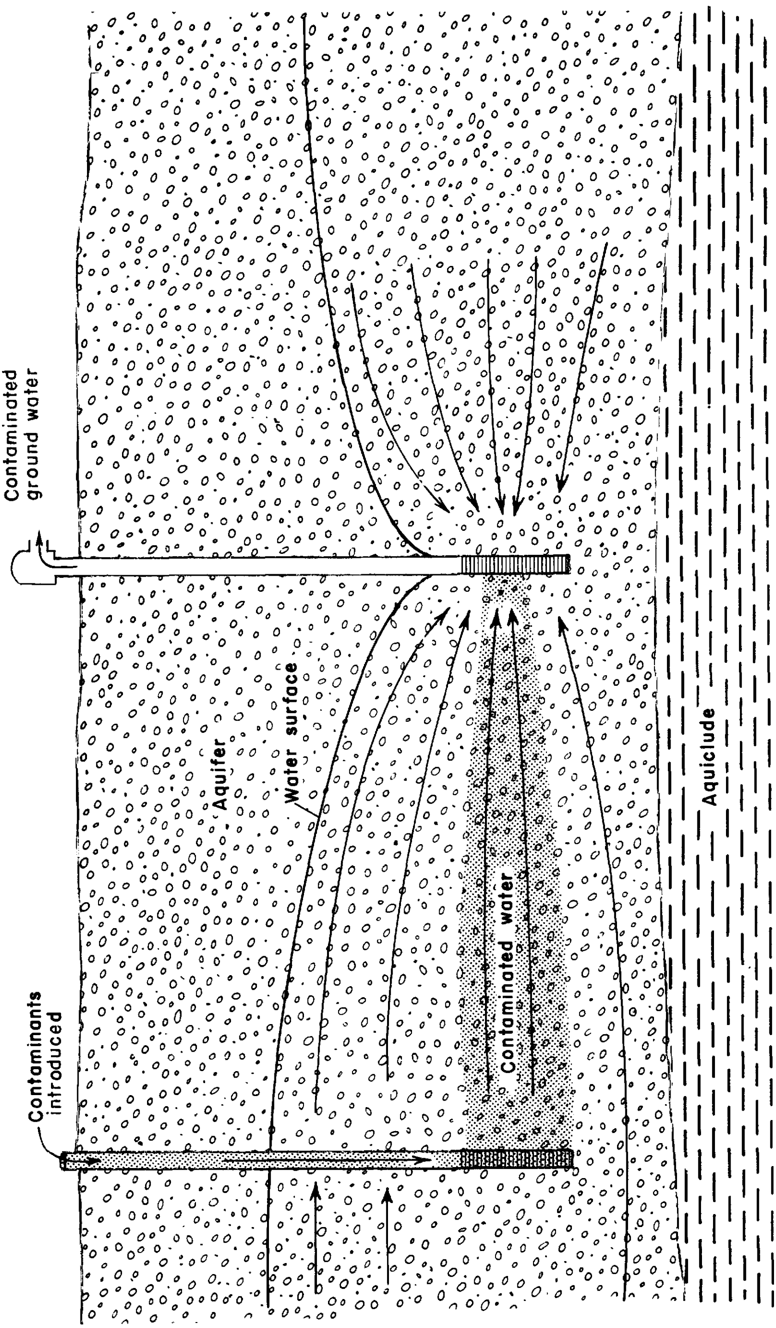

FIGURE 8.—Diagram showing movement of contaminants through a well to a nearby pumping well.

the necessity of discharging it to public sewers, whose use is taxed; to conserve or replenish ground-water supplies; or to maintain high water levels or artesian pressures. A potential hazard to the aquifer is that in addition to the spent air-conditioning water, other polluted water may be recharged to the aquifer accidently, or in an attempt to reduce input into sewage systems.

The return of warmed waste air-conditioning water to an aquifer results in a rise in temperature of the water in the aquifer. Such rises in ground-water temperatures are undesirable because:

1. The warmed ground water is of less value for reuse in air-conditioning systems and in some industrial processes.
2. The palatability of the ground water may be impaired.
3. Warmed water generally has increased capacity to dissolve and to carry soluble rock or other mineral matter in solution.
4. Discharge of warm ground water may cause undesirable rises in temperature of surface streams.

The recharge of aquifers through wells with fresh water other than that used in air-conditioning systems has been considered for some areas of the State, although at the present (1961) no such project is known to have been started. Such artificial recharge might be advantageous for several purposes—such as underground storage of spring runoff, displacement of saline waters, and recovery of water levels in aquifers subjected to significant declines of head because of pumping.

Obviously, impairment of the aquifer would occur if water of poor quality were injected into a fresh-water aquifer for any purpose.

DUG WELLS

A dug well, which is a shallow excavation extending below the water table, presents a special contamination hazard to ground-water supplies. The principles by which contaminated water from a dug well may enter an aquifer are no different from any other type well. However, a dug well is especially susceptible to contamination because of its large diameter and the attendant difficulties in properly sealing it from surface contaminants such as polluted water, sewage, small animals and insects, decaying vegetation, and rubbish. Most of the dug wells in Michigan, of which there are many still in use, range in diameter from 3 to 30 feet. The Michigan Department of Health (Faust, 1937, p. 13) discourages the use of dug wells, primarily because of the contamination threat; however, the Department acknowledges that properly constructed dug wells are justified if fresh ground water in an area is available only in an aquifer of relatively low permeability. Dug wells may yield adequate supplies from such aquifers because of their large entrance areas and storage capacities compared to those of drilled wells.

CONTAMINATED SURFACE WATERS

Several aquifers in different parts of the State have been contaminated because improperly constructed wells permitted surface water of objectionable quality to recharge through the well. Flood water carrying chemical or bacteriological matter is especially hazardous because it may rise to levels above the tops of well casings and enter the aquifer.

PONDED STORM WATER AT BAD AXE

In the spring of 1921, several serious outbreaks of intestinal influenza at Bad Axe, Huron County, were reported to the State Health Department. Investigation showed that the outbreaks coincided rather closely with rains that flooded an area around the city's pumping station. Although one of the production wells was submerged during the flooding (Hirn, 1923) the source of contamination was difficult to explain because the city wells flowed when they were not pumped and the well that produced the contaminated water was adequately sealed against contamination. The production well, however, was only 430 feet from an open abandoned well that was submerged. It is probable that pumping of the production well lowered the head in the abandoned well below the level of ponded water.

The fine dense nature of the water-bearing Marshall Formation did not prevent contamination for a distance of 430 feet. Hirn reported that the production wells had recently been developed by detonating a heavy charge of dynamite in each well, and he surmised that the sandstone had been fissured extensively to provide a ready hydraulic connection between the abandoned well and the production well. Elsewhere in the State, water in fine dense sandstone, such as the Marshall Formation in Huron County, moves through secondary openings similar to those shown by figure 2*F*. Although dynamiting may have increased the secondary permeability, it is possible that contamination of the production well would have occurred regardless, so long as contaminated surface water was permitted to enter the aquifer through an unused well.

FLOOD WATER AT SAUGATUCK

In 1951, analyses showed that water from 2 of the 3 municipal wells at Saugatuck, Allegan County, contained bacterial pollutants. The wells were of the gravel-pack type, about 50 or 60 feet deep, and drew water from sands extending to that depth below the surface. The Michigan Department of Health concluded that water from the flooded Kalamazoo River had entered the well through the gravel

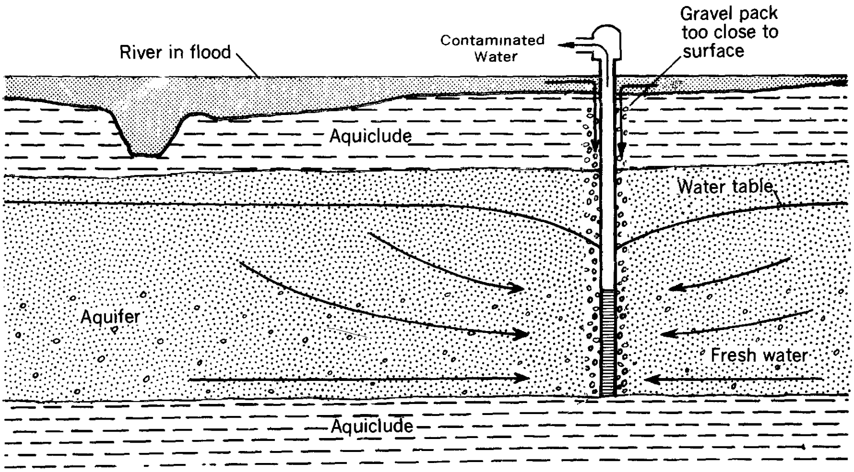

FIGURE 9.—Diagram showing floodwater entering a well through an improperly sealed gravel pack.

envelope around the well casing (fig. 9). This suggests that to seal a well effectively from surface water of objectionable quality, gravel packs should not extend to the surface or to the top of an aquifer subject to contamination.

BACKFLOODING AT MINDEN CITY

The need for preventing flood water or backflow of a distribution system from entering a well and contaminating an aquifer is illustrated by an incident that occurred at Minden City, Sanilac County. In 1956 the pump on the city's only well failed when the pit in which the pump was located became flooded. Water from two sources flowed into the well—surface floodwater and backflow from the water mains. The backflow into the well occurred because there was no plumbing fixture to prevent the return of water already in the system. In this failure the health hazard was minimized because the State Health Department operated an emergency chlorinator on the system until all the contaminated water had been pumped from the aquifer.

DRAIN WELLS

Contamination may occur also from the use of wells for drainage purposes. Horton (1905) described a subsurface drainage operation in Parma Township, Jackson County. An attempt was made to drain a surface pond by drilling a well within the pond (fig. 10). Complete drainage was not accomplished until the well was deepened into a permeable zone. Although this operation did not result in contamination of the aquifer—at least none was reported—an easy avenue of access for contaminants into the aquifer was provided.

681-387 O - 63 - 4

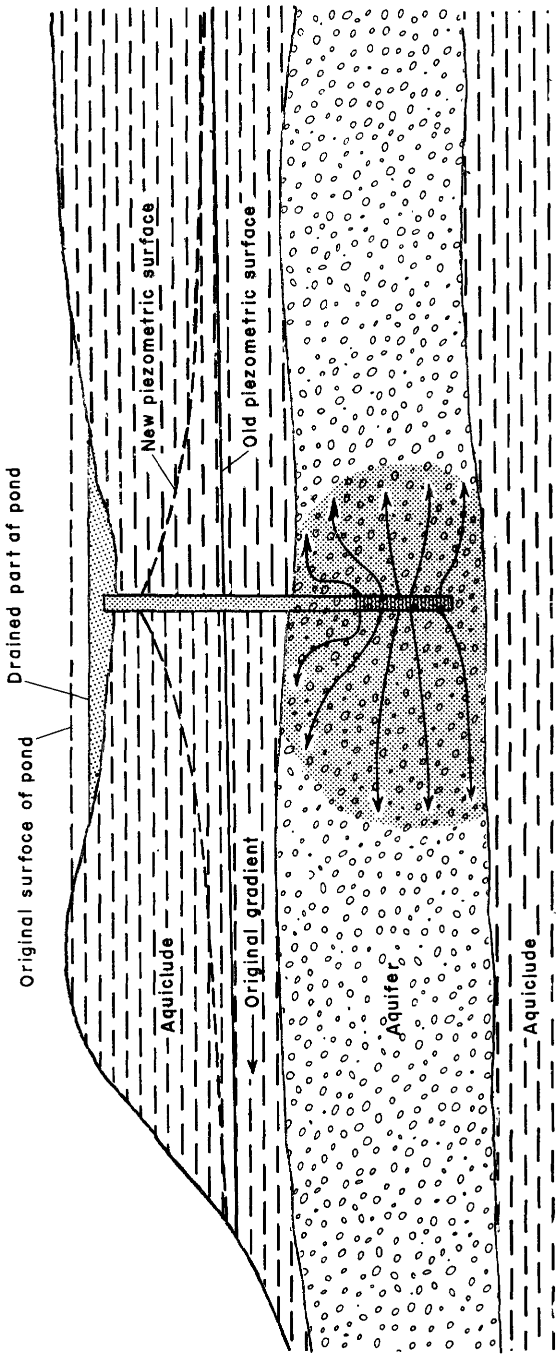

FIGURE 10.—Diagram showing drainage of a pond into an aquifer through a drain well.

Surface waters are readily susceptible to bacterial contamination and, where injected into an aquifer, may contaminate the ground water in the vicinity of the injection well. Where drain wells are used, they should not recharge aquifers that are current or potential sources of potable water supply unless the recharge water is first chlorinated and filtered.

DISPOSAL OR STORAGE IN THE ZONE OF AERATION

Waste water discharged into a so-called dry well, surface pond or settling basin, pit, trench, or septic tank may ultimately enter a fresh-water aquifer following percolation through the zone of aeration. The zone of aeration consists of the unsaturated materials above the water table in which pore spaces and interstices between rock particles contain air as well as percolating water.

A dry well, which is finished above the water table in the zone of aeration, is used commonly to dispose of water from roofs or footing drains in areas not served by storm sewers. Almost all the suspended solid material in the runoff is filtered out within a few inches from the dry well, but the water containing dissolved solids percolates through the permeable materials above the aquifer. In general the movement is downward, although some water is dispersed laterally by capillarity or deflected by materials of low permeability. Eventually the water enters the upper part of the underlying aquifer (fig. 11). The liquid waste tends to form a mound on the water surface and move radially from the mound. The distance, direction, and velocity of underflow of the waste is affected by the gradient and the velocity of ground water in the aquifer.

Disposal of sewage effluent from a septic tank is accomplished in the same manner, except that a septic tank is designed to discharge to a tile drain field, which provides, in comparison, a large infiltration area.

Percolation of the liquid wastes to the aquifer from surface ponds, pits, or trenches also occurs in the same manner; however, the water is exposed to the atmosphere and is subject to evaporation. The pond or settling basin ordinarily permits more water to enter an aquifer than a dry well because it has a much larger infiltration area.

Storage of chemicals, chemical wastes, or petroleum products in steel or concrete tanks also presents a potential hazard because corrosion of the metal or cracking of the concrete may ultimately permit seepage of contaminants into an aquifer. Contamination by seepage has occurred on several occasions in Michigan.

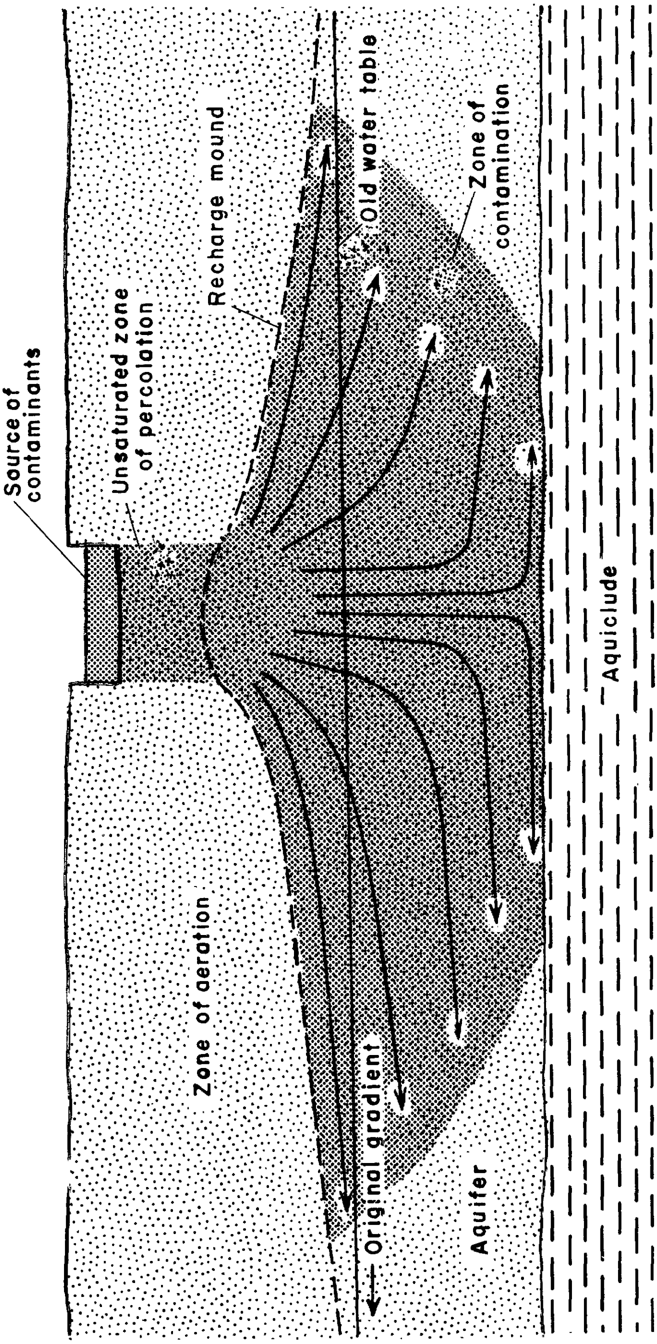

FIGURE 11.—Diagram showing percolation of contaminants through the zone of aeration into an isotropic aquifer.

PHENOLS

Phenols are among the most noxious substances that have contaminated aquifers in various areas of the State. Phenol (carbolic acid) is a hydrocarbon contained in some industrial wastes. Studies made by the Pennsylvania State Board of Health indicate that when the concentration of phenols in the Ohio River exceeds 0.02 ppm, ground-water supplies recharged by infiltration are contaminated (Noecker and others, 1954, p. 46). One or two days after the phenols appear in the river water, the water from nearby wells has the characteristic phenolic medicinal taste and odor. According to Elder and others (1948, p. 285), chlorination of water containing phenol results in chlorophenolic substances detectable to the taste in concentrations of 0.001 ppm (1 part per billion) of water.

The U.S. Public Health Service (1946, p. 383) stated that phenols in excess of 1 ppm preferably should not occur in natural or treated waters. There is some disagreement, however, on what the maximum permissible concentration of phenols in drinking water should be, although it is apparent that only a small concentration is sufficient to impart a detectable taste. Once phenol enters an aquifer, the disagreeable taste and odor that it imparts may persist for long periods of time in spite of attempts to flush or to dewater the aquifer.

CREOSOTES AT REED CITY

A somewhat ironic instance of contamination occurred at Reed City, Osceola County. In 1950, the Water Resources Commission issued an Order of Determination directing the city to complete construction of adequate sewage disposal facilities. The order was issued because of the high content of bacteriological wastes in the Hersey River caused by discharging of sanitary wastes without adequate treatment.

Dewatering operations necessary for construction required continual pumping of ground water from the treatment plant site into the Hersey River. Concurrently, many fish died in a 1½-mile reach below Reed City, and minnows and trout farther downstream were notedly distressed. Laboratory analysis showed that the ground water pumped from the excavation contained 36 ppm of phenols—decidedly above the toxic limit of various species of fish. The site selected for the sewage treatment plant was above a pit formerly used by an industrial firm for the disposal of creosote, tars, oil, and other hydrocarbons. The field inspector of the Water Resources Commission observed that "no worse spot could have been selected" for the sewage-treatment plant. To prevent further contamination of the Hersey River, it was necessary to locate the sewage treatment plant at a new site.

CHARCOAL WASTES AT MANCELONA

Another example of aquifer contamination from a pit occurred at Mancelona, Antrim County. An investigation by the Water Resources Commission revealed that phenol contamination of the ground water resulted from the disposal of industrial wastes several years earlier. The distance that waste liquids may migrate through an aquifer is indicated by the fact that a schoolhouse well about 3 miles west of a disposal pit near Mancelona showed traces of phenol. The Water Resources Commission estimated that the glacial-drift aquifer was contaminated in an area 3 miles long and half a mile wide and to a depth of about 200 feet.

REFINERY WASTES AT ALMA

At Alma, Gratiot County, during the latter part of 1945, the city began to receive complaints from consumers about the foul taste of the water supplied by city well 5. A preliminary investigation showed the presence of gasoline in the ground beneath the basement of a lodge. The gasoline was reported to have originated from a storage tank that supplied fuel for lighting purposes prior to the availability of electric power. Connection between this point of contamination and the city's well, however, was never proved. In 1949, water from city well 4 developed a similar taste, and this well was removed temporarily from service because of consumer complaints. Further investigation also revealed a concentration of phenols in the vicinity of a waste-detention pit at a local refinery. Municipal wells at Alma derive water from deposits of buried outwash. The waste pit, however, discharged liquids to a surficial aquifer consisting of about 30 feet of sand and gravel. The two aquifers are separated by an aquiclude composed of material ranging from clay to fine clayey sand.

An aquifer test conducted in the area by the Michigan Geological Survey showed hydraulic connection between the two aquifers in the vicinity of the contaminated area. Both the surficial sand and the buried outwash aquifers were contaminated for a distance of about 3,000 feet from the point of seepage and well 5 had to be abandoned. This created a serious situation at Alma because the city for many years had experienced considerable difficulty in obtaining a supply of ground water adequate for its requirements.

This case is especially significant from a hydraulic standpoint because it demonstrates the possibility of contaminating an artesian aquifer through a so-called confining bed (aquiclude). In many artesian systems in Michigan, and particularly in the glacial drift deposits, the aquicludes permit considerable leakage in either vertical direction. (See fig. 3.) Beds of clay or silt do not necessarily form a watertight protective layer.

PICRIC ACID AT LANSING

During World War II, picric acid (trinitrophenol) was discharged into a pit at a chemical plant at Lansing, Ingham County. The acid infiltrated to the Saginaw Formation, the chief aquifer in the area. The contamination extended laterally about the length of a city block and infiltrated through about 70 feet of glacial drift before entering the Saginaw Formation. The quality of water from 2 municipal wells was impaired by the acid to such an extent that 1 well was removed from service for a year. After discovery of the contamination, the well was pumped to waste intermittently for about a year before the picric acid concentration was reduced sufficiently to permit return of the well to service. However, as late as 1959, a city official reported that after municipal wells in the area were shut off and water levels were allowed to rise into the contaminated zone, the water still contained traces of picric acid and had to be pumped to waste until the levels declined below the contaminated zone.

ELECTROPLATING WASTES

Electroplating, and especially chrome plating, is a minor but locally important industry in Michigan. The electroplating process for chrome results in a problem of disposing of the plating wastes, which include hexavalent chromium, cyanide, caustic soda, and rinse waters. Disposal of electroplating wastes to surface streams in the past has created serious hazards to the public health. The U.S. Public Health Service (1946, p. 382) stated "hexavalent chromium in excess of 0.05 ppm (1 part in 20 million) shall constitute grounds for rejection of the (public water) supply." The chromate imparts a yellow tinge to the water in which it is dissolved. The toxicology laboratory of the Michigan Department of Health reported that chromium in the amount of 1 ppm may have a detrimental effect on the human nervous system and kidney tissues and that chronic illnesses may result. The presence of cyanide in any amount whatsoever will render a water supply unfit for human consumption.

As an alternative to disposal of electroplating wastes in surface streams, some concerns have attempted to dispose of these waters to infiltration pits. This practice has some merit in that the hazard from cyanide is reported to be largely eliminated. The Water Resources Commission observed that although they

> have encountered a number of ground-water pollution problems involving electroplating wastes, no instance has occurred * * * where cyanide could be traced in wells any distance from the point of disposal. This is accounted for by the various reactions to which cyanide is subjected by subsurface formation.

Disposal of the waste to the ground, however, has not solved the chromium contamination problem because chromium is not completely removed from the water by the materials comprising the aquifer. Once the chromium is introduced, the aquifer is rendered unfit as a potable water source for a prolonged, but unknown, period of time. It is not known whether natural flushing action or dewatering by pumping can effectively remove the chromium already in the aquifer.

CHROME-PLATING WASTES AT DOUGLAS

In 1947 the State Department of Health was notified that water from the west wells tapping the glacial drift at the village of Douglas, Allegan County, had turned yellow, and a sample was furnished for chemical analysis. The wells were removed from service pending the laboratory report. Analysis revealed a chromate content of 10.8 ppm, or more than 200 times the concentration for hexavalent chromium that the U.S. Public Health Service (1946) recommends as the maximum safe limit in public-supply systems.

The source of contamination was an infiltration pit and a surrounding overflow area into which chrome-plating wastes had been discharged for about 3 years. The area was about 1,000 feet south of the west wells and 2,500 feet southwest of the east well at Douglas. Discharge of the plating wastes had resulted in contamination of the glacial-drift aquifer for at least 1,000 feet in one direction from the pit and to a depth of at least 37 feet. Assuming that the contamination was detected soon after it reached the well, the waste would have migrated at a rate of about 1 foot per day along the gradient created by pumping of the west wells.

The supply from the east well also was endangered although the 1947 analyses of water from that well showed no chromate content. As a safeguard, periodic repeat chromate analyses of water from the east well were ordered for an indefinite period. The wells of a local dairy were contaminated also, and, at the request of the Health Department, the Village Council was asked to condemn all private wells in the village because there was no practical way to test the water quality in each one.

CHROME-PLATING WASTES AT BRONSON

Since 1939, electroplating industries at Bronson, Branch County, have experienced difficulty in disposing of electroplating wastes (*L. A. Darling Co.* v. *Water Resources Commission*, 286 Mich. 520). Originally, the wastes were discharged into the city's sewer system, which emptied into a county drain and a creek. Contamination of these watercourses resulted in the death of fish and cattle below Bronson. Death was due to ingestion of cyanide, and the city issued an ordinance to prohibit discharge of toxic wastes to the city's sewer systems. The plating wastes of the principal company involved subsequently were separated and discharged into two ponds. By 1942, however, renewed chromium contamination of surface water was indicated by a faint yellow color in the flow from the sewer system. The contamination was probably due to surface and subsurface leakage of plating wastes from the ponds, or possibly to reuse of the storm system for waste disposal.

In 1949, ground-water contamination at Bronson was indicated when the owner of a domestic well observed a greenish tinge in his well water. The well was 75 feet from the sewer carrying plating wastes to the disposal ponds. In December of 1949, the Water Resources Commission collected samples of water from one of the ponds, the domestic well, and a well at the county highway garage between the pond and the domestic well. The domestic well was 13 feet deep, and the water level in this well was 8 feet, 6 inches below the land surface. The well at the garage was 33 feet deep and the water level was 8 feet, 2 inches below the land surface. Both wells tapped the same shallow glacial-drift aquifer.

Results of the analyses made by the Michigan Department of Health, in parts per million, were as follows:

	Pond	*Highway garage*	*Domestic well*
Cyanide	15.6	0	Trace
Chromium	6.0	0	2.0
Nickel	49.0	0	Trace
Copper	12.0	0	0
pH	6.6	7.5	7.5

Apparently, the upper part of the aquifer, tapped by the domestic well, was contaminated at the time, but the lower part, tapped by the highway garage well, was not. A check on the sewer lines revealed that they were in good condition and were not contributing contamination to the aquifer. Evidently, the plating wastes were moving directly from the disposal ponds. By December 29, 1949, the chromium content of water in the domestic well had risen to 3.5 ppm.

Several interesting hydrologic observations can be made, from the chromium contamination at Bronson.

1. The chemical analyses reveal that the 33-foot well at the county garage was not contaminated at the time the sample was collected, although the well is between the contaminated shallow domestic well and the disposal pond. This shows that the chromium contamination was not uniformly distributed throughout the aquifer. The contaminant may have been confined to the upper part of the ground-water body and only slightly dispersed in traveling through the aquifer. Movement to the deeper well could have been impeded in part by lenses of low permeability within the aquifer.

2. The natural gradient of the water table in the shallow-drift aquifer was reported to be northwestward, but the contaminated well was southwest of the disposal pond. This indicates that a ground-water mound was built up creating a gradient that caused some of the wastes to move in a different direction than the natural gradient. Underground movement of contaminated water would tend to be radial from beneath the pond (fig. 12). The degree of buildup of the mound, and hence, the distance the water moves opposite to the natural gradient, is controlled by the slope of the natural gradient, the physical character of the aquifer, and the quantity of contaminated water introduced. Pumping of wells also would result in local gradients opposite to the natural gradient. Thus, areas upgradient under natural conditions from sources of contamination are not necessarily protected from pollution.
3. After more than a decade, there was concern that new wells proposed to be drilled to a deeper aquifer by the city might also be subject to chromium contamination. The lower aquifer is reported to be separated from the contaminated upper aquifer by a thick impervious clay stratum. The concern that deeper wells may be contaminated may be warranted, however. Aquifer tests made in numerous areas of the State by the Federal and State Geological Surveys seldom reveal artesian conditions perfect enough to completely shut off interaquifer movement of water. Ferris (1949, p. 222) noted that the permeability of a sample of clayey silt (a common aquiclude material) containing about 50 percent clay and 45 percent silt was determined to be 0.2 gpd per sq ft as determined in the hydrologic laboratory of the U.S. Geological Survey. He calculated that if the head in the water table aquifer were 50 feet greater than the piezometric surface in the lower aquifer (as might be expected if the lower aquifer were heavily pumped) 5.6 million gallons per day per square mile (mgd per sq mi) would leak through the clayey silt aquiclude into the deep aquifer. This would supply each of 56,000 people with 100 gallons of water per day.

Study of the well logs or even visual inspection of a clay layer is inadequate to determine the impermeability of clayey materials. Laboratory determination of permeability or extensive aquifer testing would be necessary to determine the hydraulic characteristics of the impervious clay stratum. Further, a determination of whether the confining layer is penetrated by wells with rusted or broken casings that would permit leakage of contaminants to the lower aquifer would have to be made. (See fig. 18.)

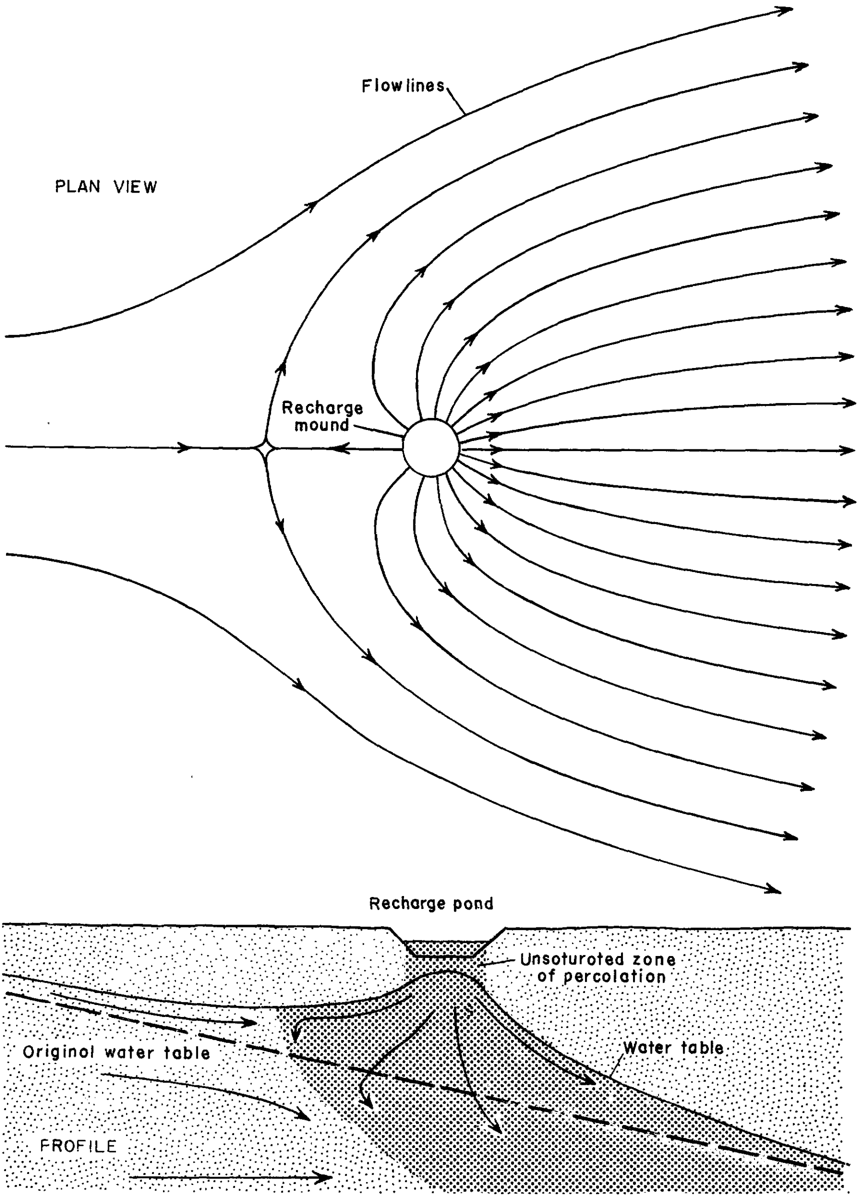

FIGURE 12.—Diagrams showing lines of flow from a recharge mound on a sloping water table.

GASOLINE AT EAST SAUGATUCK

The owner of a roadside grocery store near East Saugatuck, Allegan County, complained about a gas or oil taste and odor in water taken from his domestic well drilled to a depth of 25 feet in the glacial drift. An investigation by the Michigan Geological Survey revealed that the grocer had formerly operated a gasoline service station in conjunction with his grocery store. Apparently, gasoline from the abandoned underground storage tank had seeped into the aquifer. Drilling of a deeper well tapping the aquifer below the contaminated zone was recommended as the most economically feasible method of obtaining a potable water supply free of gasoline contamination.

This example of ground-water contamination at East Saugatuck is not unique in Michigan, as a similar problem has plagued the city of Grand Marais, Alger County. The possibility of leakage from an abandoned fuel tank at Alma has been referred to previously. Because gasoline and other petroleum products are offensive in water supplies, even in minute amounts, and may be impossible to remove from an aquifer completely, extreme caution should be taken to prevent leakage of such materials into the ground.

OIL-FIELD BRINES IN ISABELLA COUNTY

Daoust (1953) reported that the first serious brine disposal problem in Michigan occurred following discovery of oil in 1930 in the Dundee Formation in Isabella County. Pumping of crude oil from the field also yielded a large volume of brine, which is a highly concentrated solution of salt. At the time of the discovery, satisfactory methods of brine disposal in Michigan were not in use. Ponds that were constructed to hold brine were filled and the brine escaped over the tops. Larger ponds were built and even lakes were used for storage of the brine, but all techniques of surface storage or discharge proved unsatisfactory. Gross contamination of ground-water supplies in the area resulted from disposal of the brines.

Daoust described the various damages that occurred and concluded that the only practical and satisfactory method of disposal was to return the brine to some underground formation. He reported that the oil operators, with assistance of the Department of Conservation, solved the problems of brine recharge to deep formations. Since the early 1940's ground-water contamination by oil-field brines in Michigan has been virtually eliminated.

UNTREATED SANITARY WASTES

The extent and duration of pollution of ground water that can be caused by disposal of bacterial and chemical sanitary wastes are indicated by the results of experiments conducted by the U.S. Public Health Service (Stiles and others, 1927, p. 6–7). The aquifer used for the test is a surficial sand along the Atlantic Ocean near Fort Caswell, N.C. Bacterial pollutants (*Bacillus coli*) were recovered from ground water as much as 232 feet and a chemical pollutant (uranin) as much as 450 feet from a trench into which both excreta and uranin were placed. Both types of pollution traveled in the direction of ground-water flow. High ground-water levels resulting from wet weather are conductive to extension of pollution. Dry weather, which causes lowered ground-water levels, inhibits the extension of pollution. *Bacillus coli* remained alive in ground water for at least 32 months, and uranin remained visible in the ground water for at least 31 months.

SEPTIC TANK EFFLUENT

Septic tanks, which are in widespread use in Michigan, constitute a considerable hazard to the ground-water resources. They are sources of potential bacterial and chemical contaminants despite the fact that they are designed to purify, to some extent, the raw sewage discharged into them. If septic tanks are to operate efficiently, they should be installed in unconsolidated materials of at least moderate permeability. Areas underlain by such materials are favorable for ground-water recharge and septic tank effluent is, therefore, a source of recharge. This, in effect, relegates aquifers to sewage disposal rather than water-supply media. In some areas of the State, especially in the southeastern part, shallow deposits of sand and gravel, in which septic tanks are installed, are also the chief sources of ground water. As septic tank effluent is by no means pure (Hepler and others, 1953), part of the aquifer to which it precolates may become contaminated.

The Michigan Department of Health (1956, p. 9–10) reported on a survey made from 1925 to 1932 to study the effect of well depth on the bacterial quality of water affected by discharge from septic tanks. The study clearly showed a direct relation between the depth of a well tapping the glacial drift and its ability to produce water free of bacterial contamination. Very shallow wells, those less than 20 feet deep, are most likely to be contaminated. However, factors other than depth of the wells must be considered: (1) Declining levels in deeper wells would directly reduce the separation between the septic tank effluent and the well screens and thus increase the contamination hazard, (2) the thickness of the effluent layer tends to increase with time, (3) recharge from precipitation is to the top of the aquifer and must percolate through a contaminated zone before reaching the various well screens.

The effect of the septic effluents on the chemical quality of the water has grown into a major and serious problem in recent years because of the increasing use of synthetic detergents or syndets. Of the three types of synthetic detergents in use—anionic, cationic, and nonionic, the most widely used are the anionic types (Sawyer and

Rykman, 1957) that may impair the ultimate use of ground waters they enter. The anionic synthetic detergents all contain an organic surface-active agent that has the important qualities of wetting, dispersing, and emulsifying soil. Alkyl benzene sulfonate (ABS) is the most widely used of the synthetic detergents. The basic reason for the wide popularity of syndets is the fact that they are virtually unaffected by the alkaline earths, to whose presence hardness of water is attributed (American Water Works Association, 1958). The American Water Works Association (1959) reported that synthetic detergent use was estimated to be 20 pounds per person during 1959, and by 1960, the average annual use was expected to be about 23 pounds per person.

The presence of syndets in water causes unpleasant taste and frothing. Flynn and others (1958) reported that most persons detect the taste when the syndet concentration is 1.5 ppm or higher and that frothing appears at about 1.0 ppm. Their study of an area in Suffolk County, N.Y., where water is obtained from shallow glacial-drift deposits, revealed that syndets have appeared in wells as deep as 95 feet and as much as 500 feet from their source. It was found that detergents known to have been discharged several years before the study did not deteriorate or stabilize to less objectionable compounds. The study pointed out the possibility that syndets may be a vehicle to transport bacteria, viruses, and other pollutants greater distances than they might normally travel. Further, the authors stated that the phosphates present in most detergents might increase the number and survival time of bacteria in ground water as some bacteria can use phosphates as a food.

Butler and others (1954) studied movement of both bacterial and chemical pollutants and made a number of conclusions that are important in evaluating the potential hazard of aquifier contaminants from septic tank operations:

1. The movement of percolating water containing chemical and bacterial pollutants is vertical until the water table is reached.
2. Bacteria will travel only about 5 feet through fine moist or dry soils, but longer travel probably would take place in coarse materials.
3. Chemical pollutants travel farther and faster than bacterial pollutants in ground water, although coliform organisms have been reported to travel distances of 10–232 feet in ground water.

Their report also points out several serious gaps in our knowledge concerning potential contamination:

1. The movement of pollutants through the soil above the water table has been studied more extensively than movement of pollutants

in ground water, although much remains to be investigated in both fields.

2. The ability of a polluted soil to contaminate a rising ground-water table is not known. (By the same token, its ability to contaminate water recharging from precipitation is not known.)

Hazards of bacteriological pollution from septic tanks are especially great in areas where permeable limestone formations are at or near the surface. In contrast to glacial drift deposits, where the septic tank effluent moves through the interstices between the rock particles, the water in limestone, dolomite, and other dense rocks moves largely through secondary openings along bedding planes, fractures, or solution cavities (fig. 13). Little or no filtering action occurs, and, hence, the bacterial pollutants along with deleterious chemicals from the septic tank may travel large distances underground laterally or vertically.

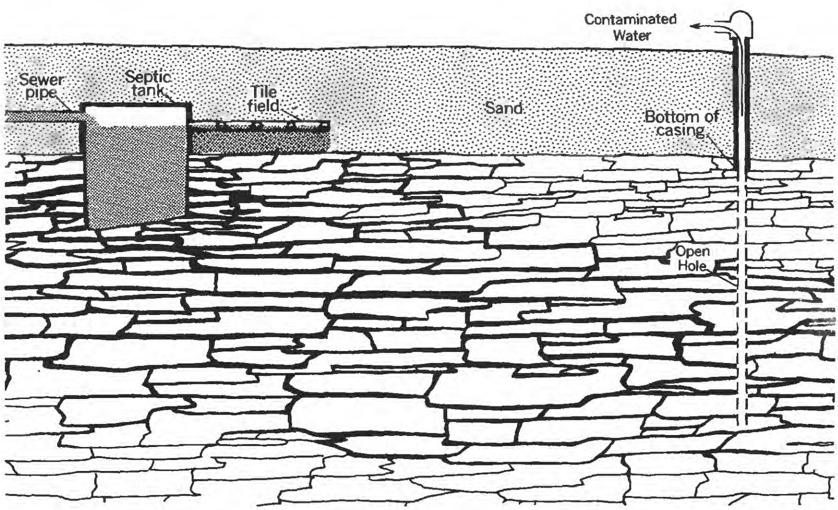

FIGURE 13.—Diagram showing movement of contaminants from a septic tank through secondary openings in limestone or dolomite.

DETERGENTS IN MUSKEGON COUNTY

Chemical analysis of water samples made by the Michigan Department of Health has shown that shallow aquifers in various parts of the State have been affected by discharge of syndets from septic tanks serving suburban housing developments. A spot check of many of the analyses from Muskegon County, where water supplies commonly are obtained from shallow sand aquifers 20 to 30 feet in depth, showed that a rather large percentage of the samples collected contained detergents. At one housing subdivision 5 to 10 years old, about half of the samples collected contained syndet concentrations of 1 to 2 ppm. In a newer development, syndets were present in water taken from wells serving houses built less than 2 years prior to the collection of the samples. The Health Department reported that in one well the concentration of syndets was high enough to cause suds to billow from water appliances.

The contamination of ground waters in Muskegon County by syndets is cited herein only as an example of a growing problem in Michigan.

SEWAGE IN THE MANISTIQUE-GULLIVER AREA

In the Manistique-Gulliver area, Schoolcraft County, the glacial drift mantle is thin and discontinuous, and the Manistique and Burnt Bluff Formations of Middle Silurian age crop out at or near the surface over a large area. These formations are the most important aquifers in the area. Contamination by liquid wastes is a constant hazard, owing to free circulation of water through solution openings and fractures at the surface of the formation (Sinclair, 1959). Residents in the area rely on septic tanks for the disposal of domestic sanitary wastes. Because of the absence of an adequate soil or sediment layer to serve as a filtering medium at many sites, virtually raw sewage spills directly into the Burnt Bluff and Manistique Formations. Many wells have been reported to yield ground water of poor bacteriological quality.

HEPATITIS EPIDEMIC AT POSEN

During the summer of 1959 a severe epidemic of infectious hepatitis (a severe liver ailment) at Posen, Presque Isle County, was investigated by personnel of the State Department of Health and State Geological Survey. A total of 89 cases were reported, although it is probable that many more cases were not reported (Vogt, 1961). Preliminary findings left little doubt that the hepatitis was caused by ingestion of polluted ground water. The source of the polluted water was the Traverse Formation of Middle and Upper Devonian age, which is quite permeable due to the presence of fractures and solution cavities. At Posen, this formation is at or near the land surface. The investigation showed that many of the wells in the area were improperly constructed and permitted drainage from the surface or from shallow depth. Also, numerous septic tanks were installed close to domestic wells in the area—in one place only 6 feet away. In addition, kitchen sinks, sump holes, and ditches drained directly into the formation.

A half a century ago, Matson (1911), describing a similar problem concerning underground streams flowing through openings in limestone, wrote as follows:

> The practice of putting rubbish, barnyard filth, etc., into (limestone) sinks should be abandoned. Still more reprehensible is the custom of running sewage into sinks, thus converting the underground channels into natural sewers * * *

SPILLING OR SPREADING ON THE LAND SURFACE

Ground-water supplies in Michigan have been contaminated in a variety of ways as a result of the presence of deleterious solid or liquid matter at the land surface. Liquid wastes disposed of, spilled, or stored on the land surface may adversely affect the quality of ground water by subsequent percolation to an aquifer. Any type of solid material that contains soluble contaminants and through which water may percolate to an underlying aquifer presents a potential hazard (fig. 14). Land fill, salts stored or spread for melting snow, dumps of various types, sanitary wastes, fertilizer, and farm animal excrement all are potential sources of contamination.

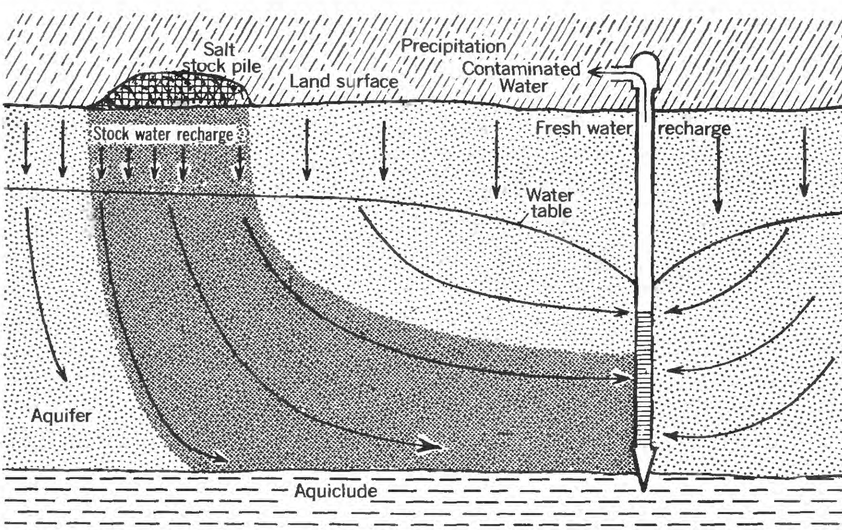

FIGURE 14.—Diagram showing contamination of an aquifer by leaching of surface solids.

The following examples of ground-water contamination resulting directly from migration of harmful substances from the land surface illustrate that public education is needed to protect ground water, especially in shallow aquifers, because the public apparently is not aware of the hazards to ground water involved in certain practices.

PICKLE BRINES AT EDMORE

In 1949 a municipal well tapping the glacial drift at Edmore, Montcalm County, began to produce water with a distinctly salty taste. Laboratory analyses by the Michigan Department of Health showed that the water contained 1,900 ppm of chloride. In 1943, the chloride content of water from this well was 34 ppm. Investigation by the Water Resources Commission revealed that brine spilled on the ground several hundred feet from this well by a pickle-brining plant was the obvious source of this contamination. The practice of spilling brines on the ground was halted by order of the Michigan Water Resources Commission. The contaminated well was plugged and abandoned. By 1957, the water from a municipal well 1½ blocks away contained only 60 ppm of chloride.

MILK WASTES AT TRENARY

According to a 1950 investigation of pollution of ground water at Trenary in Alger County made by the Michigan Department of Health and the Michigan Geological Survey, whey and milk wastes from a local cheese plant polluted at least 15 private wells in the vicinity of the plant. The polluted wells, all of which tapped shallow fractured and creviced limestone and dolomite of the Trenton and Black River Formations, ranged in depth from 35 to 75 feet. The mode of entry of the milk wastes into the aquifer is not described but it probably was either spilled on the ground or discharged to a clogged or defective sewer after a State Health Department order to cease discharging the wastes to a nearby creek. The Health Department noted that many of the wells also were contaminated by coliform organisms that usually originate from sanitary wastes.

The contamination problem at Trenary illustrates the fact that in certain shallow aquifers through which ground water may circulate freely, and especially in very permeable limestone, it may be extremely difficult or virtually impossible to dispose of sanitary or other wastes without contaminating the ground water tapped by nearby wells (fig. 13). Towns or cities located in areas supplied with ground water from such aquifers may find it impossible to provide adequate isolation distances of wells from sources of contamination such as polluted surface waters, sewers, cesspools, septic tanks, and noxious substances at the surface.

RAW LIQUID FERTILIZER NEAR HOLLAND

At a fertilizer plant near Holland, Ottawa County, raw liquid used for the manufacture of fertilizer is transported by railroad tank cars and stored in tanks mounted on platforms at the site. It was reported to the Michigan Geological Survey that the liquid in one tank was found to be unusable and so was spilled on the ground by a plant employee who opened a petcock at the bottom of the tank. Water supply at the plant came from a well tapping 20 or 30 feet of glacial lake sand. The water in the well eventually developed a brown color and a distinct ammonia odor as the spilled waste ultimately migrated to the well. The problem was compounded because the sand aquifer is the only source of fresh ground water in the area. The situation was aggravated further because the aquifer could not be dewatered inasmuch as the nearest stream usable for surface disposal was several miles distant.

LAND-SURFACE DUMPING

Of considerable hazard to water supplies in various areas of the State is the practice of dumping garbage and noxious wastes in abandoned sand or gravel pits or on land-surface dumps. According to the Michigan Water Resources Commission, "waste oils, paints, paint thinners, chemicals, and other odium" have been discarded in areas where such wastes have easy access to aquifers.

Calvert (1932) described serious contamination of wells at Indianapolis, Ind., by garbage "liquors" from a disposal site 500 feet away. This example is significant because the possibility of contamination was studied prior to the dumping of the garbage, but it was wrongly predicted that the infiltration of garbage "liquors" would be negligible. The potential hazards of such practices were indicated by Lang (1933), who reported that leachings from an old garbage dump reached wells 1,476 feet away, causing considerable increases in the hardness and the dissolved-solids content of the water. Lang and Bruns (1941) noted one area where picric acid waste traveled underground for 3 miles in 4 to 6 years. They cited another example where garbage dumped in a sand pit continued to pollute wells 2,000 feet away 15 years after dumping had ceased. This practice is common in Michigan where low-lying swampy land is reclaimed by using "sanitary land fill" until the land surface is raised to the desired level and then by covering the refuse with soil and sand.

SALT USED FOR SNOW REMOVAL

The practice of spreading salt in the form of sodium or calcium chloride on roads to melt snow is widespread in the State. The melted snow, of course, represents nothing more than contaminated recharge water, and roadside wells in areas supplied by shallow aquifers receiving such recharge are especially subject to chloride contamination.

Stockpiles of salt or sand treated with salt are stored at many of the garages of County Road Commissions in the State. Most of these stockpiles are in the open, and the soluble salts are reached readily by rainfall or melting snow. Shallow aquifers in the vicinity, if they are recharged by precipitation, are hence susceptible to chloride contamination. Although the practice of maintaining uncovered stockpiles of salt and salt-treated sand is widespread, the extent of resulting ground-water contamination in Michigan is not known. At the time of the present report, the Delta County Road Commission is alleged to have caused contamination of shallow parts of the Black River Limestone at the village of Rock by this practice. Litigation in this matter is impending. Storage of salt stockpiles in sheds, or perhaps even covering the stockpile with a tarpaulin or plastic film, may abate the nuisance by preventing leaching of the salt by rain or melting snow and subsequent migration to the water table.

MANISTEE COUNTY

Pollution of several roadside domestic wells has been reported by the Manistee County Sanitarian. The chloride contamination of shallow aquifers resulting from the spreading of salt on the roads of Manistee County undoubtedly has occurred in other areas of the State where similar practices are followed.

A domestic well 30 feet deep and located about 300 feet from a Highway Department salt pile was reported by the owner to be producing salty water. Analysis of the water revealed that it contained 4,400 ppm of chloride. Salt appeared also in drinking water along the highway near Parkdale as a result of its use on the roads for snow removal. Investigation here revealed that the dissolved salt flowed into leaky and cracked storm sewers and thence into the aquifer used by the wells located near the highway.

KENT COUNTY

An ironic incident in Kent County indicates that the practice of spreading salt for snow removal might prove detrimental to ground-water supplies for reasons other than potential chloride contamination. During the winter of 1955–56, the Wyoming Township Engineer received a call from a local resident inquiring why some of the snow along the roadside in the area was yellow. Investigation by the Township Engineer revealed that the Kent County Road Commission was using calcium chloride to melt ice and snow on the county roads. The salt, however, is reported to have been treated with a chromium-base rust inhibitor in order to allay previous complaints by county residents concerning rapid corrosion of automobile bodies caused by application of the salt. This was the first application of the treated salt to the roads in the county, but, fortunately, the Township Engineer recognized the potential hazard to the water supplies of the area and so notified the County Road Commission. An order halting the use of chromium-treated salt was issued immediately.

CHROMIUM COMPOUNDS CONTAINED IN LAND FILL AT GRANDVILLE

Ground-water was contaminated by chromium under unique conditions in the city of Grandville, Kent County. The city drilled a public-supply well into the glacial-drift deposits along the Grand River. In order to protect the well from flooding during periods of high water, the casing was extended several feet into the air, and the land surface around it was raised with sand and gravel. In time, chromium was detected in the water. This resulted in considerable consternation, because no source of chromium contamination was apparent in the vicinity. Investigation by the Grandville Superintendent of Water revealed that the sand and gravel used to raise the land surface at the well was taken from a former dumping ground for electroplating wastes. The river was in flood stage shortly before the contamination appeared. Water from the river obviously had leached the chromium from the fill and carried it into the aquifer (fig. 15).

PERCOLATION OF LEACHED NITRATES INTO SHALLOW AQUIFERS

In 1945 the Michigan Department of Health received several requests for nitrate determinations on well-water samples submitted by doctors who were trying to find the cause of methemoglobinemia or cyanosis in infants. The disease, commonly referred to as "blue babies" apparently is limited to children under 6 months of age. Methemoglobinemia occurs when nitrates in water are changed in the baby's intestinal tract to nitrites, which combine with the red blood cells to change the color of the blood and reduce its ability to carry oxygen to the body tissues (Comly, 1945).

The laboratory reports on water samples from nine wells in Saginaw, Bay, Gladwin, Wayne, Macomb, and Washtenaw Counties, where infants were afflicted with the disease, showed nitrate contents that ranged from 243 to 975 ppm. All these water sources were dug wells tapping shallow glacial-drift deposits, which are especially susceptible to contamination. The nitrates in the water were leached from decaying human and animal excreta. According to the Michigan Department of Health, none of the wells was properly constructed or located, and all should have been abandoned upon inspection.

Comly recommends that water used for the feeding of infants should have a nitrate content no higher than 10 ppm of nitrate expressed in terms of nitrogen (N) or 44 ppm when concentrations are reported

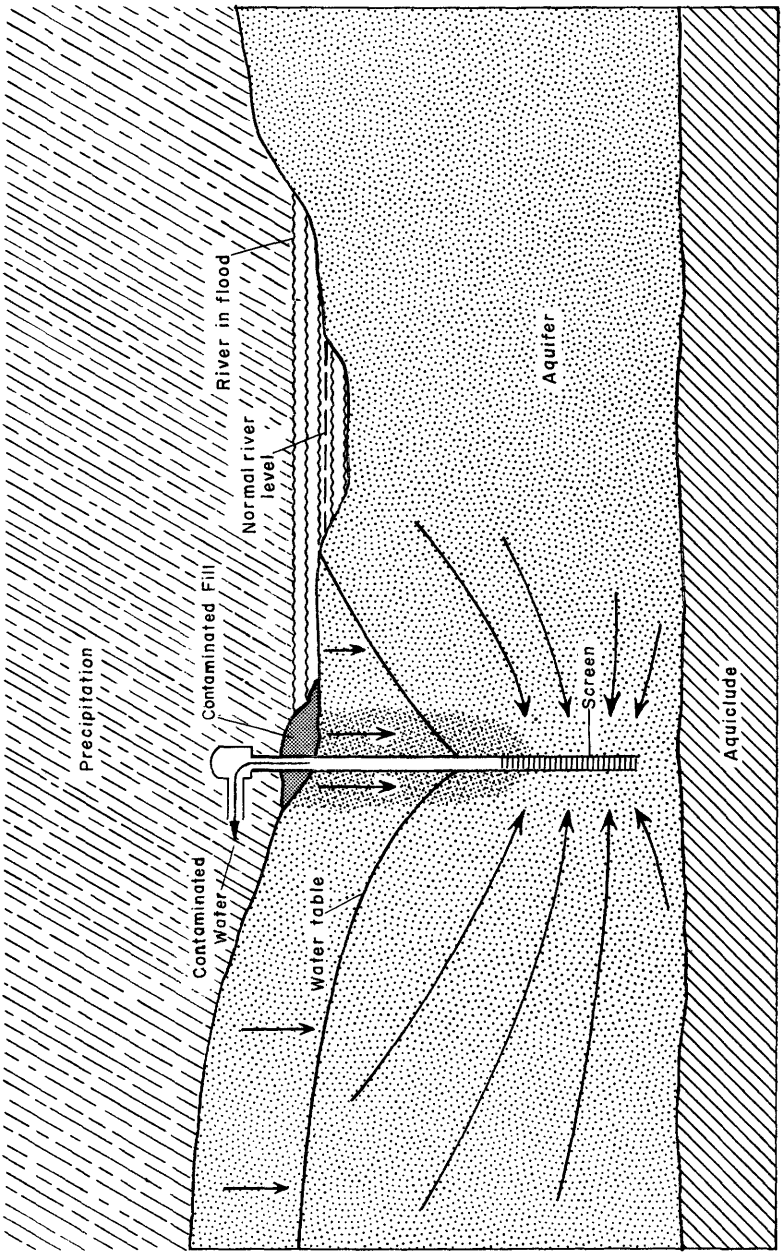

FIGURE 15.—Diagram showing leaching of contaminated fill into an aquifer by floodwater and precipitation.

as nitrate (NO_3). Hem (1959, p. 239) states that different ways of reporting nitrate concentrations have led to considerable confusion among water users concerning these limits.

LEAKING SEWERS OR PIPELINES

Leaking or broken sewers and pipelines are common sources of ground-water contamination. If the earth material in which the sewer is laid is of low permeability, the leaking fluid will generally erode a path to the surface, but if the sewer is in permeable sand and gravel outwash, for example, the fluid may contaminate a considerable volume of material in the vicinity of the leak.

SANITARY SEWER AT LANSING INDUSTRIAL PLANT

Within a 2-week period in 1952, 6 employees of a small industrial plant in the Lansing area became ill. They had complained that the water from the semipublic water system serving the plant tasted and smelled like sewage. Analysis of the water by the Ingham County Sanitarian showed that the water was grossly contaminated with coliform bacteria. The Ingham County Health Department reported that a leaded joint in the soil pipe sewer, 1 foot below land surface on the northeast side of the building, had parted—apparently from frost-heaving. The pipe had a slight rise in grade toward the septic tank allowing the sewage to leak into the ground. Also the seal between the well cap and casing consisted only of common putty and permitted the sewage to enter the well, which was on the south side of the building.

The length of time it took the sewage to permeate the ground between the sewer break and the well is not accurately known, although the plant superintendent reported that temporary sewer troubles had occurred about 5 years earlier. This incident demonstrates that even if wells are located at considerable distances from sewers or other sources of contamination, the wells must be constructed in such a manner as to prevent entrance of water from or near the surface.

LEAKING MUNICIPAL SEWERS AT STURGIS

During World War II, the Michigan Department of Health recommended that the city of Sturgis, St. Joseph County, abandon its wells or install a chlorination system because of the proximity of sewers to wells. Because of wartime conditions, however, the city was unable to make the recommended changes. The apprehension of the Health Department proved to be well founded because in 1945 a series of samples taken from the wells and various points on the water-distribution system were analyzed and all found to be bacteriologically unsafe. Attempts to clear up the contamination by chlorinating the wells were unsuccessful, indicating that sewage effluent was being induced to flow from leaking sewers to the wells in response to pumping.

PIPELINE SEALANT AT IONIA

At Ionia, Ionia County, part of the city's water formerly was taken from a shallow infiltration system in the glacial drift. The system consisted of dug wells used as collectors fed by a network of infiltration tiles. In January 1955, water from this system developed an objectionable taste, although water from wells tapping the glacial drift at depth had no such taste. The Superintendent of Water discovered that the taste originated in water from only one of the collectors and the objectionable taste disappeared when this well was valved off the system. Further examination showed that a leak existed in a 2-inch gas line only a few feet from the collector. The gas company had introduced a viscous material to the pipeline to seal small leaks. The break in the pipeline, however, was a major one and the pipeline sealer entered the ground-water collector. Chlorination of the sealant produced an extremely obnoxious taste. Because of its susceptibility to contamination, the shallow infiltration system was ultimately abandoned by the city, which subsequently constructed a deep-well pumping station.

INDUCED INFILTRATION OR LEAKAGE OF CONTAMINATED SURFACE WATERS

Surface waters from streams, lakes, swamps, or drains are still another potential source of ground-water contamination. In addition, flood water or pools of stagnating water lying on the surface after floods, storms, or spring thaws also are potential sources of contamination. Recharge from these sources may occur naturally by percolation through permeable materials such as sand and gravel or by flow through fractured and creviced limestone and dolomite. However, the greatest hazards of aquifer contamination by objectionable surface water probably results from infiltration induced by nearby pumping (fig. 16). The threat of aquifer contamination by surface water spilling or backflooding into wells has been described above under the section entitled "Injection into aquifers."

DISCHARGED SOFTENING-PLANT EFFLUENT IN PARIS TOWNSHIP

In Kent County the Water Resources Commission investigated the salt contamination of an aquifer tapped for water supply by Wyoming Township. The contamination resulted because the spent brine from a zeolite softening plant operated for the water-supply system of Paris Township was discharged to a creek that flows by Wyoming Township's 32d Street well field. Pumping by Wyoming Township

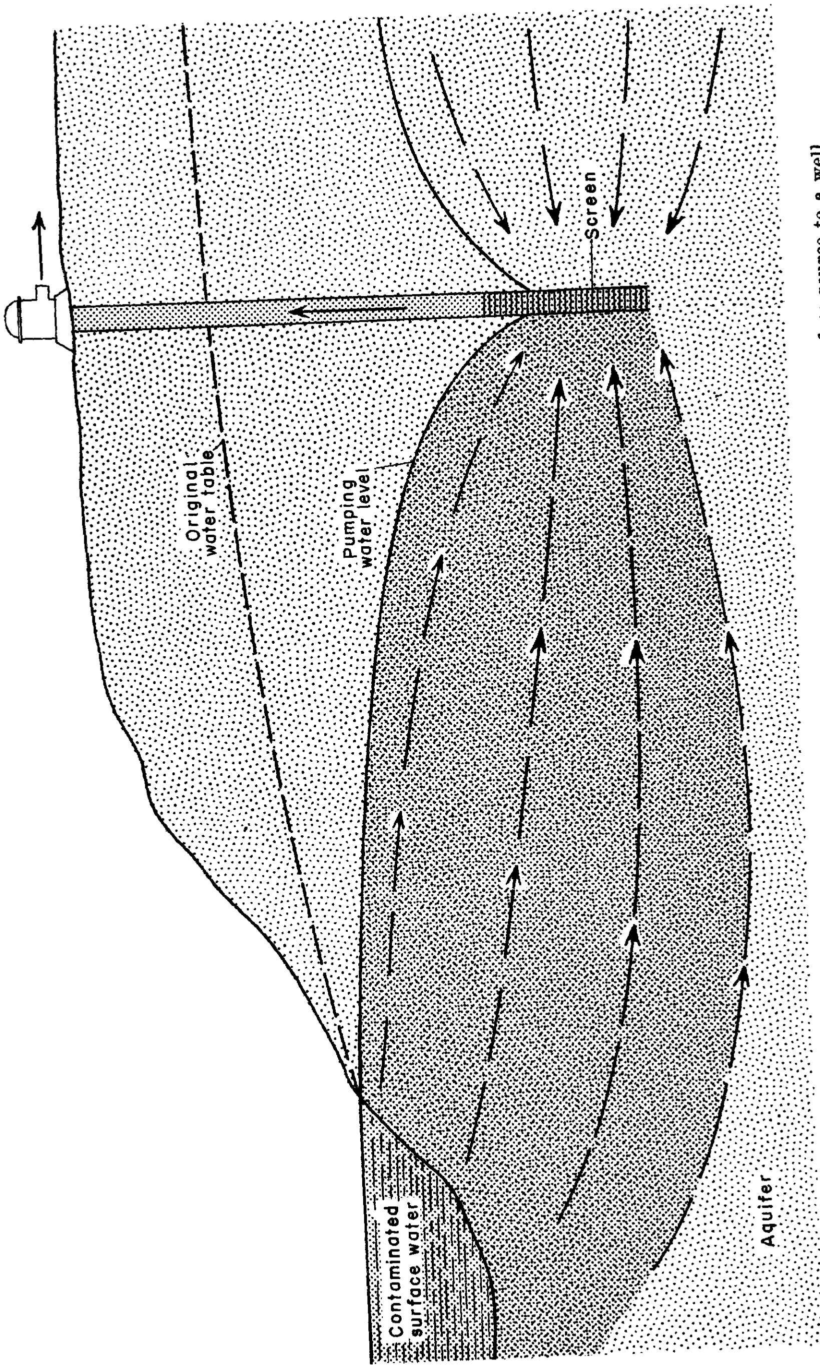

FIGURE 16.—Diagram showing how contaminated water can be induced to flow from a surface source to a well.

induced infiltration of the softening plant effluent from the creek through the aquifer into the public water-supply system.

DISCHARGED MINE WATER AT IRONWOOD

Before World War II, the city of Ironwood, Gogebic County, obtained a satisfactory supply of water from wells drilled in 1921 into the shallow gravel deposits along Siemen's Creek. The wells ranged in depth from 35 to 69 feet. The flow of the creek was sustained predominantly by water discharged from an iron mine. Because the gravel aquifer was thin, the creek was dammed and a channel was cut on the side of the wells opposite from the natural channel in order to allow maximum recharge of creek water to the wells by induced infiltration. In effect, the wells were located on an island.

Analyses of the water from these wells, made before World War II by the Michigan Department of Health, showed that hardness of water ranged from 120 to 162 ppm and chloride content from 13 to 58 ppm. During the war, however, the mines were deepened considerably. The hardness and the salinity of mine-drainage water discharged to the creek increased and the quality of Ironwood's ground-water supply deteriorated. The U.S. Public Health Service (1954, p. 17) reported a hardness of about 900 ppm and a chloride content of 1,100 ppm for the ground-water supply. An earlier analysis made in 1948 by the Michigan Department of Health showed a total hardness of 1,475 ppm and a chloride content of 1,030 ppm. The poor quality of the ground water obviously resulted from induced infiltration of contaminated water from the creek into the aquifer.

The water consumers voiced strong protests about the water quality and the city relocated its well field. The mine-waste pollution also threatened the new supply, until the State Water Resources Commission had the mine drainage diverted to another watershed.

SEWAGE-CONTAMINATED CREEK AT NORWAY

In 1947 the Michigan Water Resources Commission made an investigation of White Creek, locally known as Sewer Creek, near Norway, Dickinson County, which was reported to have been grossly polluted with untreated sanitary wastes. A farmer living near the mouth of the creek at its confluence with the Menominee River reported that water in his well 100 feet from the creek had become contaminated, which indicated that the aquifer tapped by his well was recharged at least in part by water from the creek.

When the Commission ordered the city of Norway to build a sewage treatment plant because of the gross contamination of White Creek, the city was unable to finance such facilities. The Commission granted temporary financial relief by agreeing to allow the city to dilute the creek water with water from an abandoned mine. Water had been pumped from the mine for many years in order to keep ground-water levels below basements in low areas and to keep the mine in good condition in the event mining operations were resumed. When the mine-drainage water was introduced into White Creek most of the fish were killed. The Michigan Water Resources Commission concluded that the fish kill and a temporary reduction in abundance of bottom animals in Sewer Creek was due to an almost complete lack of dissolved oxygen in the mine water. The fish literally had drowned in the mine-water diluted creek.

BACTERIAL CONTAMINATION IN COLLECTOR SYSTEM AT GRAND HAVEN

A case of contamination of the water supply at Grand Haven illustrates the hazards involved by accidental mixing of raw surface waters with water that has been naturally filtered and purified underground. Grand Haven, Ottawa County, is supplied by three collector systems in Lake Michigan. The collector systems consist of vertical caissons sunk close to the shoreline and to about 30 feet below the lake bottom. From these a series of screened collector pipes radiate horizontally into the sand and gravel aquifer beneath the lake; water enters these pipes and flows into the collectors, from where it is pumped into the city's mains. Systems of this type are installed to eliminate the filtration plant, which is normally used when surface waters are used for public supplies. Under normal operating conditions, this natural filtration reduces the bacterial content of the water delivered to the collector to satisfactory levels. However, in September 1951, a leak in the system allowed raw lake water high in bacterial content to enter the collector.

STAGNANT FLOODWATERS AT BENTON HARBOR

The following newspaper article concerning dangers to water supply as the result of flooding in Berrien County was published in the "Benton Harbor News-Palladium" on June 9, 1950:

Residents in the Marquette Woods area of Lincoln Township were warned today to boil all water used for drinking to avoid possible contamination caused by stagnant water.

Dr. C. E. Baggerly, health officer for Lincoln Township announced that officials of the State Department of Health at Lansing surveyed the area on Wednesday and issued the warning.

The township health official stated that the condition probably would last through the summer months.

Low-lying areas in the Marquette Woods district have been under water since the heavy floods earlier this spring. The condition was aggravated last week when heavy rains fell throughout Berrien County.

The drainage system is reported broken down, allowing the water to stand in vast pools throughout the area and polluting springs and wells.

The article points out the necessity of maintaining proper drainage of an area, especially after a flood, if ground-water supplies are to be protected against entry of polluted flood water through unsealed wells or against induced infiltration caused by pumping. This is especially important because floodwater almost always is grossly contaminated.

INSECTICIDES, HERBICIDES, AND WINDBLOWN WASTES

Until recent years, scant attention had been given to the possibility that insecticides, herbicides, or wastes borne in the air might adversely affect the quality of ground water. No instances of contamination of ground water in Michigan by pesticides have come to the attention of the author, but the possibility of contamination due to widespread and growing use both of insecticide and herbicide sprays in the State certainly should merit consideration. The effects of air pollution on water resources should also be studied.

Nicholson (1959) weighed the question whether insecticides damage water resources and concluded that the answer has not yet been resolved. He reported that surprisingly little is known about loss of the vast amounts of stable chlorinated hydrocarbon insecticides that have been applied to the soils in some of the southeastern States. He suspects that much of it is washed into the nearest watercourse from the soil surface, and he states, "Reason dictates that insecticides cannot be deposited on the uplands year after year without eventually getting into lakes and rivers." He makes no mention of the entrance of insecticides into ground-water reservoirs, but he reports that the U.S. Public Health Service at Cincinnati is seeking to determine the identity and concentration of insecticides present in surface and ground waters.

Chlorinated hydrocarbons are the most widely used of the various synthetic insecticides. They are absorbed and retained by the soil and hence tend to accumulate (Eno, 1959). Because the chlorinated hydrocarbons are resistant to decay, they could have adverse effects on the soils. Eno reports that for the most part, chlorinated hydrocarbons are only slightly soluble—leading to the inference that they are not readily susceptible to leaching by rainwater and subsequent recharge to underlying aquifers.

Herbicides have great potential value in various phases of soil and water conservation. At the time of the present report, however, information concerning the effects or potential effects of herbicides on the ground-water resources of the State is not available.

CHROME-LADEN DUST IN WYOMING TOWNSHIP

Airborne chromium has been suspected as the source of ground-water contamination in only one known instance in Michigan. For several years, Wyoming Township, Kent County, had difficulty in obtaining water free from chromium in one of its well fields. An electroplating firm on adjacent property was the apparent source of the chromium contamination. Accordingly, an engineering firm was retained to study the problem and to report on the possibility of further contamination and of means of abatement.

The firm's report (Williams and Works, 1956) concluded that air-borne chromium could have been introduced to the aquifer in several ways, including the following:

1. Chrome-laden dust was discharged through ventilators on the roof. Some of the dust settled to the ground, where it accumulated until rainfall washed it down to the water table, as depicted by figure 17. A general relation was shown between precipitation and chromium contamination in the township wells.
2. A dry well at the site, into which water from the roof of the plant drained, was another likely source of intermittent contamination. Some of the dust probably washed out of the air and onto the roof by precipitation, flowed down a rainspout into the dry well, from where it infiltrated to the aquifer and subsequently migrated to the well field in response to pumping.

In addition the Michigan Geological Survey reported that chrome-powder residue was present in or on containers left in the yard. Some of this hazardous powder may have been spilled on the ground from where it readily could have been leached and carried into the underlying aquifer by subsequent rainfall.

CONTAMINANTS INDUCED FROM NATURAL SOURCES

Fresh ground water in Michigan has been contaminated not only by the introduction of various deleterious substances from the surface but also indirectly by encroachment of natural waters of poor quality. Well drilling, pumping, dewatering, and construction activities have resulted in local changes of the ground-water regimen in ways that have caused migration of water of inferior chemical quality into various fresh-water aquifers. The contaminants induced to flow into fresh ground-water sources include brine and other water high in chlorides, sulfates, sulfides, or other naturally occurring fluids, including oil and gas. The source, chemistry, significance, and range in concentrations of the various mineral constituents present in natural water are described in detail by Hem (1959) and are mentioned only briefly here.

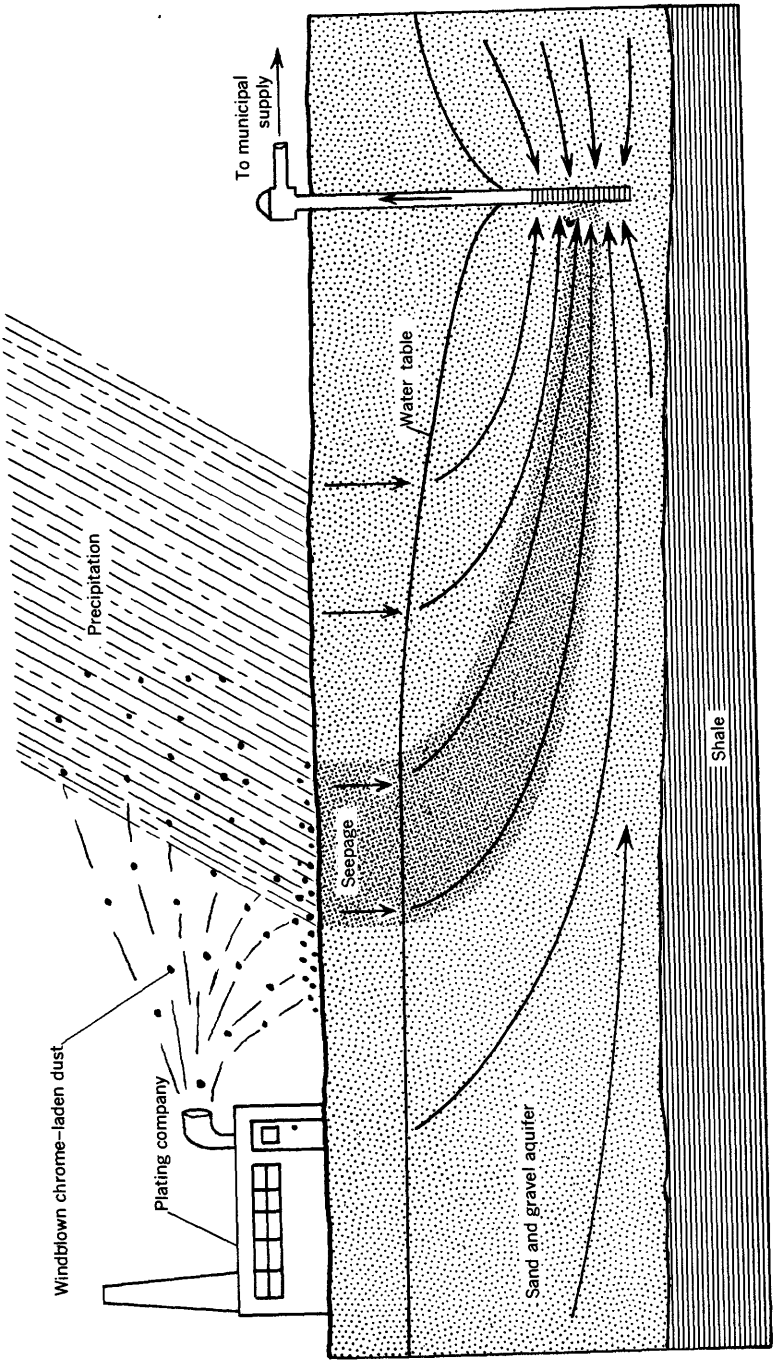

FIGURE 17.—Diagram showing possible mode of entry of windblown wastes into an aquifer.

VERTICAL LEAKAGE THROUGH OPEN HOLES

Extensive contamination of fresh-water aquifers in Michigan has been caused by vertical leakage of highly mineralized water into fresh-water aquifers through unplugged wells or test borings. Most of the test holes were put down in exploration for coal, oil, gas, brine, salt, or other economic mineral products. If the wells were not cased, as is common when drilling is through bedrock formations, water in any of the formations would flow up the well in response to the artesian pressure under which it is confined. The well is an avenue of nearly infinite vertical permeability through which the undesirable water may move. Protection from natural upward migration of mineral water afforded by confining beds of low permeability, such as shale or unfractured beds of limestone, dolomite, or siltstone, is lost. Pumping from fresh-water aquifers may lower the piezometric surfaces in the higher formations to levels below the piezometric surfaces of the various mineral-water-bearing formations. The saline water may then leak into permeable zones in formations containing fresh water under lower head or artesian pressures (fig. 18).

Saline waters commonly are found at relatively shallow depth in lowlands along the lower reaches of major rivers and along the Great Lakes and connecting waterways. The natural fresh-water head in some of these areas, especially in the Saginaw and Lake Erie Lowlands (fig. 19), is not great enough to prevent saline water from occupying shallow aquifers or from discharging into surface streams. The water table in the shallow fresh-water aquifers in these areas commonly is below the piezometric surface of the deeper saline-water aquifers. A reduction in the head of fresh water above the fresh- and saline-water interface, as a result of overpumping, also causes the interface to move upward as is indicated in figure 20.

BRINES FROM OIL WELLS AND TEST HOLES AT LOWELL

Chloride contamination of the fresh-water supply at the village of Lowell, Kent County, is an example of the adverse effects of brine flowing upward through wells and entering an overlying aquifer. For many years Lowell was supplied with water obtained from gravel deposits along the Flat River approximately half a mile north of the village limits; first, from a dug well 20 feet deep and 20 feet in diameter, and then from a tubular well 24 inches in diameter and 72 feet deep.

In 1933 the Michigan Department of Health determined the chloride content of a water sample from the tubular well and recorded only a trace of chloride. In the period 1935–37, several oil wells and test holes were drilled about half a mile upstream from the water-supply

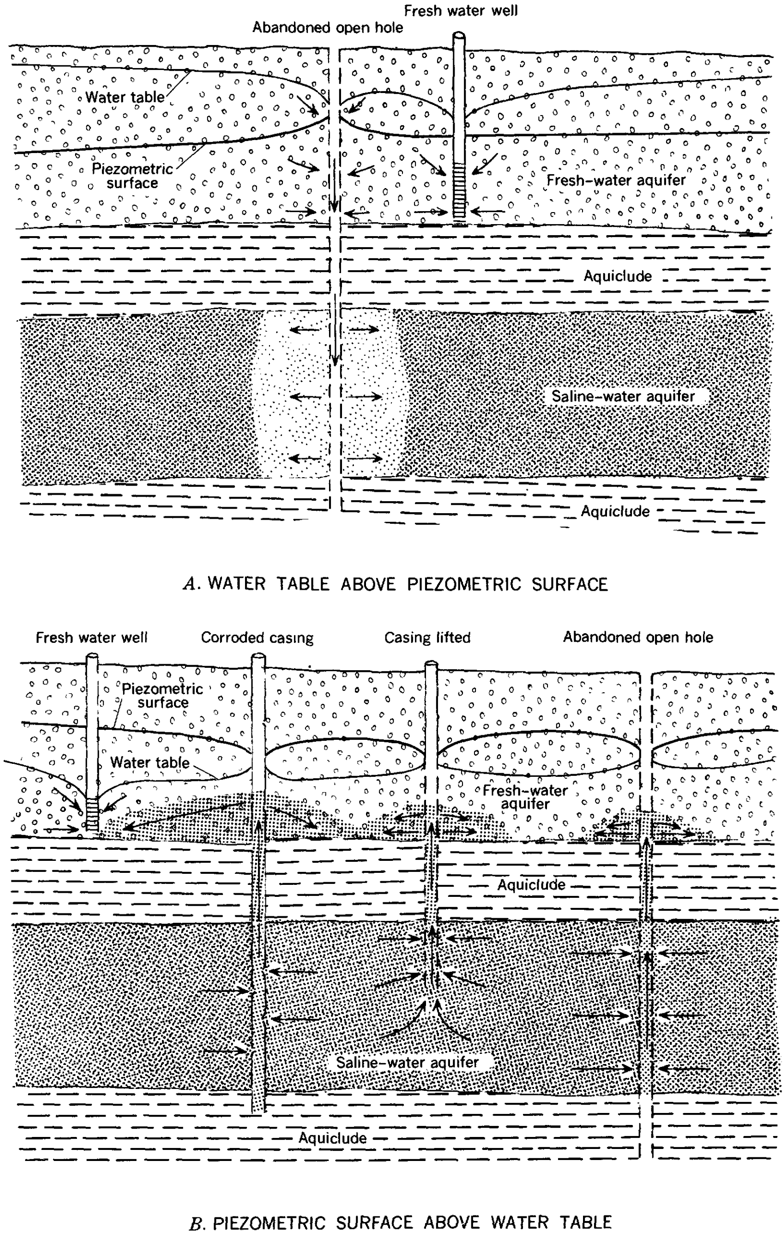

Figure 18.—Diagrams showing interformational leakage by vertical movement of water through open holes.

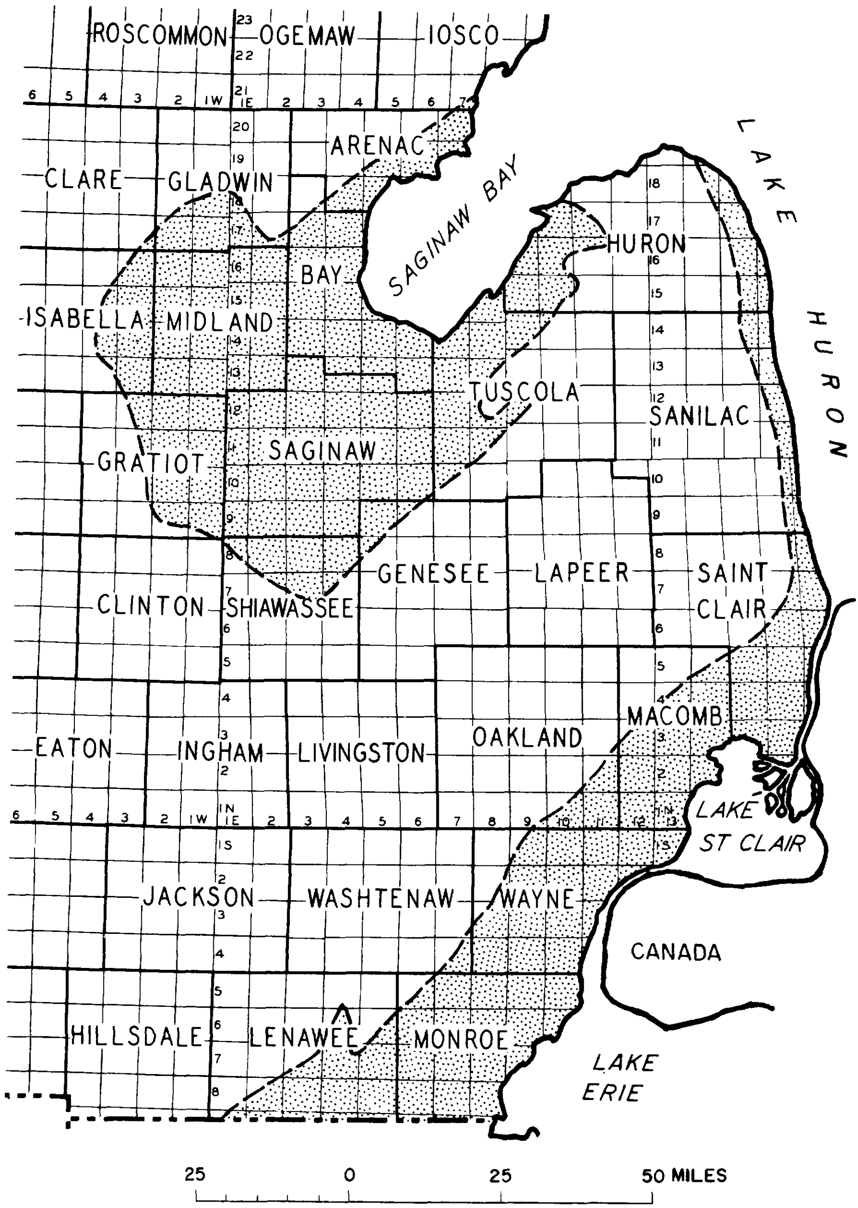

FIGURE 19.—Map of southeastern Michigan showing areas of heavily mineralized shallow water. (After Lane, 1899.)

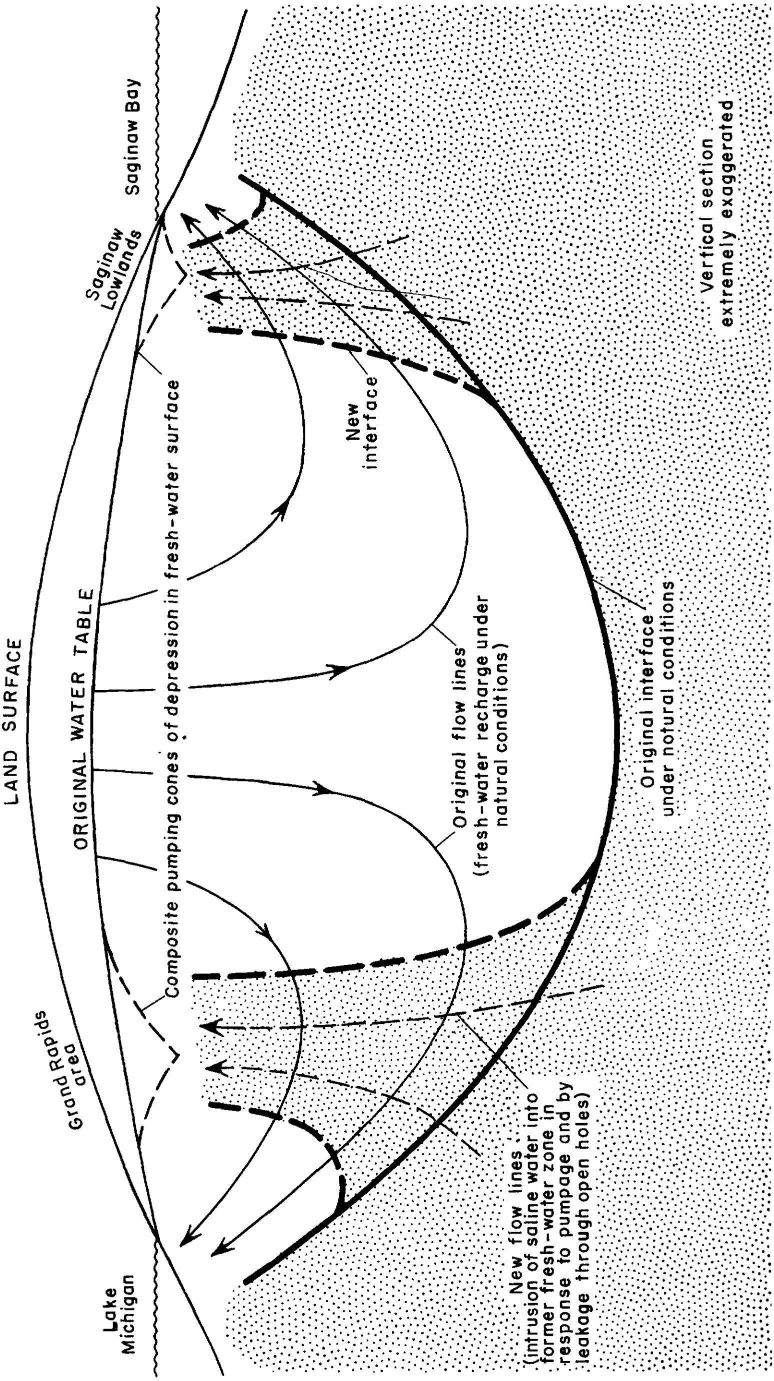

FIGURE 20.—Hypothetical section across the Southern Peninsula of Michigan showing fresh- and saline-water interface relations assuming a single homogeneous aquifer with uniform recharge.

wells. In 1939 after complaints about the taste of the water, the village had the chloride content of water from the tubular well determined again. By that time, the chloride content of water from the deep well had increased to 775 ppm, which far exceeds the 250 ppm limit recommended by the U.S. Public Health Service (1946). In 1945, the chloride content of the tubular well reached 925 ppm. In 1941, the chloride content in the shallow dug well reached 225 ppm, which indicated that the chloride concentration was greatest in the basal part of the aquifer and also that the chloride contamination was spreading through the aquifer. As a result the village was advised by a consulting engineering firm to develop a new source of supply.

The high chloride water taken from the hitherto fresh-water aquifer probably was derived from brine in the Traverse or the Detroit River Groups of Devonian age at great depth and from shallower sandstone of the Marshall Formation of Mississippian age. Records of the oil wells and tests reveal that water was found in these formations, which is significant in that oil and gas drillers commonly report water only when it is present in appreciable quantities or causes difficulty in drilling.

The offending wells were plugged, but the effectiveness of plugging operations is not known. If the plugging operations were fully effective, then the source of chlorides to the aquifers should have been shut off. If so, natural recharge to the fresh-water aquifers ultimately should flush out the chlorides, and pumping should accelerate the natural flushing action.

SALINE WATER IN THE SAGINAW LOWLANDS

Widespread impairment of fresh-water aquifers resulting from leakage of natural contaminants has occurred in large areas of the Saginaw Lowland. Bowman (1906, p. 94) attributed the deterioration in quality of water from the Saginaw Formation at Saginaw to infiltration of brine from abandoned salt wells. The city of Saginaw was forced to plug an unspecified number of these salt wells. In 1902, the city abandoned its wells tapping the sandstone aquifer in favor of wells tapping glacial sands and gravels.

Smith (1944, p. 59) vividly described the deleterious effects on overlying fresh-water aquifers of numerous wells and test holes drilled into formations containing oil, gas, brine, coal, and other minerals.

Man, not satisfied with his attack on our surface-water resources, has attacked from below. He has drilled hundreds of thousands of wells for water, coal, oil, gas, and other minerals. Many of these wells encountered salt or mineral waters, or, as oil and gas wells, ultimately went to salt water. Thousands of these wells were left unplugged or inefficiently plugged, with the result that the salt or mineral waters migrated upward and into beds containing fresh waters. This has been going on for more than a century, but more especially during the period of most rapid development of the coal and oil and gas industries. In many areas once fresh water-bearing beds have been in part or wholly destroyed. * * * The upward seepage of salty or mineralized waters has so narrowed the zone of fresh waters of the soils and rocks, that the available supply is already inadequate for metropolitan needs. These areas are faced with the necessity of building great aqueducts to large sources of supply many miles distant * * *

A further study of the history of brine contamination in the Saginaw Valley was made by Smith and Frye (1945, p. 8) who wrote in part as follows:

In the 1860's drilling began in search of stronger brine-bearing beds at greater depths. After discovering such brines many wells were drilled, chiefly along the Saginaw River, to supply brine to the lumber mills and other industrial plants for making salt.

With the settlement of Saginaw and Bay Counties, many wells were drilled for domestic water supplies. It was found that the fresh waters were largely confined to the first 80 to 100 feet and below those depths brackish or very salty water was found. In places the depth to salt water was less than 50 feet, in others as much as 200 feet.

With the passing of the lumber industry along the Saginaw River some 280 salt wells gradually were abandoned. The State Salt Commissioners plugged as many as could be found. Many, however, had been abandoned years before saw mill operations ceased and even their locations were lost.

Over the years the brine corroded and ate through many of the casings allowing the salt water to rise into the fresh water beds and also the fresh water to go down into the underlying salt water beds making the brines much weaker. As a result valuable fresh waters were destroyed and likewise strong brines were made so weak as to be useless for chemical purposes.

In the 1890's hundreds of test holes were put down in the Saginaw Valley to locate mineable areas of coal. In the areas where the coal was of mineable thickness the test holes were plugged but in areas where little or no coal was found many of them were not plugged. These holes usually were deep enough to penetrate the brackish and salt water beds. The unplugged holes allowed the salty waters to rise and spread into the formations carrying fresh water.

Many wells for fresh water on farms penetrated brackish or salt water beds. Those too salty for use were abandoned. Undoubtedly, over the years, the casings were eaten through and the salty waters invaded some of the fresh water beds above, which locally were too thin to furnish an adequate supply but were channels through which salt water could migrate into the thicker and more productive areas of fresh water. In numerous instances wells yielding brackish but usable waters gradually became so salty they were abandoned.

Smith and Frye, however, did not attribute all the damage or destruction of fresh waters to manmade operations and state that natural migration of brine to fresh-water beds also has occurred.

SALINE WATER IN THE GRAND RAPIDS AREA

In the Grand Rapids area, Kent County, sandstone of the Marshall Formation is the only bedrock aquifer that yields large quantities of water. The water pumped by most wells tapping this aquifer may be classified as saline because the dissolved-solids content generally is well in excess of 1,000 ppm. Historical evidence (Winchell, 1861, p. 91) indicates that the present dissolved-solids content of the water in the aquifer is far greater than it had been in the past. Winchell stated that the water in the Napoleon Sandstone Member (upper) of the Marshall Formation was fresh although the term "fresh" is merely relative and the exact quality of the water at the time of his study is not known.

The increase in mineralization that has occurred since the time of Winchell's study has been attributed to the many old brine wells that were not properly sealed. Nellist (1906, p. 272) stated that some flowing wells in the area penetrated to the Marshall Formation and obtained water "sufficiently fresh to be suitable for drinking." He reported that these wells penetrate the salt- and gypsum-bearing beds of the lower Grand River Formation, which previously had been explored for brine. By the time of the 1906 study, however, most of those wells had been abandoned and Nellist concluded that brine had flowed "from these old salt wells down into the Marshall sandstone."

Stramel and others (1954, p. 27) concurred with Nellist's observation but reasoned that failure to plug the old salt holes was but one cause of the increased mineralization of water in the Marshall Formation. They surmised that increased pumping in the area since the turn of the century contributed to the increased dissolved-solids content of the water by causing mineralized water present downdip in the formation to migrate to the area. In addition, they stated that pumping probably increased the leakage from the old wells.

HIGH-CHLORIDE WATER AT LANSING

In 1956 the Lansing Board of Water and Light drilled a new well in the central part of the city into the Saginaw Formation, the source of the city's water supply. When the well was first drilled the chloride content of its water was less than 100 ppm. However, after the well was put into production the chloride content increased rapidly and after 2 months of pumping it was about 900 ppm. This concentration of chloride is unusual for water from the Saginaw Formation in the Lansing area.

Investigation by the Board of Water and Light suggested that a probable source of the chloride was highly mineralized water flowing upward through a well tapping one or more underlying saline-water aquifers. A well had been drilled nearby in 1867 to a depth of 1,400 feet and had flowed initially 1,600 gallons per hour of water containing 4,575 ppm of sodium chloride (Lane, 1899, p. 58, no. 242). The brine was unsuitable for commercial salt production but was later used as a source of mineral waters at a spa and hotel built at the site. The hotel was destroyed by fire in 1879 and the well had been buried and subsequently built over. The well was relocated beneath a garage and in January 1957 it was reopened and sealed with cement grout from a depth of 557 feet to the surface.

The city supply well was then pumped for several months in 1957, the water being discharged to the Grand River, and then was retired from use until May 1958. It was used for public supply from May to October 1958. When the well was first pumped in 1958, the chloride content was less than 100 ppm. The chloride content rose gradually to 441 ppm on October 1 when the well was again retired from use until the summer of 1959. During the 1959 period of pumping, the chloride content again increased but at a slower rate.

The efforts of the Board of Water and Light to seal the mineral well and reclaim the aquifer at the site of the municipal well apparently will be successful. Probably a large part of the aquifer was contaminated, however, and it will take considerable time to pump out the contaminated water and to restore the aquifer to its original quality.

This case history also reveals one of the benefits of a program of basic-data collection. Without the published State and Federal records (see Lane, 1899, p. 60) the problem of identifying the source of the chloride and the general location of the well would have been much more difficult and perhaps impossible.

HIGH-CHLORIDE WATER AT GRAND LEDGE AND EATON RAPIDS

Several years ago village officials at Grand Ledge, Eaton County, investigated the possibility of using saline water for belaying dust on unpaved roads. The source of the water considered for this use was a flowing salt-water well drilled for a health spa in the latter part of the 19th century. Further study, however, revealed that the chloride concentration was much too small to accomplish this purpose. The possibility that this well may be a potential source of contamination should be considered as the chloride concentration of the water, which probably is from the Michigan Formation, is great enough to contaminate parts of the overlying Saginaw Formation into which it is believed to be leaking. The village obtains its water supply from wells tapping the Saginaw Formation. In similar circumstances, wells discharging salt water, also from the Michigan Formation, into overlying fresh-water aquifers at Eaton Rapids, Eaton County, have created difficult problems of obtaining fresh-water supplies.

OVERPUMPING

Overpumping also has adversely affected the quality of water from several fresh-water aquifers of the State. There is, of course, no sharp line of demarcation as to what rate of withdrawal constitutes overpumping, although rates of pumping may be considered excessive if they result in a continuing decline in water levels, seriously reduce the yields of wells tapping the aquifer within its cone of drawdown, or adversely affect the quality of the water. Adverse effects on quality are common in areas where fresh-water aquifers are directly underlain by aquifers containing saline water or where the fresh-water aquifer contains saline water downdip, or at depth. Pumping from fresh-water aquifers connected hydraulically to the saline-water aquifer tends to cause migration of the saline water toward the well. As the fresh-water head is reduced by pumping (water levels lowered) saline waters will rise and migrate toward the pumping wells. Unrestricted or excessive flow from artesian wells results in similar effects.

Numerous geochemical data show that overpumping has resulted in deterioration in quality of water pumped from equifers in various parts of the State, and, furthermore, that pumping from the fresh-water aquifers that have been penetrated by uncased test holes tapping saline-water aquifers will aggravate the quality problem.

INTRUSION OF HIGH-CHLORIDE WATER

ROYAL OAK AREA

The chloride content of water from a well at Royal Oak, Oakland County, was 365 ppm in 1926. In 1930, when the city decreased pumping from this well and purchased additional supplies from Detroit, the chloride content fell to 140 ppm. By 1936, however, as a result of increased draft from the aquifer, chloride content had risen to 290 ppm. Marked differences in chloride content due to pumping were also noted for other wells in the vicinity. Ferris and others (1954, p. 136–7) studied the effects of pumping on the sodium and chloride content of water from wells in southeastern Oakland County. They found that when the drawdown of water level in the buried outwash aquifer tapped by the wells is appreciable, the resultant gradient developed between the aquifer and the underlying bedrock induced the upward migration of the water contained in the bedrock (fig. 21).

It was thought probable that there are places in the Royal Oak area where there are good hydraulic connections between saline-water bedrock aquifers and fresh-water drift aquifers. It was surmised also that induced migration of mineralized water is accentuated by leakage from wells drilled to the salt-water formations.

Chlorides are not the only potentially deleterious substances that might migrate from bedrock formations into the gacial drift aquifers in the Royal Oak area. One well produced appreciable quantities of gas, presumably from the Antrim Shale, until the gas was accidentally exploded and wrecked the pumphouse enclosing the well (Ferris and others, 1954, p. 137).

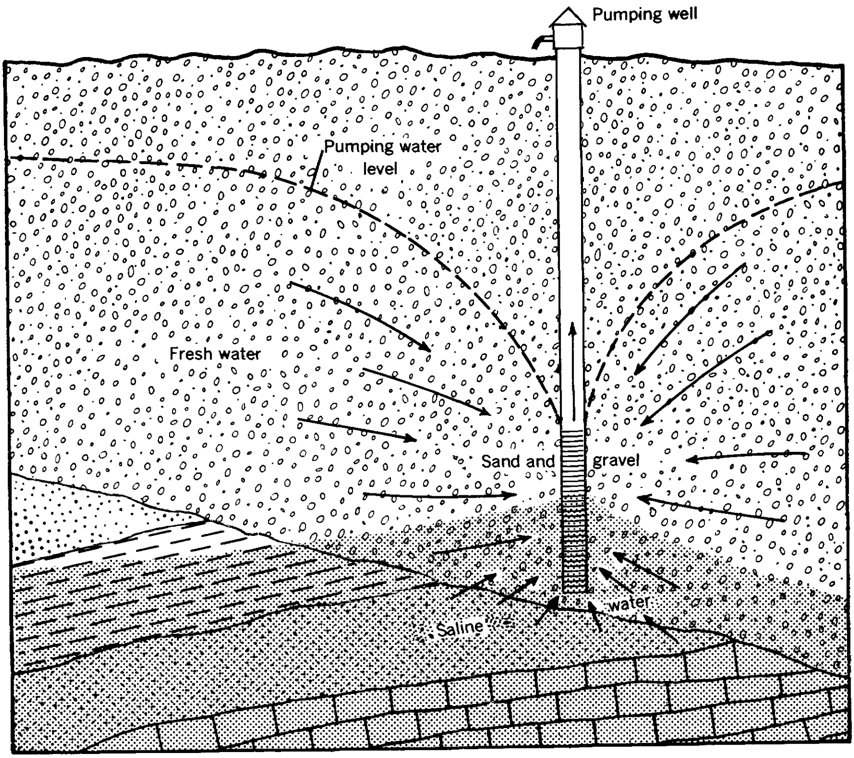

FIGURE 21.—Diagram showing how a pumping well can cause a fresh-water aquifer to be contaminated by saline water from underlying rocks.

FLINT AREA

In the Flint area, overdrafts from the Saginaw Formation commonly result in increasing chloride content. This indicates an upward migration of saline water, which effectively limits the amount of fresh water that can be withdrawn from the formation (Wiitala and others, 1962). A 300-percent increase in chloride content of the water in the Saginaw Formation forced Burton Township, south of Flint, to abandon the Saginaw Formation as a source of supply, except for emergency purposes. The township now uses the glacial-drift aquifer overlying the Saginaw Formation as its main source of water supply.

The steady increase in chloride content since 1946 of Burton Township well 2, tapping water from the Saginaw Formation, is shown by the following table:

Date collected	Chloride (ppm)
Nov. 5, 1946	135
Feb. 11, 1953	190
Aug. 18, 1953	230
June 13, 1955	240
Dec. 12, 1956	375

INTRUSION OF HIGH-SULFATE WATER

PONTIAC

Ferris and others (1954, p. 112–114) noted that the sulfate content of ground water in an area of heavy pumping in the central part of Pontiac was steadily increasing. Ground-water contamination by sulfate-bearing wastes from the land surface was not found. The source of the ground-water supply is the glacial drift, which generally is not high in sulfate content, but the drift is underlain by the Coldwater Shale, which is a known source of high-sulfate water. Hence, it became apparent that induced migration of water from the Coldwater Shale was the source of the sulfate water from wells tapping the glacial drift. Analyses showed that the sulfate content of the water pumped from the glacial drift at Pontiac was greatest in the area of concentrated pumping. Subsequent changes in the pattern of pumping by the city of Pontiac have been effective in reducing the amount of water migrating from the Coldwater Shale, and the sulfate content has decreased.

HOLLAND

The city of Holland also experienced increasing sulfate concentrations in its water supply before the city abandoned its well system in favor of a Lake Michigan water supply (Deutsch and others, 1958). The city's chief source of ground-water supply since 1921 had been its well station on Eighth Street. When pumping began at that station in 1922, the water was under sufficient artesian pressure to flow several feet above land surface, and the sulfate content of the water delivered by the station was 19 ppm. The sulfate content rose steadily as water levels declined and by 1943 reached 156 ppm. The increase in sulfate was due to migration of water from the underlying Coldwater Shale.

By 1957, water levels in the field were about 110 feet below land surface. Further increases in sulfate contents probably occurred although no further chemical analyses were made of the water from the well previously sampled.

MANISTIQUE

Some of the residents of the city of Manistique, Schoolcraft County, obtain water supplies from artesian wells finished in the Burnt Bluff Formation of Middle Silurian age. The hardness of water from this formation generally is greater than 200 ppm, owing to the presence of calcium and magnesium ions leached from limestone and dolomite strata. The water produced by some wells tapping the Burnt Bluff at Manistique has a high sulfate content, which is not characteristic of water from that formation. The results of a study made by Sinclair (1959) show that water yielded by these wells is contaminated by upward leakage of calcium sulfate water from the Cataract Formation, which underlies the Burnt Bluff. The Cataract Formation also is composed predominantly of dolomite, but it contains numerous layers of gypsum and gypsiferous shale. Gypsum, which is relatively soluble, is a source of objectionable quantities of calcium and sulfate in ground water with which it comes in contact. Migration of calcium sulfate water from the Cataract Formation apparently has been caused by pumping or permitting unrestricted discharge from flowing wells tapping the basal part of the Burnt Bluff Formation. Sinclair pointed out that wells tapping shallower permeable zones in the Burnt Bluff do not yield water high in calcium sulfate and to prevent contamination of the Burnt Bluff Formation suggests avoidance of drilling into the Cataract Formation.

DEWATERING OPERATIONS

Pumping water from wells for water supply is not the only manner for which the above principle of induced migration is applicable. Where saline and fresh-water aquifers are connected hydraulically, dewatering operations, such as for quarries, roads, or excavations, also may tend to cause vertical migration of the saline water (fig. 22). Excavation of a hole in a confining layer may accelerate encroachment of saline water. The danger of contaminating fresh-water aquifers as a result of dewatering operations is especially great in parts of the Saginaw Lowlands and in southeastern Michigan where relatively shallow artesian aquifers commonly contain saline water.

SULFIDE WATER AT FLAT ROCK

Several householders living along the Huron River near Flat Rock, Wayne County, complained that water in their wells turned black and developed an obnoxious odor as a result of blasting in a nearby limestone quarry. Although there is little geologic or hydrologic basis to support the contention that the blasting caused deterioration in water quality, the Michigan Geological Survey was called upon to make an investigation of the ground-water conditions in the area.

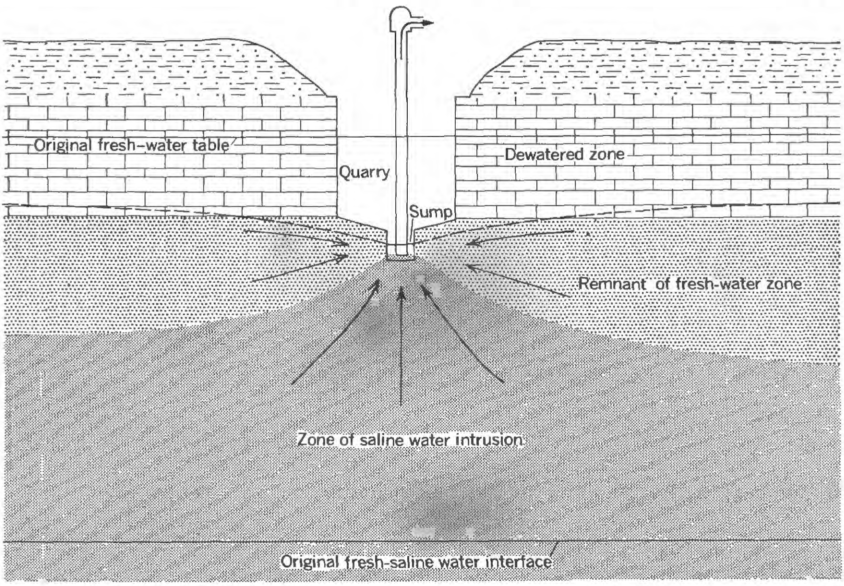

FIGURE 22.—Diagram showing migration of saline water caused by dewatering in a fresh-water aquifer overlying a saline-water aquifer.

The geologic section in this area as revealed in the quarry consists of: (1) the Sylvania Formation, at the base of the quarry; (2) an overlying 15-foot section of the Amherstburg Formation, which is being quarried, and (3) about 30 feet of glacial drift. The wells in the area are completed in the glacial drift or penetrate the dolomite and are completed in the sandstone.

The State Geological Survey reported that the quarry was dewatered by means of a sump at one end of the quarry and that dewatering operations contributed to the lowering of water levels, at least in rock wells. They also reported that "it appears that the lowering of water levels caused by pumpage at the quarry has accelerated the normal encroachment of water with a high degree of mineralization." Unfortunately, data are not available concerning the altitude of the interface of the saline and fresh water or its rate of encroachment before the dewatering operations at the quarry. Analysis by a commercial laboratory of a water sample collected from one well in the area before dewatering operations at the quarry, reportedly showed that the water was very hard and high in sulfate content. According to the State Geological Survey the analysis indicated "that the encroachment of highly mineralized water was already in progress, and had affected at least some of the wells in the area prior to the opening of the quarry."

The obnoxious odor of the water at the time of the investigation indicates that the wells were producing water containing hydrogen sulfide. The black color revealed that other sulfides, including iron sulfide that would result from chemical reaction of the hydrogen sulfide and iron, were present. The iron may have originated in the ground water or in the well casing and other parts of the plumbing system or from a combination of both sources. Historical data indicate that hydrogen sulfide in ground waters is not uncommon along the lower reaches of the Huron River. Records of "sulfur" water predate the quarrying operations. Fuller (1905, p. 17) reported that several wells in this general area produced "sulfur water" and that one well yielded "black sulfur water." He also concluded that in this general area the "Monroe beds" (Amherstburg) yielded "waters that are hard but are not characterized by much sulfur" and that the Sylvania Formation yielded water of good quality. Data obtained since 1905 indicate that the Sylvania now yields water containing excessive concentrations of sulfate.

Neither the occurrence and chemistry of sulfates in the ground water in the area, nor the relation of the sulfates to the sulfides, is completely known. Hem (1959, p. 223) reported that sulfates could be reduced by hydrogen released by decomposition of organic matter by anerobic bacteria. As the ground water in the area contains a considerable amount of sulfate and organic materials are present in the form of peat and muck, as well as septic tank effluent and other sewage, it seems reasonable to assume that the hydrogen sulfide in the well waters of the area may be in part of local origin.

CHANNEL DEEPENING OR DREDGING

The deepening or dredging of an effluent stream (a stream being fed by ground water) will cause a lowering of the head in the streamside aquifer. In areas where the streamside aquifer is hydraulically connected to an underlying saline-water aquifer, the lowering of head will induce upward flow of saline water (fig. 23) in much the same manner as caused by overpumping or dewatering. In such areas encroachment of saline water is a potential problem where flood control or other projects involving lowering of stream stage are contemplated. Some thin and shallow fresh-water aquifers in parts of southeastern Michigan (fig. 19) are especially susceptible to contamination from underlying saline-water aquifers. The possibility of detrimental effects on ground-water quality resulting from changes in hydrologic regimen for any project of this type should be studied. Such a study would require the collection of detailed geologic and hydrologic information.

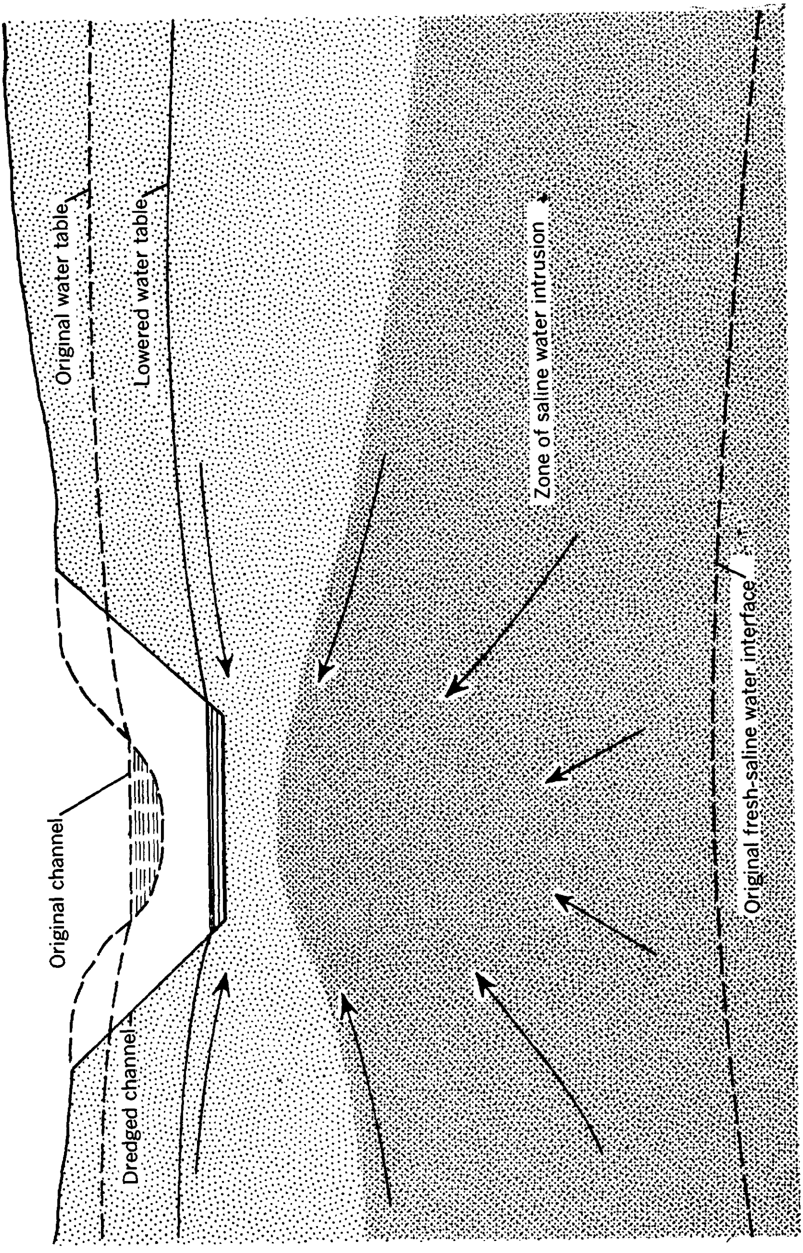

FIGURE 23.—Diagram showing migration of saline water caused by lowering of water levels in an effluent stream and streamside aquifer hydraulically connected to an underlying saline-water aquifer.

LEGAL SAFEGUARDS AGAINST GROUND-WATER CONTAMINATION IN MICHIGAN

Legislative authority to abate ground-water pollution had been granted to various agencies of the State as early as 1889. The U.S. Public Health Service (1954, p. 22) reported that

> The water pollution control laws are adequate to abate existing pollution and to prevent or control new or increased sources of pollution. The water pollution control agencies have been given sufficient legal authority to carry on their programs and they have used this authority judiciously and effectively in carrying out their work.

The Michigan Water Resources Commission has been assigned the general overall authority relating to the control of pollution of any waters of the State. Various divisions of the Department of Conservation and the State Health Department also have been delegated related water-pollution control functions.

ACTIONS OF THE MICHIGAN SUPREME COURT

A few cases in the State dealing specifically with contamination or alleged contamination of ground-water supplies have appeared before the Michigan Supreme Court (Olds, 1952). The earliest of these was the case of *Upjohn* v. *Richland Township* (46 Mich. 542), decided in 1881. In this case, Upjohn sought to enjoin an addition to a nearby cemetery on the basis that it would contaminate his well. The court held that the plaintiff failed to sustain the burden of proof in saying as follows:

> The movements of subsurface waters are commonly so obscure that rights in or respecting them cannot well be preserved. They do not often have a well-defined channel, and it is not easy in many cases to determine in what direction their movements tend. If corrupted at one point the effect may be confined within very narrow limits, while at another, though no surface indications would lead one to expect it, the taint might follow the water for miles.

In the 1894 case of *Brady* v. *Detroit Steel and Spring Company* (102 Mich. 277) the court accepted the doctrine of correlative rights in saying

> It is well settled that the percolation of deleterious matter, from the premises of the party who suffers it, through the soil, upon the lands of the adjacent owner, to the injury of the latter, is an actionable nuisance.

In the 1938 case of *Joldersma* v. *Muskegon Development Co.* (286 Mich. 520), the complainant alleged that his underground water had been contaminated by the defendant's act of allowing salt-water wastes from an oil well to seep into the soil on defendant's premises. However, again the plaintiff failed to sustain the burden of proof.

In the 1955 case of *L. A. Darling Co.* v. *Water Resources Commission* (341 Mich. 654), the Water Resources Commission charged that the defendant contaminated several private wells and threatened to pollute one of the public wells of the municipality of Bronson. The judgment of a lower court in favor of the Commission's order to the defendant to abate contamination was reversed by the Supreme Court, on appeal, but not because it was found that contamination had not occurred. The court held that the Commission denied the Darling Co. procedural due process by failure to conduct a formal hearing. The court did, however, confirm the power of the Water Resources Commission to control pollution of ground water, and, according to Lauer and others (1958), thus established the act as a reasonable use standard in Michigan, despite the fact that no Supreme Court cases resulted in an injunction against ground-water contamination or in recovery of damages.

ACT CREATING THE WATER RESOURCES COMMISSION

In 1929 the Michigan Legislature passed Act No. 245 creating the Stream Control Commission, but this commission was given authority only to control pollution of surface waters. This act was amended in 1949 by Public Act 117 and the commission's name was changed to Water Resources Commission, its powers expanded, its procedures streamlined, and its authority extended to the control of pollution of underground waters (Olds, 1952). The act delegates to the commission the responsibility "to protect and conserve the water resources of the state and great lakes * * *." Broad powers to attain these objectives are also conferred upon the commission by this act, along with the duty "to enforce any and all laws relating to the pollution of the waters of this state * * *."

Act 117 specifically states that

> The Commission shall protect and conserve the water resources of the state and shall have control of the pollution of surface or underground waters of the state * * * which are or may be affected by waste disposal * * *

and further that the commission

> shall have the authority to make regulations and orders restricting the polluting content of any waste material or polluting substances discharged or sought to be discharged into any * * * waters of the state. It shall have the authority to take all appropriate steps to prevent pollution which is deemed by the Commission to be unreasonable and against public interest * * *

The disposal of water or return of air-conditioning water into the ground through a recharge or return well is also subject to regulation by the Water Resources Commission, inasmuch as the act considers this a new use of the waters of the State, and hence approval must be granted by the commission before such a well is constructed.

Since its creation by legislative enactment in 1949, the Water Resources Commission, by use of its broad legal authority, has been effective in abating contamination of ground-water supplies in cases that have been brought to its attention. In addition the commission has denied applications for new uses of the water of the State when such use would result in further and undesirable contamination of any ground- or surface-water source.

CONSERVATION LAWS

Throughout the years the people of Michigan have been concerned with conservation of the waters of the State for various purposes. Accordingly, a number of laws have been passed which directly or indirectly provides for the conservation of water by protecting this resource from contamination. Since 1921 these laws and various amendments have been administered by the Department of Conservation, which was created in part "to provide for the protection and conservation of the natural resources of the state * * * ."

ACT 190 OF THE PUBLIC ACTS OF 1889

Johnson (1905, p. 42) outlined the features of an early law pertaining to underground waters passed in 1889 (but repealed in 1929) which prohibited parties owning flowing artesian wells to allow the well

> to flow a larger stream than will flow through a pipe 1 inch in diameter, to the detriment or injury of any other well or wells, without the consent of the owner of such well or wells or injured.

This act probably was designed to protect nearby flowing wells from undue loss in head, which might cause the flow to cease.

ACT 107 OF THE PUBLIC ACTS OF 1905

Another conservation law dealing with ground water is Act 107 of the Public Acts of 1905, which is similar to the 1889 act. Act 107 provides for the restriction of unreasonable waste flows from artesian or flowing wells, which damage other wells supplied from the same head or reservoir. According to Wisler and others (1952, p. 35) the law is unworkable because of the "difficulty of defining what is reasonable in any case and of proving that any particular waste flow is responsible for the damage * * *" Their argument appears to have merit because the law has never been utilized.

ACT 326 OF THE PUBLIC ACTS OF 1937

The Department of Conservation is charged with important duties in preventing contamination of ground-water supplies incidental to administering Act 326 of the Public Acts of 1937, which regulates the production and handling of natural dry gas in the State. The act appoints the Director of Conservation as Supervisor of Wells and requires specifically that he protect the various natural resources of the State against contamination resulting from natural gas production activities. Section 4 of the act states

It shall be the duty of the supervisor of wells * * * to inspect the locating, drilling, casing, deepening, sealing, and operating of gas wells or test holes, so far as the same may endanger * * * or do damage to the gas, the fresh, brine, and mineral waters, and other mineral resources * * *

A variety of duties to accomplish this purpose of the act is spelled out in detail. Section 8 requires

Every person who shall drill, sink, or cause to be sunk, such a well or test hole penetrating bedrock shall case and seal off each oil, gas, brine or water stratum or formation to effectually prevent migration of gas or fluids to other strata, and such casing or sealing off shall be effected and tested in such manner and by such methods and means as may be prescribed or approved by the supervisor of wells or his authorized representative.

Section 10 requires that dry or abandoned wells

be plugged in such a way as to confine the oil, gas, and water in the strata in which they are found and to prevent them from escaping into other strata; or to the surface.

Section 11 provides that in the event such a well is not plugged in 30 days the owner must give satisfactory proof that no damage is being done to any water-bearing or other mineral-bearing formation penetrated.

Section 25 of the same act exempts most holes drilled for exploration of or extraction of water and all other minerals from the general regulation of the act, but does provide

That when any such well or hole penetrates salt or mineral water-bearing formations, the owner or operator shall upon completion or abandonment plug such well or test holes in such manner and by such means as the supervisor shall prescribe or approve that will prevent migration of such brine or mineral water into the oil, gas and fresh water-bearing formations or to the surface.

It is not clear how this section would apply in the case of a hole drilled through an oil- or gas-bearing formation in quest of other mineral resources.

ACT 61 OF THE PUBLIC ACTS OF 1939

This act, which is designed to prevent waste and to conserve the oil and gas resources of the State, is similar to Act 326 in its incidental powers to protect the fresh ground-water resources in areas of oil test or well drilling. Section 6 of the act empowers the Supervisor of Wells to require plugging of wells drilled for oil and gas or for geologic information or as key wells in secondary recovery projects, * * * in such a manner and by such means so * * * as to prevent damage to or destruction of fresh water supplies.

Section 12 of the act contains a provision requiring each well to be drilled in the center of any drilling unit or tract, with various exceptions, including instances where water or other natural resources are threatened by drilling at that point.

PUBLIC HEALTH LAWS

The Michigan Department of Health, under its broad police powers to protect the public health, is also actively engaged in protecting the fresh-water supplies of the State from pollution, as an activity incidental to its duties to inspect and approve public water and sewerage systems, and in regulating the construction and operation of drains.

THE DRAIN CODE OF 1956

Section 423 of Act 40 of the Public Acts of 1956 also is designed to protect the waters of the State by providing that

It shall be unlawful * * * to discharge or permit to be discharged into any county drain or inter-county drain of the state any sewage or waste matter capable of producing in said drain or drains detrimental deposits, objectionable odor nuisance, injury to drainage conduits or structures, or such pollution of the waters of the state receiving the flow from said drains as to injure livestock, destroy fish life, or be injurious to the public health.

This act authorizes the State Health Commissioner to cause such measures to be taken as he deems necessary to abate the nuisance or menace to the public health. The act is important in protecting the ground waters of the State from contamination, because a drain may be a source of recharge to an aquifer as, for example in the case of the disposal of zeolite-softening-plant effluent in Paris Township, Kent County, cited previously.

WATERWORKS AND SEWERAGE SYSTEM LAW

The Waterworks and Sewerage System Act (Act 219 of the Public Acts of 1949) is an important Michigan statute providing protection from pollution for the ground waters of the State. Under the act the State Health Commissioner supervises and controls waterworks (including wells) and sewerage systems. Section 4 of the act requires the commissioner to investigate waterworks systems and have bacteriological analyses made of water when there is reason to believe that any public-water supply is contaminated. Section 6 requires plans and specifications that show all the sources through or from which water is or may be at any time pumped or otherwise permitted or caused to enter into such system, and such drain, water course, river or lake into which sewage is to be discharged.

This in effect provides the State with valuable geologic information, and indirectly with geochemical information inasmuch as water samples from potential public-supply sources are chemically analyzed, as it is also the duty of the commission to determine if any public water supply is impure and a menace to the public health.

The sewage-disposal information, of course, permits the commissioner to evaluate potential hazards to ground- or surface-water supplies and to stipulate changes that will cause reduction or removal of such hazards to render the sewage "not potentially prejudicial to the public health."

REGULATORY POWERS OF THE STATE HEALTH COMMISSIONER

By authority of Act 146 of the Public Acts of 1919 as amended, the State Health Commissioner has also published a series of regulations establishing minimum standards for the location and construction of water supplies (other than municipal)

serving schools, trailer coach parks, motels, resorts, hospitals, convalescent homes, milk and food handling establishments, places of assembly, and the like.

The regulations (Michigan Department of Health, 1957) prohibit drilling of such wells within 75 feet from sources of contamination. Sewers or sumps may not be located less than 10 feet from such wells, and if less than 75 feet must be watertight. Furthermore, these wells must be in areas not subject to flooding. The regulations also stipulate certain well construction techniques to protect the public health. Dug wells or wells less than 25 feet deep for public supply are no longer permitted in the State without written approval of the State Health Commissioner.

Regulations concerning water supplies for grade A milk plants and dairy farms, as required by Act 216 of the Public Acts of 1956, are similar to those outlined for public-water systems.

FEDERAL INTEREST

The first comprehensive Federal legislation in the pollution control field was the Water Pollution Control Act of 1948 (Pubic Law 845). This law added the principles of State-Federal cooperative program development and limited Federal enforcement authority and financial aid. The growing concern of the Federal Government in the national and international pollution problem resulted in the new Federal Water Pollution Control Act of 1956 (Public Law 660).

Because the Congress has stipulated that primary responsibility in pollution control rests with the States, both laws declare the policy of Congress "to recognize, preserve, and protect the primary responsibilities and rights of the States in controlling water pollution."

Included in the act, which was summarized by the U.S. Public Health Service (1957), are provisions for:

1. Continued Federal, State, and interstate cooperation in the preparation and development of comprehensive programs for controlling water pollution.
2. Increased technical assistance to States, a broad research program, the establishment of research fellowships, and the use of contract research and research grants.
3. Collection and dissemination of basic data on water quality and other information relating to the prevention and control of water pollution.
4. A cooperative program to control pollution from Federal installations.

The Federal Government, however, has no part in the direct enactment and enforcement of the water law of any State. Where interstate water sources and problems are involved, machinery is provided for facilitating settlement of disputes by negotiation and compact.

McGuinness (1951, p. 2) summarized the policy of the U.S. Geological Survey on water law as follows:

> It is the belief of the Geological Survey that the required legal control can be achieved most effectively at the State level; further, that the restrictions on water use should be the minimum consistent with effective control, and that maximum reliance should be placed on voluntary cooperation of water users based on adequate public information on the hydrology of each area.
>
> The Geological Survey has no part in the enactment and enforcement of water law. It acts as an impartial source of basic hydrologic data. However, it has an important advisory function, for it is in a position to comment on the hydrologic feasibility of proposed water laws and thus to contribute to their effectiveness.

SUMMARY AND CONCLUSIONS

Numerous aquifers in Michigan have been contaminated to various degrees by the introduction of a wide variety of substances both natural and manmade. In general, the destruction of the fresh ground-water resources of the State by contaminants introduced from the surface has not been nearly as widespread or detrimental to the public as was the pollution of the rivers and streams prior to enactment of abatement legislation. Contamination of ground water by sanitary and industrial wastes may be expected to decrease as a result of the statutes enabling the Michigan Department of Health and the

Water Resources Commission to take effective control actions. Pollution incidental to oil and gas production in the State virtually has been eliminated since enactment of the laws directing the Department of Conservation to protect the water resources from hazards of contamination by supervising construction and operation of wells.

In areas where important sources of ground water have already been contaminated, especially by such noxious chemicals as chromates and phenols, many years may pass before the aquifers may become usable again. Where aquifers have been contaminated the water should be sampled and analyzed periodically to determine when the concentrations of contaminants are reduced to tolerable levels. Economically feasible techniques of speeding restoration of such aquifers to usable condition should be developed where possible.

One especially great hazard to the ground-water resources of the State lies in the pattern of development of ground-water supplies in the rapidly growing suburban areas around most of the larger municipalities. In many suburban developments septic tanks are used to dispose of sewage, even where individual domestic wells on the lot (some of which tap shallow aquifers) are used for water supplies. The fact that synthetic detergents are in widespread use makes it inevitable that many shallow aquifers that are recharged by septic tank effluent will ultimately be contaminated also by these chemicals. Preservation of shallow aquifers as a source of potable water in densely populated suburban areas will require construction of public sewage systems and treatment plants and eventual abandonment of septic-tank installations. Construction of public-supply wells beyond the area of contamination, of course, in no way protects ground water from contamination, but indeed may result in more widespread contamination before proper remedial action is taken.

Other remaining major hazards to the ground-water resources of the State are overpumping and other changes in the ground-water regimen that induce waters high in sulfate, chloride, or other mineral constituents to flow into fresh-water aquifers. Induced encroachment of saline water is an especially difficult problem to deal with as a wealth of geochemical and hydrologic data is needed even to recognize it, and probably even more data would be needed to offer conclusive legal proof of contamination from natural sources. Subsurface encroachment of saline water occurs at shallow depth. Figure 19, which shows such areas in southeastern Michigan, was prepared in 1899 (Lane, 1899, pl. IV). Further work should be done not only to cover the rest of the State but to bring Lane's map up to date, and also to delineate the actual depths of saline-water occurrence. Such work has been done only in a few areas of the State where detailed geologic and hydrologic studies and interpretations have been made.

Requisites for protecting ground-water resources from further impairment are as follows: A general awareness of various ways an aquifer may become contaminated; a comprehensive set of statutory controls to cover all probable modes of introduction of contaminants; adequately staffed regulatory agencies to implement the control statutes; and a comprehensive program for collection, compilation, and interpretation of bacteriological, chemical, geological, hydrological, and hydraulic data.

The above requisites have been fulfilled in part in Michigan, although a considerable amount of public education will be required to promote an understanding of how aquifers might be safeguarded. If needed, specific statutory authority should be vested in an appropriate State agency to control migration of natural saline water into fresh-water aquifers induced by pumping, dewatering, interformational leakage in wells, channel dredging, and other activities of man. Act 117 may already be sufficiently broad in scope to be invoked to control activities resulting in migration of saline water by the above causes, but it has not yet been applied in such cases. To increase the effectiveness of present and possible future control statutes, the programs of collection and interpretation of appropriate data must be sufficiently comprehensive to define the geochemical regimen in problem areas. The data collection and interpretation program should be implemented, if possible, by basic research concerning methods of controlling contamination of various types and of restoring to use aquifers already contaminated.

As Billings (1950) succinctly and appropriately wrote, "The importance of water, especially ground water, is constantly growing. The public cannot afford to despoil it."

REFERENCES CITED

Adams, M. P., 1944, Water in its relation to pollution: Michigan Dept. Conserv. Water Conserv. Conf. Proc., p. 69–80.

American Water Works Association, 1957, Underground waste disposal and control: Am. Water Works Assoc. Jour., v. 49, no. 10, p. 1334–1342.

——— 1958, Determination of synthetic detergent content of raw-water supplies: Am. Water Works Assoc. Jour., v. 50, no. 10, p. 1343–1352.

——— 1959, Effects of synthetic detergents on water supplies: Am. Water Works Assoc. Jour., v. 51, no. 10, p. 1251–1254.

Billings, N. F., 1950, Ground-water pollution in Michigan: Sewage and Indus. Wastes, v. 22, p. 1596–1600.

Bowman, Isaiah, 1906, Problems of water contamination, *in* Fuller, M. L., Underground water papers: U.S. Geol. Survey Water-Supply Paper 160, p. 92–95.

Butler, R. G., Orlob, G. T., and McGauhey, P. H., 1954, Underground movement of bacterial and chemical pollutants: Am. Water Works Assoc. Jour., v. 46, no. 2, p. 97–111.

California Water Pollution Control Board, 1953, Field investigation of waste reclamation in relation to ground water pollution: California Water Pollution Control Board Pub. 6.

——— 1954a, Report on the investigation of leaching of a sanitary landfill: California Water Pollution Control Board Pub. 10.

——— 1954b, Report on the investigation of travel of pollution: California Water Pollution Control Board Pub. 11.

Calvert, C. K., 1932, Contamination of ground water by impounded garbage waste: Am. Water Works Assoc. Jour., v. 24, no. 2, p. 266–270.

Comly, H. H., 1945, Cyanosis in infants caused by nitrates in well water: Am. Med. Assoc. Jour., v. 129, no. 2, p. 112–116.

Daoust, W. L., 1953, Salts of the earth: Michigan Conserv., v. 22, no. 1, p. 23–24.

Deutsch, Morris, 1956, Effects of dissemination of radioactive materials on water resource conservation with special reference to Michigan: Michigan State Univ. Agr. Expt. Sta. Water Bull. 2.

Deutsch, Morris, Burt, E. M., and Vanlier, K. E., 1958, Summary of ground-water investigations in the Holland area, Michigan: Michigan Geol. Survey Prog. Rept. 20.

Elder, A. L., Scott, E. C., and Kanda, F. A., 1948, Textbook of chemistry: New York, Harper and Bros.

Eno, C. F., 1959, Chlorinated hydrocarbon insecticides—what have they done to our soil? Univ. Florida Agr. Expt. Sta. Research Rept., v. 4, no. 3, p. 14–15.

Faust, R. T., 1937, Well water supplies for municipalities: Michigan Dept. of Health Eng. Bull. no. 19.

Ferris, J. G., 1949, Ground water, chap. 7 *in* Wisler, C. O., and Brater, E. F., Hydrology: New York, John Wiley and Sons, p. 198–272.

——— 1951, Ground-water aquifers as waste-disposal reservoirs—an outline of the basic hydrologic problems involved: Manufacturing Chem. Assoc. Trans., p. 68–74.

Ferris, J. G., and others, 1954, Ground-water resources of southeastern Oakland County, Michigan: Michigan Geol. Survey Prog. Rept. 16.

Fiedler, A. G., 1936, Occurrence of ground water with reference to contamination: Am. Water Works Assoc. Jour., v. 28, no. 12, p. 1954–1962.

Flynn, J. M., Andreoli, Aldo, and Guerrera, A. A., 1958, Study of synthetic detergents in ground water: Am. Water Works Assoc. Jour., v. 50, no. 12, p. 1551–1562.

Fuhrman, R. E., 1955, Treating waste water for cities and industries, *in* Water: U.S. Dept. of Agriculture Yearbook, p. 644–649.

Fuller, M. L., 1905, Failure of wells along the lower Huron River, Michigan, *in* Lane, A. C., and others, Sixth annual report of the State Geologist: Michigan Geol. Survey Ann. Rept. for 1904.

Garver, H. L., 1955a, Water supplies for homes in the country, *in* Water: U.S. Dept. of Agriculture Yearbook, p. 655–663.

——— 1955b, Safe sewage disposal for rural homes, *in* Water: U.S. Dept. of Agriculture Yearbook, p. 663–665.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Hepler, J. M., and others, 1953, Septic tanks for rural and suburban areas: Michigan State Coll. Ext. Bull. 118.

Hirn, W. C., 1923, Underground contamination of the Bad Axe water supply: Eng. News-Record, v. 91, no. 4, p. 138–139.

Horton, R. E., 1905, The drainage of ponds into drilled wells, *in* Fuller, M. L., Contributions to the hydrology of eastern United States: U.S. Geol. Survey Water-Supply Paper 145, p. 30–39.

Johnson, D. W., 1905, Relation of the law to underground waters: U.S. Geol. Survey Water-Supply Paper 122.

Lane, A. C., 1899, Lower Michigan mineral waters, a study into the connection between their chemical composition and mode of occurrence: U.S. Geol. Survey Water-Supply Paper 31.

Lang, A., 1933, Pollution of water supplies, especially of underground streams, by chemical wastes and by garbage [abs.]: Am. Water Works Assoc. Jour., v. 25, no. 8, p. 1181.

Lang, A., and Bruns, Hayo, 1941, On pollution of ground water by chemicals [abs.]: Am. Water Works Assoc. Jour., v. 33, no. 11, p. 2075.

Lauer, T. E., King, D. B., and Ziegler, W. L., 1958, Water law in Michigan, *in* Pierce, W. J., ed., Water resources and the law: Ann Arbor, Univ. Michigan Law School, Legislative Research Center, p. 423–532.

MacKichan, K. A., 1957, Estimated use of water in the United States, 1955: U.S. Geol. Survey Circ. 398.

Matson, G. C., 1911, Pollution of underground waters in limestone, *in* Fuller, M. L., and others, Underground water papers: U.S. Geol. Survey Water-Supply Paper 258, p. 48–56.

McGuinness, C. L., 1951, Water law with special reference to ground water: U.S. Geol. Survery Circ. 117, 30 p.

Meinzer, O. E., 1923, The occurrence of ground water in the United States, with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489.

Michigan Department of Health, 1948, Chemical analyses and their interpretations—public water supplies in Michigan: Michigan Dept. Health Engr. Bull. 4.

——— 1956, Ground water supplies for homes and small institutions: Michigan Dept. Health Engr. Bull. no. 14.

——— 1957, Regulations for certain water in Michigan: Michigan Dept. Health Bull.

Nellist, J. F., 1906, Water supplies of Kent County, *in Leverett*, Frank, and others, Flowing wells and municipal water supplies in the southern portion of the Southern Peninsula of Michigan: U.S. Geol. Survey Water-Supply Paper 182, p. 267–278.

Nicholson, H. P., 1959, Insecticide pollution of water resources: Am. Water Works Assoc. Jour., v. 51, no. 8, p. 981–986.

Noecker, Max, Greenman, D. W., and Beamer, N. H., 1954, Water resources of the Pittsburgh area, Pennsylvania: U.S. Geol. Survey Circ. 315.

Olds, N. V., 1952, Legal aspects of ground-water contamination: Michigan Conserv., v. 21, no. 4, p. 10–12, 24.

Parker, G. G., 1955, The encroachment of salt water into fresh, *in* Water: U.S. Dept. of Agriculture Yearbok, p. 615–635.

Pierce, W. J., ed., 1958, Water resources and the law: Ann Arbor, Univ. Michigan Law School, Legislative Research Center, 614 p.

Piper, A. M., and Thomas, H. E., 1958, Hydrology and water law: What is their future common ground? *in* Pierce, W. J., ed., Water resources and the law: Ann Arbor, Univ. Michigan Law School, Legislative Research Center, p. 7–24.

Sawyer, C. N., and Ryckman, D. W., 1957, Anionic synthetic detergents and water-supply problems: Am. Water Works Assoc. Jour., v. 49, no. 4, p. 480–490.

Sayre, A. N., 1950, Ground Water: Sci. Am., v. 183, no. 5, p. 14–19.

Schwab, C. E., 1955, Pollution—a growing problem of a growing nation, *in* Water: U.S. Dept. of Agriculture Yearbok, p. 636–643.

Sinclair, W. C., 1959, Reconnaissance of the ground-water resources of Schoolcraft County, Michigan: Michigan Geol. Survey Prog. Rept. 22.

Slaughter, J. L., and Campbell, J. M., 1952, A few pointers on ground-water supplies: Michigan Geol. Survey inf. pamph.

Smith, R. A., 1944, Water in its relation to the community, *in* Michigan's water problems: Michigan Dept. Conserv., Water Conserv. Conf. Proc., p. 53–61.

Smith, R. A., and Frye, F. R., 1945, Saginaw Valley brines pose problems: Michigan Conserv., v. 14, no. 12, p. 8.

Stiles, C. W., Crohurst, H. R., and Thompson, G. E., 1927, Experimental bacterial and chemical pollution of wells via ground water, and the factors involved: U.S. Public Health Service Hygienic Lab. Bull. 147, 136 p.

Stramel, G. J., Wisler, C. O., and Laird, L. B., 1954, Water resources of the Grand Rapids area: U.S. Geol. Survey Circ. 323.

U.S. Public Health Service, 1946, Public Health Service drinking water standards, 1946: Public Health Reports, v. 61, no. 11, March 15, p. 371–384.

——— 1954, A comprehensive water pollution control program for the Lake Superior Drainage Basin: U.S. Public Health Service Pub. no. 367, Water pollution series no. 66.

——— 1957, The Federal water pollution control act of 1956: U.S. Public Health Service Pub. no. 555.

Vogt, J. E., 1961, Infectious hepatitis epidemic at Posen, Mich: Am. Water Works Assoc. Jour., v. 53, no. 10, p. 1238–1242.

Wiitala, S. W., Vanlier, K. E., and Krieger, R. A., 1962, Water resources of the Flint, Michigan area: U.S. Geol. Survey Water-Supply Paper 1499E (in press).

Williams and Works, 1956, Report to the Grand Rapids Brass Company on industrial wastes and water supply: Grand Rapids, Williams and Works mimeo. rept.

Winchell, Alexander, 1861, First biennial report of the Geological Survey of Michigan—Lower Peninsula: Lansing, 399 p.

Wisler, C. O., Stramel, G. J., and Laird, L. B., 1952, Water resources of the Detroit area, Michigan: U.S. Geol. Survey Circ. 183.

World Health Organization, 1957, Pollution of ground water (excerpt): Am. Water Works Assoc. Jour., v. 49, no. 4, p. 392.

INDEX

[Major references are in italic]

U. S. GOVERNMENT PRINTING OFFICE : 1963 O - 681-387

-