

GROUND-WATER CONTAMINATION AND
LEGAL CONTROLS IN MICHIGAN

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY

Morris Deutsch

1960



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By

MORRIS DEUTSCH

AN ABSTRACT

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Resource Development

1960

Approved



C. R. Humphrys, Associate Professor

ABSTRACT

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

Man-made 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, and possibly by dewatering operations and surface-stream channel deepening. 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. Despite the contamination that has occurred in the State, however, the total amount of ground-water

supplies which have been spoiled account for a small percentage of the total resource and is not as widespread as the impairment in quality from their original state to which many of our surface streams have been subjected following settlement of Michigan by the white man.

Overall legal authority to control most types of ground-water contamination in the State has been assigned to the Water Resources Commission by the Legislature, although various divisions of 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 various 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 man-made changes in the hydrologic regimen.

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ACKNOWLEDGMENTS

Sincere thanks are due Mr. Norman F. Billings, Chief, and other personnel of the Hydrology Section, Michigan Water Resources Commission, and to Mr. Theodore 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. John 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. Arthur E. Slaughter, also of the Michigan Geological Survey, provided further pertinent data on contamination cases in the Northern Peninsula. Mr. Edward M. Burt of Williams and Works, Consulting Engineers, Grand Rapids, contributed interesting information in addition to technical assistance concerning instances of ground-water contamination in the Grand Rapids area.

Appreciation is expressed also to personnel of the U. S. Geological Survey who greatly aided the author as follows in preparation of this thesis: Messrs. Kenneth E. Vanlier and Paul R. Giroux provided technical assistance during preparation of various illustrations and portions of the manuscript. Mr. John G. Ferris permitted use of pertinent unpublished file data and illustrative matter prepared by him. Mr. Charles J. Doonan drafted various of the illustrations presented herein from pencilled sketches. Miss Janet K. Olmstead typed the manuscript.

The author is grateful also to Dr. Clifford R. Humphrys of the Department of Resource Development, who encouraged undertaking of the study and who offered many helpful suggestions and criticisms.

Lastly, deep appreciation is expressed to Dr. A. N. Sayre, former chief of the Ground Water Branch, U. S. Geological Survey, who approved a grant of federal funds for the study culminating in the present thesis. A limited amount of federal funds are used for the purpose of supporting research projects of direct interest to the government which can also serve as graduate school theses. This grant enabled the author to make the present study in conjunction with his full-time duties as District Geologist, Ground Water Branch, U. S. Geological Survey, Lansing, Michigan.

Manuscript copies of this thesis have been released to the open file for public inspection by authority of the Director, U. S. Geological Survey.

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INTRODUCTION

The ever-increasing use of water for all purposes in Michigan has caused considerable attention to be focused on methods of protecting and conserving the water resources of the State as the use of water by man generally tends not only to reduce the supply, but frequently results in deterioration of quality.

It is readily apparent that, while the State's water resources must in the future be protected from undue deterioration in quality by chemical, biological, or even physical agents including heat and various types of suspended matter, such has not been the case in the past. The use of streams in Michigan for disposal of sanitary and industrial wastes, especially in the southern half of the Southern Peninsula, 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. The public health and economic welfare of Michigan, however, depend upon the use of streams as mediums for disposal of sewage effluent, and their use for this purpose cannot be totally eliminated.

Where supplies of surface water of suitable quality cannot be obtained, water users generally rely on ground-water sources for supply, or, at great cost, have constructed or are planning pipelines to the Great Lakes to obtain water. Some of this water has already "flowed by their front doors." Ground water is in widespread use in Michigan, however, not only to replace unsuitable surface sources, but because of the several basic inherent advantages of a ground-water supply. The

advantages have been expressed succinctly by the World Health Organization (1957) which reported "It has been found that ground water is of excellent bacterial quality over large areas, and this is one of the reasons why it is so widely used for public water-supply purposes. Other reasons are its clarity, palatability, its freedom from organic matter, its relatively constant temperature, and its reliability summer and winter alike."

In Michigan, ground water can be obtained over most of the State by wells drilled into one or more of the numerous aquifers in the State. Hence, most rural and suburban homes, and many industries, municipalities, and irrigators obtain water supplies from wells drilled within their respective property boundaries. MacKichan (1957) estimated that ground-water sources supply about 22 percent of the total amount of water used for public supply in the State, demonstrating the importance of the resource. Table 1 shows that, although less than 10 percent of the total amount of water used in the State for all purposes was ground water, about 90 percent of the rural supplies were derived from ground-water sources. From figures published by the Michigan Department of Health (1944), it

Table 1. Estimated withdrawal of water in Michigan, 1955, in million gallons per day. (after MacKichan, 1957)

	Public supplies	Rural	Irrigation	Self supplied industrial	Total excluding water power	Water power
Ground Water	180	73	5.3	3,315 <u>1/</u>	573	-
Surface Water	640	8	44	5,700	6,391	-
TOTAL	820	81	48.3	6,015	6,964	60,000

1/ Includes 25 mgd saline water

was estimated that 26 percent of the water used for public supply in the State was from ground-water sources, tending to confirm MacKichan's estimates. Excluding the population supplied with surface water by the city of Detroit, however, it was estimated that 70 percent of the remainder of the population relied on ground-water sources for supply.

The above estimates clearly demonstrate the great importance of the ground-water resources of the State, and make it apparent that our ground-water aquifers must be safeguarded from contamination that would render some of the resource unusable. Studies of the ground-water resources of various parts of the State by the Federal and State Geological Surveys, and investigations made by, or reports submitted to, the State Department of Health and the Water Resources Commission have revealed, however, that numerous instances of contamination of the ground-water aquifers in the State have occurred.

The necessity of conserving the ground-water resources of the State by protecting them from unnecessary contamination is stated rather directly in the general provisions of the "Model Water Use Act" prepared by the University of Michigan Law School, (Legislative Research Center, 1958). This model act was prepared because of the widespread need of various states for guidance in preparing legislation designed "to protect, conserve, fairly allocate for use, and where necessary, reserve water resources in the interest of the health and welfare of the people." Part VI of the Model Act provides that "Any pollution of the water resources.... is subject to management, control, and regulation....under provisions of this Act. The Act would grant an appropriate agency of a state rather

general but broad powers to curb, abate, or prohibit new pollution of the water resources of the state.

The purpose of this paper is: 1. To review the various ways in which the quality of water in aquifers in this State has been impaired. 2. To cite briefly many of the case histories of ground-water contamination and to point out practices which may result in contamination. 3. To examine hydraulic principles involved in the migration of contaminants to fresh ground-water reservoirs. (The figures used herein that show migration of contaminants through aquifers all are schematic and illustrate principles and are not based on actual field data.) 4. To review Michigan Supreme Court decisions and Legislative acts pertinent to the subject of ground-water contamination so as to determine the extent of legal safeguards which may be utilized to prevent further contamination of the aquifers of the State.

While numerous instances of contamination of ground-water resources in Michigan have occurred, it is probable that the total amount of contamination is not unusual for a highly populated industrial state. It is believed that discussion of the many instances cited herein may increase awareness of the hazards to ground-water supplies involved in various practices and thus indirectly lead to the curtailment of ground-water contamination in the future.

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 single tabulation of all known cases or types of contamination in the State has as yet been prepared. Most cases of contamination of public water supplies, however, have been investigated by the Michigan Department of Health, and personnel of that organization have described many of the cases presented herein in various issues of the Department's informal publication, the Michigan Water Works News. 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, the Quarterly Bulletin, issued by the staff of the Commission, has also been used extensively as a source for material contained in this report.

A significant advance in the understanding of principles involved in ground-water contamination was made by Fiedler (1936) who described, in general, geologic and hydrologic controls governing the migration of contaminants to 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) described the roles that aquifers might play as waste-disposal reservoirs and he outlined the basic hydrologic problems which are essentially the same as those involved in aquifer contamination cases.

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, thus demonstrating the advantages of pure water to all interests in the State.

A very informative pamphlet covering various aspects of ground-water pollution was prepared for general public use by Slaughter and Campbell (1952). The pamphlet contains a number of cartoons depicting problems of ground-water contamination, one of which is reproduced herein.

Parker (1955) in a paper included in Water (a symposium published by the U. S. Department of Agriculture as the 1955 Yearbook of Agriculture) discussed the encroachment of saline waters into fresh-water aquifers of Michigan. The yearbook contained several other papers of general interest to those concerned with the protection of water resources: Schwab (1955, p. 636-643) wrote on the problems of pollution of water in our growing nation. Fuhrman (1955, p. 644-649) discussed treatment of waste waters for cities and industries. Garver (1955a, p. 655-663) wrote on ways by which rural water supplies may be contaminated and of protective measures which may be taken, and also (1955b, p. 663-665) 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, b). These reports are of added value to researchers in the field of water pollution as they contain very comprehensive bibliographies.

The American Water Works Association (1957) is also 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.

This report contains no mention of the threat of 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 references.

The Legislative Research Center of the University of Michigan Law School (Pierce, 1958) published contributions prepared for the Tenth Annual Summer Institute of the Law School in the form of a symposium entitled "Water Resources and the Law." An especially valuable contribution for those interested in the legal aspects concerning contamination of water supplies is the paper entitled "Water Law in Michigan," by Lauer, King, and Ziegler (1958). An equally important contribution was presented by Piper and Thomas (1958) who describe the inappropriateness of common law in defining rights to water because of the complexities of the hydrologic cycle, or even of adapting statutory law to "the realities of applied hydrology."

SUMMARY OF GROUND-WATER OCCURRENCE IN MICHIGAN

Fresh ground water can be obtained throughout most of Michigan by wells drilled into one or more of the numerous aquifers of the State. An aquifer is a rock formation, part of a formation, or group of formations that yields water in usable quantities. In some areas of the State ground water is relatively difficult to obtain and aquifers yielding only a few gallons per minute of water are of considerable importance. In other areas where aquifers may yield several hundred gallons per minute, formations capable of yielding small amounts may be classed as non-productive.

The imaginary surface consisting of all points to which water would rise in wells tapping an aquifer is called the piezometric surface. On the basis of water occurrence, aquifers may be classified as water-table or artesian. In a water-table aquifer, ground water is unconfined and the water table may be considered the piezometric surface of that aquifer. In an artesian aquifer, ground water is confined under pressure between relatively impermeable strata termed aquicludes or confining beds (strata through which water does not readily move). Under natural conditions, a well that is finished in an artesian aquifer and tightly cased through the overlying confining bed will permit water to rise above the bottom of that bed, and therefore, the piezometric surface is above the top of the aquifer. An artesian aquifer is full of water at all times even when some water is being removed from it. Eventually, however, enough water may be pumped to draw the piezometric surface below the bottom of the overlying aquiclude, thus locally creating water-table

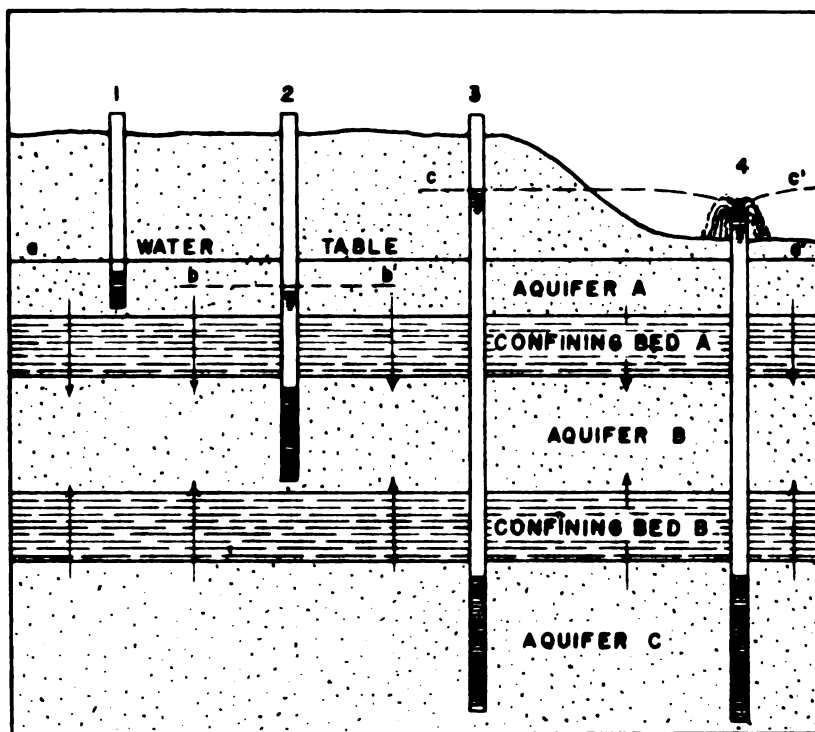
conditions. In topographically low areas, the piezometric surface of an artesian aquifer may be higher than the land surface. Wells tapping artesian aquifers in such areas will flow at or above the land surface.

\ The initial source of nearly all the ground water of Michigan is precipitation, which averages about 30 inches annually. If all the moisture that fell upon the State entered into uniformly distributed permeable aquifers, a bountiful supply, more than enough to satisfy any foreseeable needs, would be insured. However, much of this water does not enter the ground-water reservoirs, but is lost by evaporation, by transpiration, and by direct runoff to the Great Lakes drainage system.

The amount of precipitation that enters the aquifers and ultimately becomes available to wells depends upon the regional and local geologic and hydrologic characteristics of the aquifer; climatic conditions including the duration, intensity, and type of precipitation; the density and types of vegetation; the topography; and the hydraulic properties of the soils and subsurface units in the recharge area. The quantity recharged may also be affected by agricultural conditions and land-use practices.

The movement of ground water is somewhat similar to that of surface streams in that the water moves by gravity from areas of high pressure head to areas of low pressure head. Movement of water through the interstices between rock particles or along bedding planes, fractures of various types, or solution openings below the surface involves a great amount of friction and hence is much slower than flow of water upon the surface. Rates of ground-water movement range widely from a few feet per year to many feet per day.

Water may travel great distances underground from recharge areas to areas downgradient where it may once more reach the surface and join the flow of streams, appear as a seep or spring, enter a lake, or escape directly to the atmosphere by evaporation and transpiration. Where undisturbed by man-made diversions, the piezometric surface of an aquifer near the surface conforms generally to the configuration of the overlying land surface. In the deeper artesian aquifers, however, the piezometric surface may differ considerably from the overlying land surface, and locally its gradient may be in a direction opposite to the slope of the land surface. Where more than one aquifer underlies the same area, water will migrate or leak from an aquifer of high head to the overlying or underlying one of lower head. In this way, water commonly leaks slowly through the confining beds of an artesian system. 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 1 illustrates principles involved in natural inter-aquifer leakage. The water surface in well 1 coincides with the top of the zone of saturation and hence aquifer A is termed water table or non-artesian. Aquifers B and C 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 which causes the water table or piezometric surface in one aquifer to decline below the previously lower level of the piezometric surface of a second aquifer as illustrated in figure 2. By the same token, normal upward leakage from a lower aquifer may be reversed by pumping of the lower aquifer.



EXPLANATION

a-a' is the water table in aquifer A and well 1 is a water table well. b-b' is the piezometric surface in aquifer B and well 2 is an artesian well. 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.

Figure 1. Section showing hydrogeologic conditions for water-table and artesian aquifers (after Ferris and others, 1954)

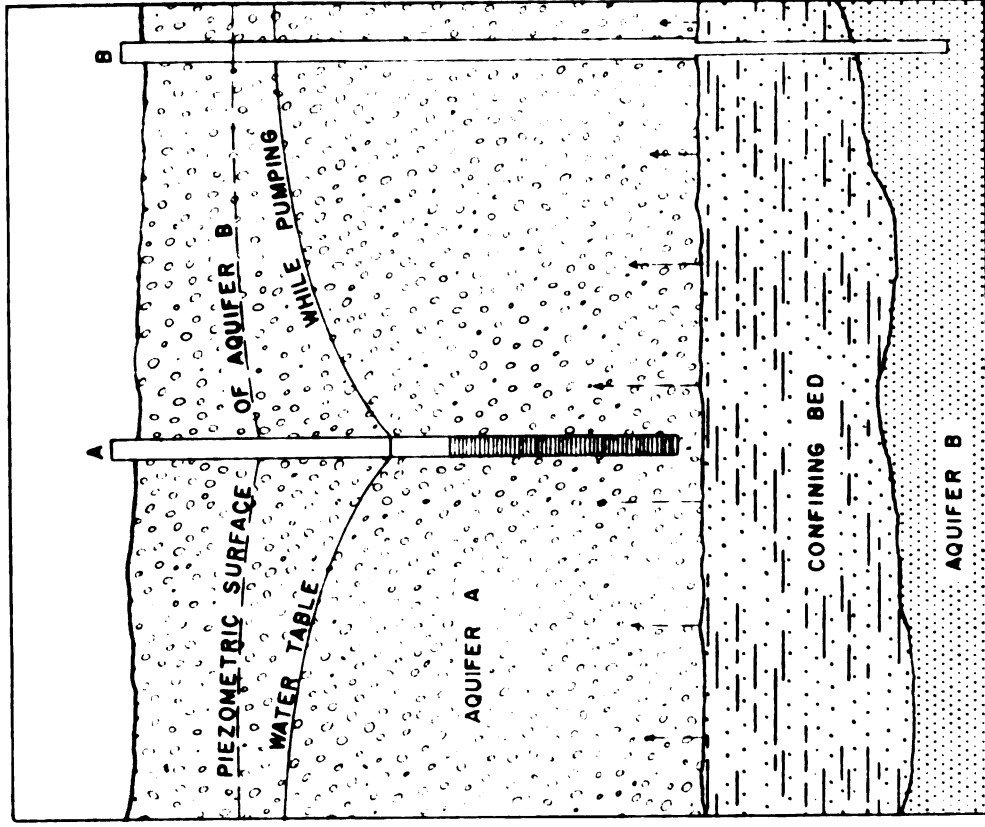
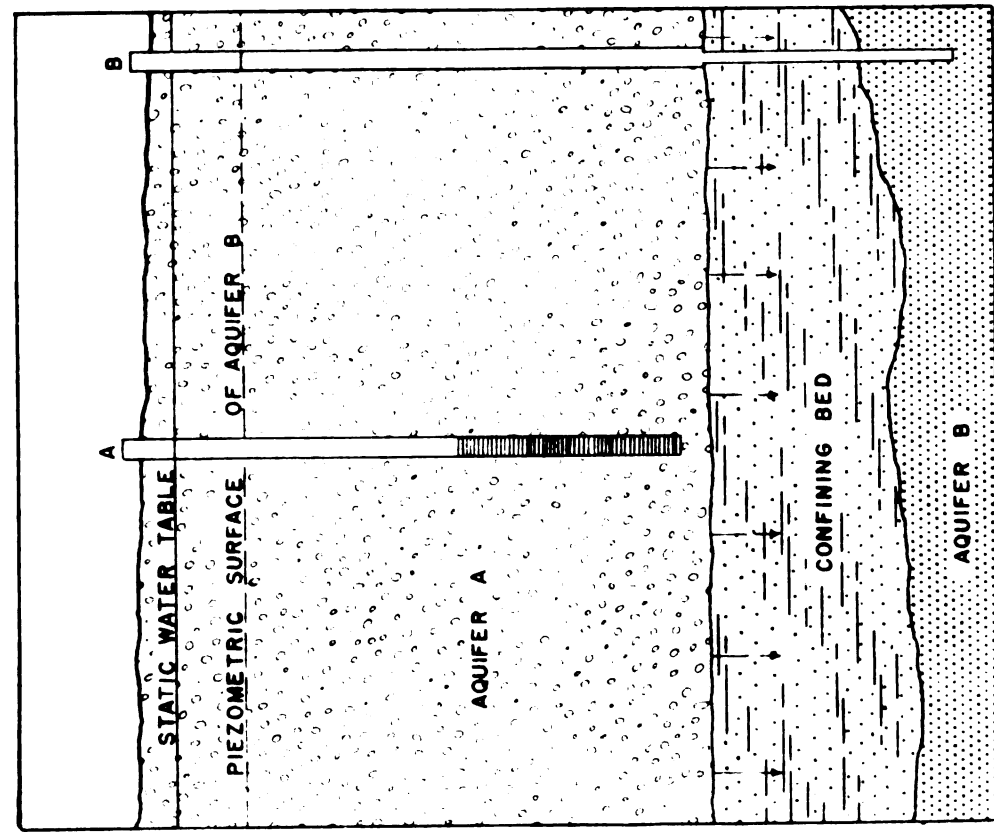


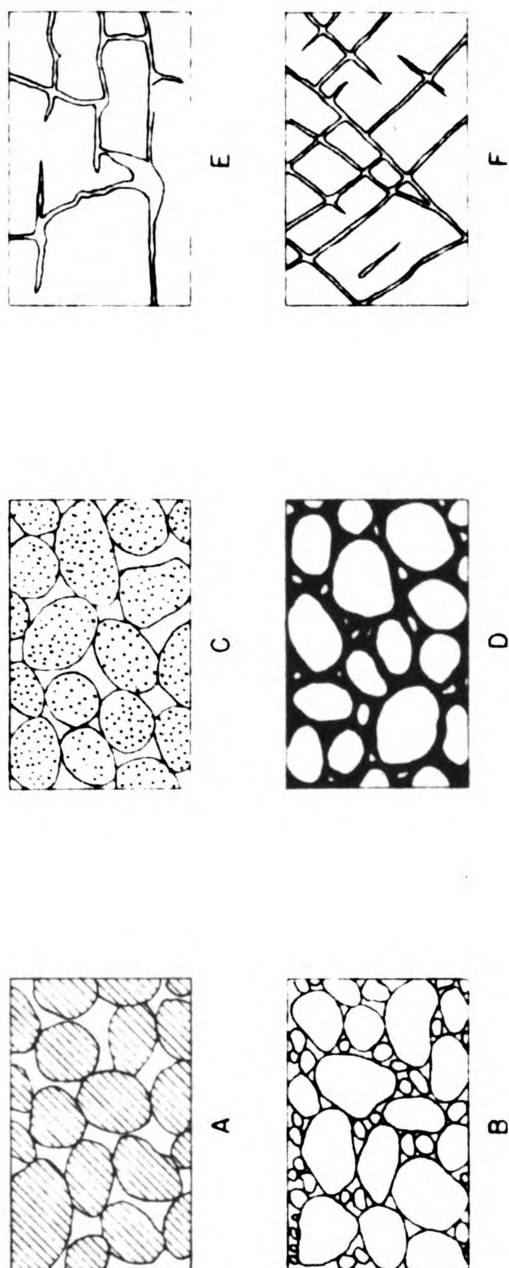
Figure 2. Interformational leakage reversed by pumping
(after Ferris and others, 1954)

Meinzer (1923) showed that the hydrologic properties (permeability and porosity) of aquifers are determined basically by the character of the interstices between grains, or open spaces within the rocks, that form the aquifers (fig. 3). Interstices in rocks can be grouped into two main classes--the original interstices, which were formed when the rocks came into existence, and the secondary interstices (joints, fissures, solution passages), which were developed later.

In Michigan, water-bearing rock formations are commonly classified into two broad categories; namely, bedrock and glacial drift aquifers. The bedrock or consolidated rock aquifers include both 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 the sedimentary rocks of Paleozoic age which overlie the Precambrian rocks elsewhere in the State (fig. 4). Over all but 2 or 3 percent of the area of Michigan the bedrock is mantled by glacial drift deposited during the Pleistocene epoch or Ice Age. Table 2 is a generalized columnar section listing the major rock formations of Michigan, including those referred to herein.

The Precambrian rocks commonly are very dense, and hence of low permeability. 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 drilled into such openings. Where mines penetrate such permeable zones, dewatering operations may be necessary.

The Paleozoic rocks underlie all of the State except for the parts of the western section of the Northern Peninsula where the Precambrian rocks form the bedrock surface. The Paleozoic rocks are consolidated



EXPLANATION

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.

Figure 3. Diagram showing several types of rock interstices and the relation of rock texture to porosity
(after Meinzer, 1923)

Table 2.

GENERALIZED COLUMNAR SECTION OF THE MAJOR
GEOLOGIC UNITS OF MICHIGAN

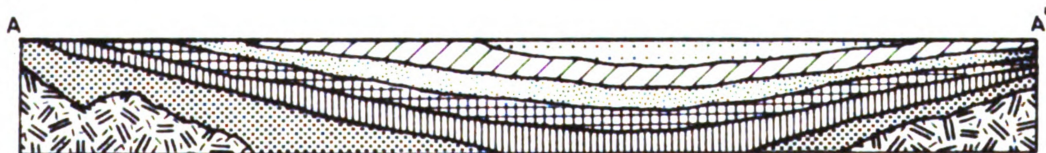
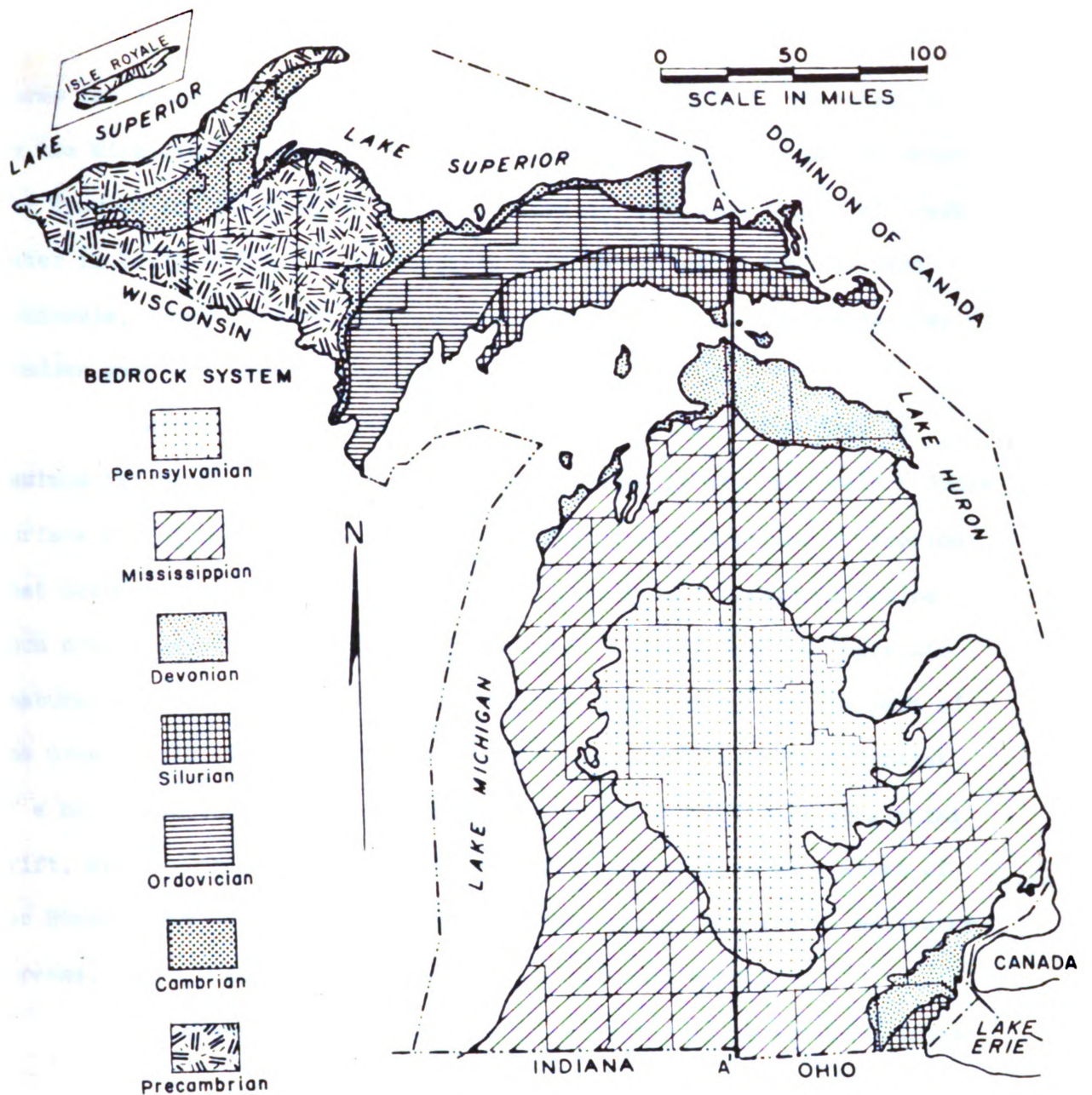
(adapted from columns and terminology of the Michigan Geological Survey)

Subsurface terminology is disregarded in favor of the nomenclature
commonly used in outcrop areas.

SYSTEM	SERIES	GROUP OR FORMATION	LITHOLOGY	THICKNESS (FEET)	ECONOMIC PRODUCTS
QUATERNARY Pleistocene		Glacial Drift		0-1200	Fresh water, sand and gravel, clay, marl, peat.
PERMIAN (?)		"Red beds"	Shale, clay, sandy shale, gypsum		
PENNSYLVANIAN		Grand River	Sandstone, sandy shale	80-95	Building stone, fresh water
		Saginaw	Shale, sandstone, lime- stone	20-535	Shale, coal, brine,
CAMBRIAN		Munising	White sandstone	50-200+	Fresh water
		Jacobsville	Red sandstone	1200+	Building stone, fresh water
PRECAMBRIAN	Upper	Keveenawan Series (copper fms.)	Lava flows, conglomer- ate, shale, sandstone	9800- 35,000	Copper, silver, road metal, semi- precious gem stones
		Granitic intrusives (Killarney)	Granite, gneiss, diorite, syenite		
	Middle	Animikie (iron fms.)	Slate, hematite, schist, quartzite, granite, marble, dolomite	2000+	Iron ore, roofing slate, road metal, graphite, marble
		(Laurentian)	Gneissic granite, schist		Road metal, building stone, verde antique
	Lower	(Keewatin)	Schist, greenstone, slate		talc, gold, road metal

sediments consisting of strata of limestone, dolomite, shale, sandstone, and breccia which are commonly 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 gradual subsidence and compaction of the beds, which was contemporaneous with deposition and greatest in the center of the basin, produced a bowl-shaped structure (fig. 4). The youngest beds are exposed at the surface in the central part of the structure and the formations crop out in roughly concentric bands. 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 joints, other 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. They are significant in the hydrologic system because they impede vertical movement of ground water, and hence retard solution in underlying soluble rocks, and also act as confining beds in artesian systems.

In general most of the fresh water in the sedimentary rock aquifers is in the portions of the formation where they form the bedrock surface or are close to the surface. Where the aquifers are buried at depth beneath younger Paleozoic rock formations the water present is generally saline. For example, the Marshall sandstone is the principal source of fresh ground water at Battle Creek in Calhoun County where it



Schematic geologic cross-section along line A-A'
(Vertical scale greatly exaggerated)

Figure 4 Geologic map of the bedrock systems of Michigan.

forms the bedrock surface, but in Ingham County, where it is overlain by the Michigan formation and Saginaw sandstone, it yields saline water. The Trenton and Black River limestones are an important source of fresh water in Delta County in the Northern Peninsula, but in the Southern Peninsula, these formations are at great depth, and in some areas they produce gas, oil, and brine.

Unconsolidated sediments slightly more than 1,000 feet in maximum thickness were deposited on the Precambrian and Paleozoic bedrock surface during the Pleistocene epoch following a long period of erosion that occurred prior to the glacial age. During this erosional period much consolidated rock was removed and some of the major physiographic features of Michigan, including the major valleys which are now part of the Great Lakes, were formed. The Pleistocene deposits, which consist of a heterogeneous mixture of 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 primarily by ice, meltwater streams, lakes, and wind action during the glacial epoch.

The water in these aquifers is contained in the voids between rock particles. The permeability of the drift is determined by the size of the individual grains, the degree of sorting, and the amount of compaction and cementation. The most permeable deposits, and hence those which form the best aquifers are the stream-laid outwash deposits, which are composed of the larger particles of rock debris and are relatively well sorted. On the other hand, till deposits are of low permeability and are not important as aquifers in most of the State except in the

Lake Superior area and in the northern part of the Southern Peninsula where they are composed largely of sand. Till is generally unstratified drift that was deposited directly by the ice, with water playing a minimum part in the process of deposition. Also included within the glacial drift mantle are large quantities of clay, silt, and fine sand deposited in the waters of the numerous glacial lakes which existed during and after the Pleistocene epoch. Most of these deposits comprise rather poor aquifers in Michigan except locally where they are composed chiefly of fine sand and will yield small amounts of water to wells. Extensive dunes composed of well-sorted sand deposited by wind action during late- and post-glacial times are present in several areas of the State, especially along the Great Lakes shorelines. Although permeable, they are not important as aquifers as they generally lie above the regional water table.

GROUND-WATER CONTAMINATION IN MICHIGAN

Contaminants, both natural and man-made, which may ultimately deteriorate the quality of water in any aquifer, may come in contact with water at various points in the hydrologic cycle. Figure 5 (after Sayre, 1950) is a schematic section showing water-table and artesian aquifers as part of the hydrologic cycle. In addition, modes of introduction of contaminants into aquifers are numerous, as is illustrated by the large variety of instances of contamination in Michigan cited below.

Fresh water, as defined herein, is 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). However, the dissolved-solids content of water of good chemical quality should not exceed 500 ppm. Waters containing more than 1,000 ppm of dissolved mineral matter but not necessarily limited to sodium chloride, are referred to in this report as "saline" or "mineralized." The primary source of the dissolved solids present in some highly saline ground waters in the State is believed to be connate water entrapped at the time of deposition of sediments in the Michigan basin, and formations containing soluble minerals, which are being dissolved and removed in solution by percolating ground waters. Variations in mineral content result from the mixing of saline and fresh waters in various proportions, the solubility of mineral constituents in various aquifers, and the quantity of fresh ground water moving through the aquifer.

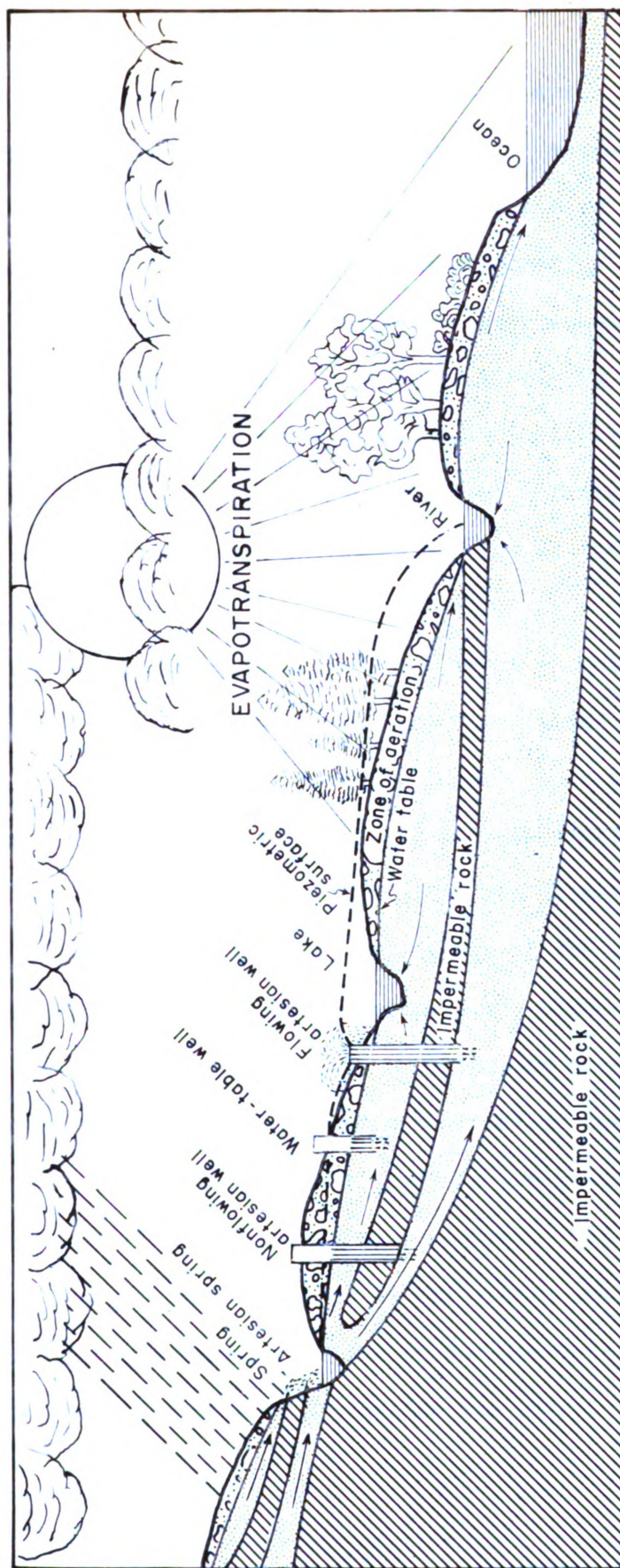


Figure 5. Diagrammatic section showing water table and artesian aquifers as part of the hydrologic cycle
(after Sayre, 1950)

For the purposes of this report, a fresh-water aquifer is considered to be contaminated if it is subjected to encroachment of natural ground waters containing one or more minerals in concentrations greater than permissible in drinking water as defined by the Public Health Service. Introduction of chemicals or other substances to an aquifer that may cause deleterious physiological effects or those which impart objectionable taste, odor, chemical quality, or even temperature, are also considered as instances of contamination. Bacterial contamination cases discussed herein are those described as such by the Michigan Department of Health.

The extent of contamination of the fresh ground waters which has already occurred in Michigan has not been determined. Further, it is most unlikely that it would be possible to make such a determination. The distribution of instances of ground-water contamination in Michigan described herein are shown on figure 6. It is the author's opinion, however, that only a relatively small percentage of the entire ground-water resource of the State has been contaminated, although in some areas especially in the Saginaw Lowlands, the Grand Rapids area, and other places in southern Michigan, widespread contamination has seriously impaired important aquifers. In other areas of the State, serious, but much more localized contamination has occurred. The total extent of ground-water contamination probably is not nearly comparable to the widespread and serious contamination of surface water which took place incidental to the growth of population and industry in Michigan.



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

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. Objectionable substances which have contaminated ground waters in the State 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. Methods of entry of harmful substances to ground-water supplies include direct injection to various aquifers through a number of types of wells; percolation from dry wells, pits, underground storage tanks, and septic tanks; and from percolation of liquids spilled at the surface, or leached from the surface by precipitation. Other instances of contamination have occurred because of leaking or broken sewers, or entrance of polluted surface waters into the ground. Even airborne wastes are suspected to have contaminated ground-water supplies in one locality.

Injection into Wells

① The most direct method by which aquifers in Michigan have become contaminated has been by discharging wastes directly into wells tapping fresh-water aquifers. As long as a head of waste water in such a well is above water table or piezometric surface the waste water will flow into an aquifer (fig. 7). The water which enters the well will flow radially from the well into the aquifer. Ultimately, the direction of flow away

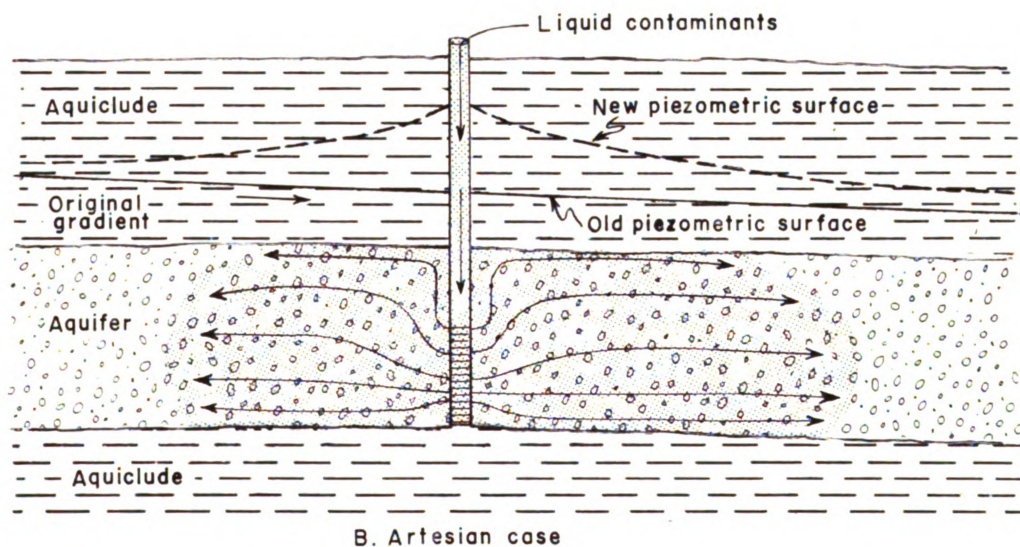
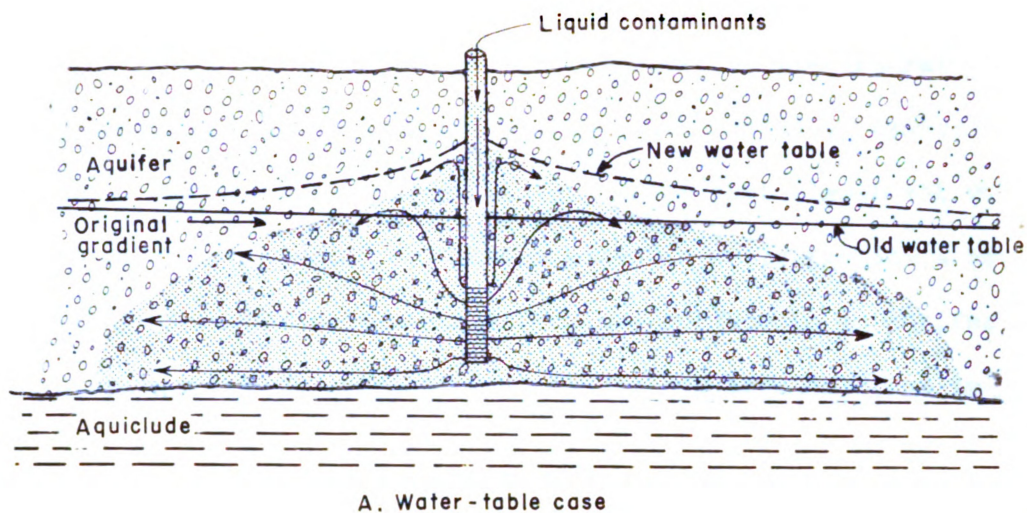


Figure 7. Diagrams showing spread of contaminants injected through wells into isotropic water-table and artesian aquifers

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 almost all wells, except those which are plugged or flowing artesian wells provide a possible avenue of entry of liquid contaminants from the surface to an aquifer.

In some cases the injection of wastes has been resorted to because of the ease and lack of expense involved. In other cases, the injection was accidental or the results of the injection were unanticipated.

Sanitary wastes at Elkton

At Elkton in Huron County during the summer of 1945, it was discovered that the municipal well which taps the sandstones and limestones of the Marshall formation yielded water contaminated with sanitary and domestic wastes. At the request of the Village Council the State Health Department with the assistance of the Michigan Geological Survey made an investigation which showed that a practice of using abandoned domestic wells for draining basements, laundry and kitchen wastes, and septic tanks was quite widespread in the area owing to poor surface draining conditions. These wells also tapped the Marshall formation and hence the aquifer, which was the village's main source of supply, was directly polluted. Plugging of all of these so-called "leak wells" was proposed as a solution, but this was found to be impractical. It was estimated that there were 50 to 75 "leak wells" in town, many of which could not be located. In order to provide a safe ground-water supply, the village had no alternative but to construct a new well outside of town and upgradient in relation to the natural direction of flow of the ground water.

Fuel oil at Holt

An occurrence of fresh-water contamination at Holt in 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. When an automatic shut-off device failed to operate after the fuel tank should have been filled, and the pumping continued, the delivery man investigated. To the consternation of all concerned, it was found that the oil was 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 grossly contaminated with fuel oil (fig. 8).

Well reconditioning at Mt. Morris

The city of Mt. Morris in Genesee County has 2 wells located within 35 feet of each other. It became necessary to recondition the west well and this was done by pulling the screen and installing a new gravel pack. During the reconditioning operations bacterial contamination of water pumped from the east well was noted. It was apparent that bacterial contaminants entered the west well while it was being repaired. Inasmuch as the west well was not being pumped and the nearby east well was, a cone of depression was formed around the east well. Water, moving radially toward the pumping well, carried with it the contaminants injected into the west well (fig. 9). The possibility of this and similar types of

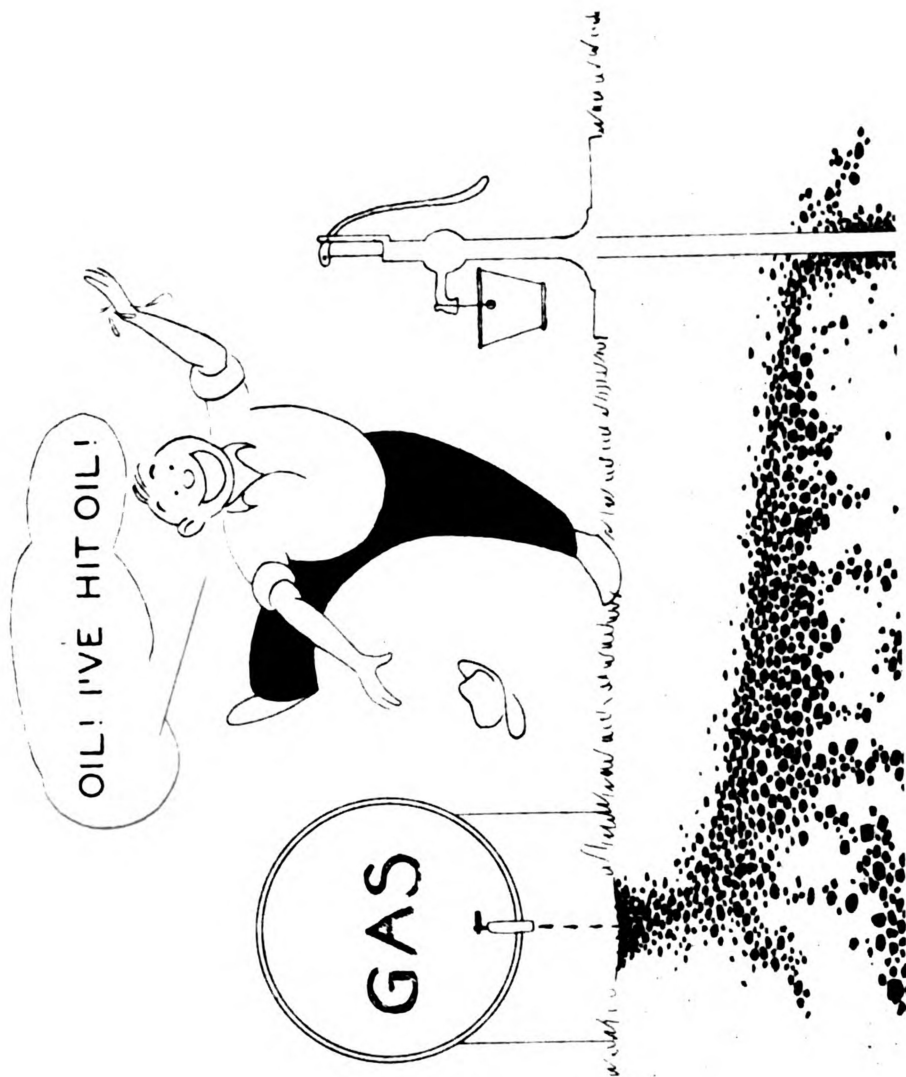


Figure 8. Oil! I've hit oil!
(after Slaughter and Campbell, 1952)

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 in accordance with recommendations which may routinely be made by an appropriate health officer.

Air-conditioning return or recharge wells

2 The widespread use of ground water for air-conditioning purposes presents a potential hazard to the ground-water resources of the State inasmuch as it is common practice to return the water to the ground after it has circulated through the system. The water generally is returned to the ground either to avoid the necessity of discharging the water to public sewers which commonly are financed by use taxes, or as a conservation practice to replenish ground-water supplies or to maintain water levels or artesian pressures as high as possible. The potential hazards to the aquifer lie in the fact that waste waters other than the spent air-conditioning water may be recharged to the aquifer through such wells either accidentally or in an attempt to reduce input into sewage systems.

The return of warmed, waste air-conditioning water to an aquifer will result in a rise in temperature of the water in the aquifer to which it is returned. Such rises in ground-water temperature may be undesirable for a number of reasons:

1. The warmed ground water is of less value for reuse in air-conditioning systems and for use in some industrial processes.
2. The palatability of the ground water is impaired.
3. Warmed water generally has increased capacity to dissolve and carry in solution soluble rock or other mineral matter.

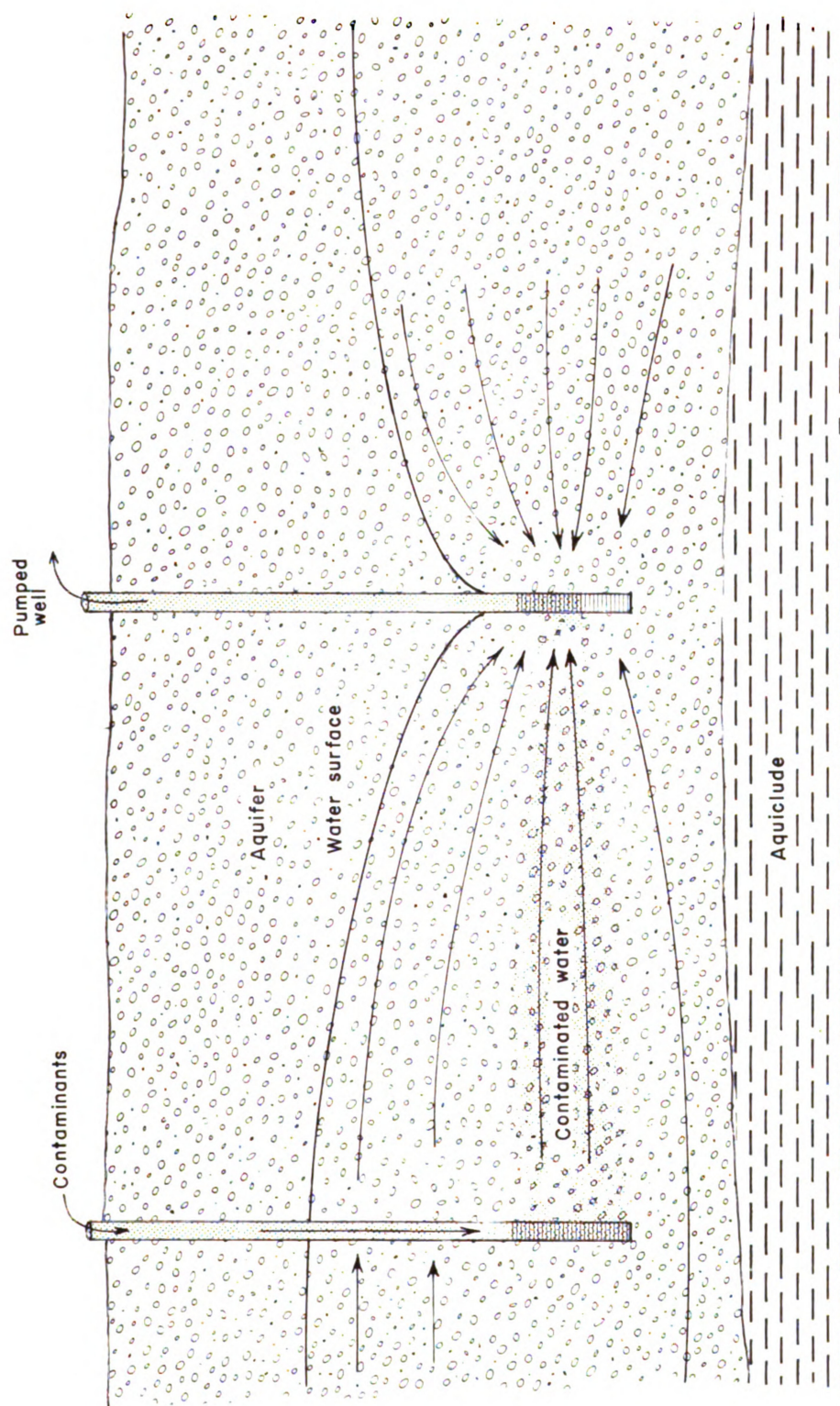


Figure 9. Schematic diagram showing movement of contaminants through a well to a nearby pumping well

4. Discharge of warm ground water may cause undesirable rises in temperature of surface streams.

Recharging 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 date of the present paper no such project is known to have been started. Such artificial recharge might be advantageous for several purposes:

1. Underground storage of spring runoff.
2. Displacement of saline waters.
3. Recovery of water levels in aquifers which have been subjected to significant declines of head because of pumping.

It is apparent that unless only water of good quality is injected into a fresh-water aquifer for any purpose, impairment of the aquifer could readily occur.

Billings (1955), in discussing artificial ground-water recharge, wrote as follows:

"Where heavy pumping depletes local supplies great possibilities for their artificial replenishment lie in the copious, ice-cold winter flow of streams. With filtering and chlorination, such water can be very acceptable for introduction into the ground through recharge wells. Then how about underground return of spent air conditioning waters? To the writer's notion, this is a very questionable practice--a stop-gap, half measure that can do more harm than good. Where recharge is needed, why not use pure cold water instead of doubtful cast-off stuff?"

Dug wells

A dug well, which in effect is an excavation extending a relatively shallow depth into the aquifer 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, except for the fact that a dug well is especially susceptible to contamination because of its large diameter and 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 justifiable if fresh ground water in an area is available only in aquifers of relatively low permeability through which water moves very slowly. Dug wells may yield adequate supplies from such aquifers because of their relatively large entrance areas and storage capacities.

Contaminated surface waters

A number of aquifers in various areas of the State have been contaminated because improper construction of wells permitted surface waters of objectionable quality to recharge through the well. Flood waters of objectionable chemical or bacteriological qualities are especially hazardous in this respect, as they may rise to levels greater than the tops of well casings in low areas and enter the aquifer.

Ponded storm water at Bad Axe.--In the Spring of 1921, several serious outbreaks of intestinal influenza at Bad Axe in Huron County were reported to the State Health Department. The resulting 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) it was difficult to explain the source of contamination as the city wells flowed when they were not pumped and the well which produced the contaminated water was adequately sealed against contamination. The production well, however, was only 430 feet from an open abandoned well which was submerged and it appeared most probable that pumping of the production well had lowered the head in the abandoned well below the level of ponded water. Thus, the contaminated ponded water flowed into the abandoned well and through the aquifer to the production well in a manner similar to the Mt. Morris case cited above.

It had been thought that the fine dense nature of the Marshall sandstone would preclude the possibility of contamination from a distance of 430 feet. However, 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 to a considerable extent, opening a very permeable hydraulic connection between the production well and the abandoned well. Studies of sandstone aquifers made elsewhere in the State by the author have shown that in fine dense sandstones such as the Marshall formation in Huron County water moves through secondary openings similar to those shown in figure 3F. Although dynamiting may have increased the secondary permeability somewhat, it is possible that

contamination of the production well would have occurred regardless, as long as contaminated surface water was permitted to enter the aquifer through an unused well.

Flood water at Saugatuck.--In 1951 at Saugatuck, in Allegan County, analyses showed that water from two of the three municipal wells 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 from the surface. Investigation by the Michigan Department of Health indicated that water from the flooded Kalamazoo River was the source of contamination, and that the water entered the well through the gravel envelope around the well casing. (See fig. 14B.) It is apparent from this case that to effectively seal a well from surface waters of objectionable quality, any gravel packs used in construction of the well should not extend to the surface, or even to the very top of an aquifer which is subject to contamination.

Backflooding at Minden City.--The need for preventing flood waters or backflow from a distribution system from entering a well and contaminating an aquifer is illustrated by an event at Minden City in Sanilac County. In December 1956 the pump on the city's only well failed when the pit in which the pump was located became flooded, allowing surface water to flow into the well. In addition, water backflowed into the well from the water mains. Water backflooding into a well because of the absence of pressure on a system is subject to contamination through such defective or unprotected plumbing fixtures as may exist. In this instance the supply was not seriously affected by the contaminated backflow

and surface water as the State Health Department operated an emergency chlorinator on the system until all of the contaminated water was flushed from the aquifer by the pump. Emergency chlorination was discontinued after three days. Decontamination was indicated by the absence of sanitary wastes as determined by bacteriological analysis. Failure to take prompt and effective corrective measures, as was done in this case by the State Health Department, could have resulted in serious after-effects.

Drain wells.--Another activity which might result in an aquifer becoming contaminated is the use of wells for drainage purposes. Horton (1905) described a subsurface drainage operation in Parma Township, Jackson County. The owner of a surface pond wished to drain it, but surface drainage was not feasible, presumably because of topographic or economic considerations. A well was drilled into the aquifer from the bottom of the pond, and the well casing allowed to project into the pond in a manner similar to that shown in figure 10. Although the water level in the pond was visibly lowered, complete drainage was not accomplished. The well was deepened into a more permeable zone and the pond was then rapidly and completely drained.

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. Surface waters are readily susceptible to bacterial contamination, and when they are 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 which are current or potential sources of potable water supply unless the recharge water is first chlorinated and filtered.

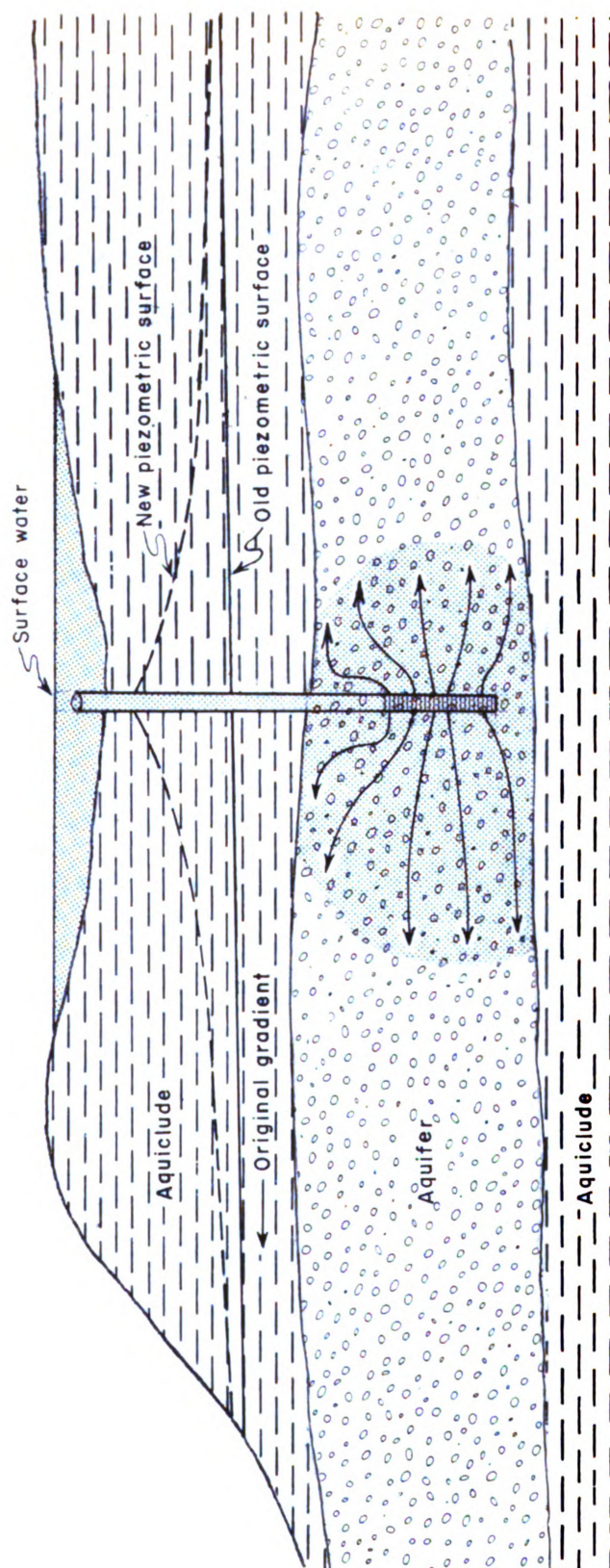


Figure 10. Schematic diagram showing discharge of surface water through a drain well to an underlying aquifer

Dry Wells, Ponds, Pits, or Underground Storage

A well that is open in permeable materials and finished in the unsaturated zone, or zone of aeration, above the water table (a so-called "dry well") provides another possible entryway for wastes to enter an aquifer. Almost all of the suspended solid material will be filtered out within a few inches from the dry well, but the liquids containing dissolved solids will percolate vertically through the permeable materials above the aquifer, except as dispersed laterally by capillarity or deflected by materials of low permeability, and will enter the upper portion of the underlying aquifer (fig. 11). The liquid waste will tend to form a mound on the water surface and move radially from the mound. The distance, direction, and velocity of underflow of the waste will be affected by the gradient and velocity of ground water in the aquifer.

Waste water discharged into a surface pond, pit, or settling basin also may ultimately enter a fresh-water aquifer. Percolation of the waste to the aquifer is in the same manner as from a dry well, except that because the water in the pond is exposed to the atmosphere over a relatively large surface, it is also subject to evaporation. The pond or settling basin, however, ordinarily will permit more water to enter an aquifer than a dry well because of its much larger infiltration area.

Similarly, where various liquid chemicals or chemical wastes are stored underground, they also present a potential hazard to ground-water supplies. Another dangerous practice is to store wastes in a covered but unlined earthen pit which behaves like a surface pond so

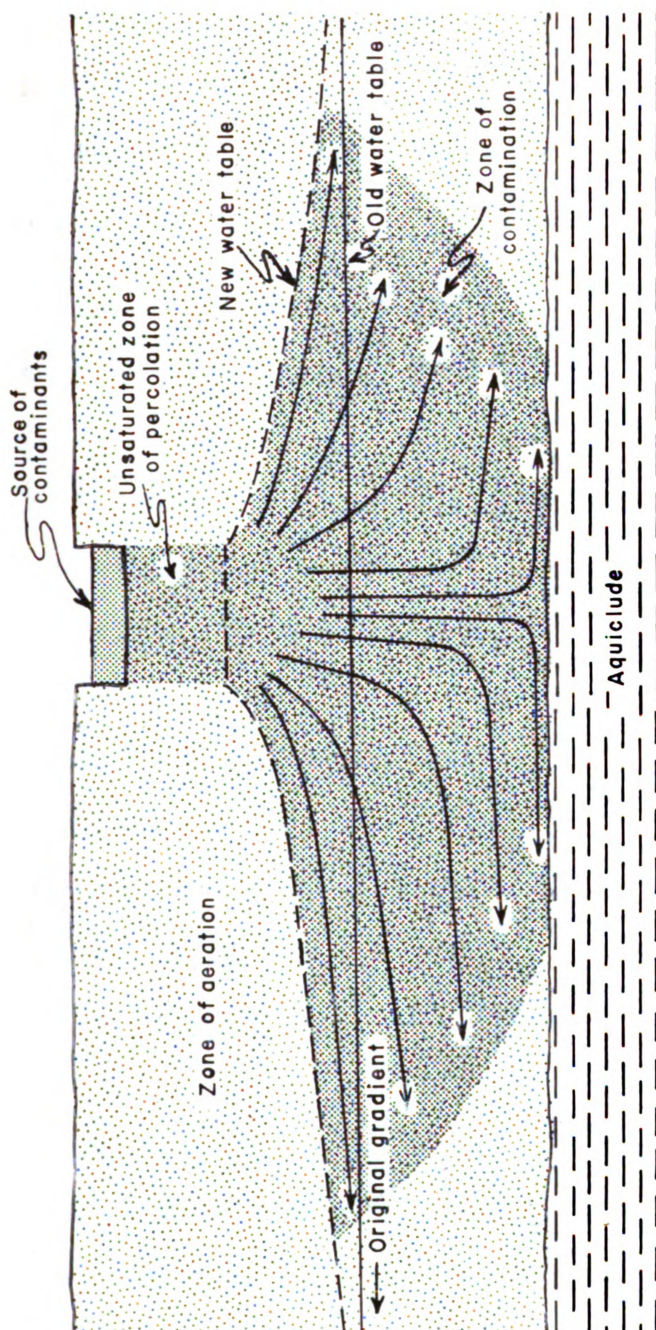


Figure 11. Schematic diagram showing percolation of contaminants through the zone of aeration and in an isotropic aquifer

far as infiltration is concerned. Storage of noxious materials even in steel or concrete tanks presents a potential hazard as corrosion of the metal or cracking of the concrete may ultimately permit seepage of contaminants into an aquifer. Contamination resulting from such instances has occurred on several occasions in Michigan.

Phenols

Among the most noxious substances which have contaminated aquifers in various areas of the State are phenols. Phenol (carbolic acid) is a hydrocarbon contained in some industrial wastes. Noecker, Greenman, and Beamer (1954, p. 46) reported that studies made by the Pennsylvania State Board of Health indicate that when the concentration of phenols in the Ohio River exceed 0.02 ppm, ground-water supplies recharged by infiltration are contaminated. They report that one or two days after the phenols appear in the river water, the water from wells nearby has the characteristic phenolic medicinal taste and odor. According to Elder, Scott, and Kanda (1948, p. 285) if water containing phenol is chlorinated the resulting chlorophenolic substance is detectable to the taste in concentrations of 0.001 ppm or 1 part per billion of water.

The U. S. Public Health Service (1946, p. 383) states that phenols in excess of 1 part per billion should preferably not occur in natural or treated waters. There is some disagreement, however, as to what the maximum permissible concentration of phenols in drinking water should be, although it is apparent a concentration sufficient to impart a detectable taste would be very small. Once it has entered an aquifer,

the disagreeable taste and odor it imparts may persist indefinitely, even if attempt were made to artificially flush or dewater the aquifer.

Creosotes at Reed City.--A case of contamination of an aquifer at Reed City in Osceola County was discovered by a rather ironic set of circumstances. In 1950 the Water Resources Commission issued an Order of Determination stipulating "that the city of Reed City be directed...(in accordance with Common Council commitment favoring the construction of adequate sewage disposal facilities)...to complete its adequate sewage disposal facilities..." The order arose because of the high content of bacteriological wastes in the Hersey River caused by discharging of sanitary wastes without adequate treatment.

The site inadvertently selected for the sewage treatment plant was above a pit formerly used by an industrial firm for disposal of creosote, tars, oil, and other hydrocarbons. Dewatering operations necessary for construction at the site required continual pumping of ground water from the excavation into the Hersey River. Heavy fish mortality $1\frac{1}{2}$ miles below Reed City and distress of minnows and trout farther downstream was noted. It was found that the ground water pumped from the excavation contained quantities of phenols above the toxic limit for various species of fish. Phenol content was determined to be 36 ppm. To prevent further contamination of the Hersey River, it was necessary to locate the sewage treatment plant at a new site. The field inspector of the Water Resources Commission observed that "no worse spot could have been selected than the original excavation."

Charcoal wastes at Mancelona.--Another case of aquifer contamination from a pit occurred at Mancelona in Antrim County. A study in the area by the Water Resources Commission revealed the presence of chemical contaminants in the ground waters due to the disposal of phenol-bearing wastes from the charcoal iron industry some years earlier. The distance through an aquifer that waste liquids may migrate 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 over an area 3 miles long and $\frac{1}{2}$ mile wide, and to a depth of 200 feet.

Refinery wastes at Alma.--At Alma in Gratiot County, during the latter part of 1945, the city began to receive complaints from consumers about the foul taste of the water supplies from the city's no. 5 well. A preliminary investigation showed the presence of gasoline in the ground beneath the basement of a lodge. It was reported that the gasoline 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 the city's no. 4 well developed a similar taste, and this well temporarily was removed from service because of consumer complaints.

Further investigation of the area revealed a concentration of phenols in the vicinity of a waste-detention pit at a local refinery. At Alma, municipal wells derive water from deposits of buried outwash.

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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 a 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.

It was determined that both the surficial sand aquifer and the buried outwash aquifers were contaminated for a distance of about 3,000 feet from the point of seepage. It became necessary to abandon well no. 5. This created an extremely serious situation at Alma inasmuch as 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 points out the possibility of contaminating an artesian aquifer through a so-called confining bed (aquiclude). In many artesian systems in Michigan, and especially in the glacial drift deposits,--the aquicludes permit considerable leakage in either vertical direction (fig. 1). Hence, a clay or silt layer does not necessarily form a watertight protective layer.

Picric acid at Lansing.--In Lansing in Ingham County during World War II, picric acid (trinitrophenol) that was discharged into a pit at a chemical plant infiltrated to the Saginaw sandstone, the chief aquifer in the area. It was determined that the contamination extended laterally about the length of a city block, and had infiltrated through about 70 feet of glacial drift before entering the Saginaw sandstone.

The quality of waters from two municipal wells was impaired by the acid to such an extent that one well was removed from service for a year. Following discovery of the contamination the well was pumped to waste intermittently for about a year before the concentration was reduced sufficiently to permit return to service. However, as late as 1959, a city official reported that when municipal wells in the area are shut off and water levels rise into the contaminated zone, water subsequently pumped still contain traces of picric acid and must be pumped to waste until the levels decline below the contaminated zone.

Electroplating wastes

Electroplating, and especially chrome plating, is a relatively minor but important industry in Michigan. The electroplating process for chrome, however, 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) states "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 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 wastes to infiltration pits. This practice has some merit in that the hazard from cyanide will largely be eliminated. The Water Resources Commission observed that

while they "have encountered a number of ground-water pollution problems involving electroplating waters, 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 formations."

Disposal of the waste to the ground, however, has aggravated rather than helped the chromium contamination problem, as 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 in 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 which the U. S. Public Health Service (1946) recommends as the maximum safe limit in public-supply systems (0.05 ppm).

The source of contamination was quickly located. About 3 years before the contamination appeared, a metal plating concern in town began discharging chrome-plating wastes into an infiltration pit and surrounding overflow area located 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. It had taken about 3 years for the waste to migrate 1,000 feet, or about 1 ft. per day, through the aquifer along the gradient created by pumping of the west wells. Health Department personnel estimated at the time that if disposal to the pit were abated immediately, it would take 6 years or longer for the aquifer in the vicinity of the west wells to be free of chromates.

In addition to the contamination of the west wells, the supply from the east well 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 made for an indefinite period. The wells of a local dairy were contaminated, and at the request of the Health Department, the Village Council was asked to condemn all private wells in the village since there was no practical way of observing water quality from each.

Chrome-plating wastes at Bronson.--Since 1939 difficulties had been encountered in disposing of electroplating wastes originating at the electroplating industries at Bronson, in Branch County. Fish and cattle on Branch County Drain No. 30 and Big Swan Creek below Bronson had been killed. It was found from examination of internal organs of the dead cows that the cause of death was ingestion of cyanide. The city subsequently issued an ordinance to prohibit discharge of toxic wastes to the city's sewer systems. All of the plating wastes of the principal company involved

subsequently were separated and discharged to 2 ponds. In 1942 it was found that the dikes around the ponds were in an unsafe condition and inspection of the storm system flow discharging into the creek revealed a faint yellow color characteristic of chromium wastes due probably to leakage of water from the ponds, ground water under the ponds, or use of the storm system for waste disposal. Subsequent cases of surface-water contamination were reported.

In 1949, the presence of ground-water contamination was indicated when the owner of a domestic well located 75 ft. from the sewer carrying plating wastes to the disposal ponds observed a "greenish tinge" in his well water. The Water Resources Commission studied the local situation, and on December 6, 1949 collected samples of water from one of the ponds, the domestic well, and a nearby well at the Branch County Highway Garage located between the pond and the domestic well. The domestic well was 13 ft. 6 in. deep, and the water level in this well was 8 ft. 6 in. below land surface. The well at the highway garage was 33 ft. deep and the water level was 8 ft. 2 in. below 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:

	<u>Pond</u>	<u>Highway Garage</u>	<u>Domestic Well</u>
Cyanide	15.6	0	Trace
Chromium	6.0	0	2.0
Nickel	49.0	0	Trace
Copper	12.0	0	0
pH	6.65	7.5	7.5

It was evident that the part of the aquifer tapped by the domestic well was contaminated at the time, but not the deeper portion which was tapped by the Highway Garage well.

A check on the sewer lines revealed that they were in good condition and not contributing contamination to the aquifer. Evidently, the plating wastes were moving directly from the disposal ponds. By December 29, 1949 the chromium content in the domestic well had risen to 3.5 ppm. The toxicology laboratory of the Michigan Department of Health has found 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 U. S. Public Health Service (1946, p. 382) however, sets the safe maximum limit of hexavalent chromium in drinking water as .05 ppm (1 part in 20 million).

On January 24, 1950, the Water Resources Commission issued an Order of Determination charging failure to control pollution of the underground waters in the vicinity of secs. 1 and 2, T. 7 S., R. 8 W., (Bronson Twp.) "due to the disposal of electroplating process waters to a system of sewers and storage ponds...operated jointly with the city of Bronson and other electroplating industries within the city, which act permits seepage and percolation of toxic substances into the underground waters..." Failure to abate the alleged contamination resulted in legal action, which in 1955 reached the Michigan Supreme Court (L. A. Darling Co. v. Water Resources Commission, 286 Mich. 520), after trial by the Branch County Circuit Court.

A number of interesting hydrologic observations can be made using the instance of chromium contamination at Bronson as an example.

1. The chemical analyses show that the well at the County Garage was not contaminated at the time the sample was collected although the well is located between the contaminated domestic well and the disposal pond. This indicates that ground water does not necessarily flow in a straight line, because of the heterogeneous nature of the materials comprising the aquifer and pumping of nearby wells may also influence the direction of movement of the water in the aquifer. In addition, the Water Resources Commission sounded both wells and found that the County Garage well was 33 ft. deep and the domestic well 13 ft. 2 in. deep. There is no reason to expect that a contaminant introduced at a source of limited area should be uniformly distributed within a given period of time, if ever, throughout the thickness of an aquifer or several aquifers which are hydraulically connected. Further, water injected at a point or limited area source might be dispersed only slightly in traveling through the aquifer especially if the specific gravity does not significantly differ from that of the ground water.

2. The natural gradient of the water table in the shallow drift aquifer was reported to be in a northwesterly direction, but the contaminated domestic well is southwest of the disposal pond. This illustrates that ground water (and liquid wastes) may move in a different direction from the natural gradient. If the surface of a recharge pond is above the normal water level in the aquifer, a mound of water may be built up in the aquifer and the direction of flow of the mound of water would tend to be radial from

the point of injection (fig. 12), subject, of course, to the water-level gradient in the aquifer and to the velocity of the natural ground water, and the physical characteristics of the aquifer.

3. Almost a decade after the court action, the State Health Department became concerned about the possibility that new wells proposed to be drilled to a deeper aquifer by the city would also be subject to contamination. Despite the reported separation of the upper and lower aquifers by an aquiclude consisting of a "thick impervious clay stratum," the concern of the Department may be well founded. Although impermeable clays are known to exist, confining layers in artesian glacial drift aquifer systems in Michigan commonly have some degree of permeability, as aquifer tests conducted in numerous areas of the State by the Federal and State Geological Surveys rarely reveal perfect artesian conditions. 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/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 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 permeability of clayey materials. Laboratory analysis of permeability or extensive aquifer testing would

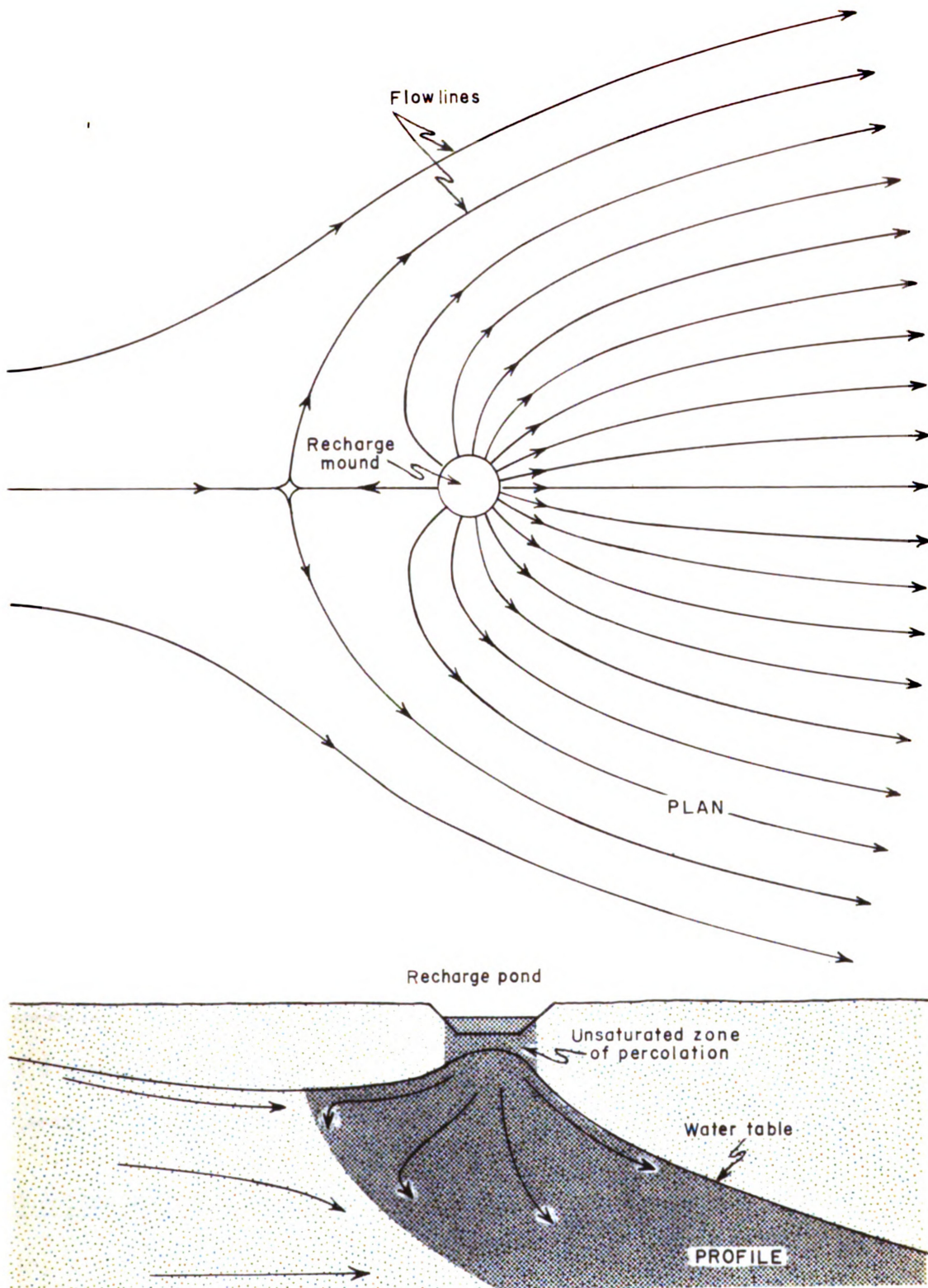


Figure 12. Diagrams showing lines of flow from recharge mound on sloping water table

be necessary to determine the hydraulic characteristics of the so-called "impervious clay stratum." Further it would have to be determined whether any rusted or broken well casings which would permit leakage and which penetrate the confining layer exist in the area. (See fig. 16.) Finally, the direction of flow in an undetermined area in the lower aquifer would be toward the municipal wells, as a lowering of water level or artesian pressure at the site of the well is necessary if the well is to be pumped. The above statements, of course, are not to be construed as predictions of ultimate contamination of the lower aquifer but merely to point out basic hydraulic principles in a two-aquifer system.

Chromates at Tecumseh.--Although the adverse effects of disposal of chrome-bearing wastes to the ground have been well recognized in this State since at least the late 1940's, the hazard has not been entirely eliminated. This is illustrated by an instance of contamination by hexavalent chromium of water from 2 private wells in Tecumseh, Lenawee County, in July, 1959.

The source of the chromium was traced to a small machine shop which occasionally used a chromium compound for cleaning purposes. The material is presently being discharged into the city sewers, but previously a disposal pond was used on the ground surface. It is believed the chromium leaked from the pond into the aquifer tapped by the private wells.

Gasoline at East Saugatuck

The owner of a roadside grocery store near East Saugatuck in 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. It was apparent that gasoline from the abandoned underground storage tank had seeped into the aquifer, thus contaminating the well. The State Geological Survey recommended drilling of a deeper well tapping the aquifer below the contaminated zone, as the most economically feasible method of obtaining a potable water supply free of gasoline contamination.

This instance of ground-water contamination at East Saugatuck is not unique in Michigan as a similar problem has plagued the city of Grand Marais in Alger County. The possibility of leakage from an abandoned fuel tank at Alma has been referred to on page 41. Because gasoline and other petroleum products are offensive in water supplies even in minute amounts, and are almost impossible to remove completely from an aquifer, extreme caution must be taken to prevent leakage of such materials into the ground. It would seem advisable to remove underground storage tanks when no longer needed, as the tanks, most of which probably contain small residues of gasoline, may eventually corrode.

Oil field brines in Isabella County

Daoust (1953) reported that the first serious brine disposal problem in Michigan occurred following discovery in 1930 of oil in the Dundee formation in Isabella County. Pumping of crude oil from the field also yielded large volumes of brine waters, which are highly concentrated solutions of salts and other minerals. 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 but the number of failures increased. 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 which 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 the assistance of the Department of Conservation solved the problems of brine recharge to deep formations and since the early 1940's ground-water contamination by oil-field brines in Michigan has been virtually eliminated.

Septic Tanks

Septic tanks, which are in widespread use in Michigan, constitute a considerable hazard to the ground-water resources as they are sources of large quantities of potential bacterial and chemical contaminants. If they are to operate efficiently, septic tanks must 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. In some areas of the State, especially in the southeastern part, shallow deposits of sand and gravel in which septic tanks are installed are the chief sources of ground water, thus creating a conflict in use to which the aquifer is put. As septic tank effluent is by no means pure (Hepler and others, 1953) part of the aquifer to which it percolates may become contaminated.

The Michigan Department of Health (1956, p. 9-10) reported on a survey made by that organization 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. Many wells less than 20 feet deep show evidence of dangerous contamination. The report states "Bacterial contamination on reaching the water table travels horizontally in a thin film in the direction of ground-water flow. Placing the screen below the ground-water level at a depth equivalent to at least 4 or 5 times the drawdown of the water in the well during pumping permits the pollution to pass by above the actual source of supply."

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 limestones, dolomites, 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.

Included among the various chemicals which may enter an aquifer from a septic tank are synthetic detergents, commonly known as syndets. Of the 3 types of synthetic detergents in use--anionic, cationic, and non-ionic, the most widely used are the anionic types (Sawyer and Rykman, 1957) which may impair the ultimate use of ground waters that they enter.

The anionic synthetic detergents all contain an organic, surface-active agent which has the important qualities of wetting, dispersing, and emulsifying soil, the most widely used of which is alkyl benzene sulfonate or ABS. The syndets are virtually unaffected by hardness-forming constituents in the water, which is the basic reason for their wide popularity (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 is expected to be about 23 pounds per person.

The extent to which the ground waters of Michigan have been contaminated by synthetic detergents has not been determined. The results of a study made by Flynn, Andreoli, and Guerrera (1958) in Suffolk County, N. Y., where ground water is derived from shallow glacial drift deposits, however, indicate that contamination of similar aquifers in Michigan is to be expected. The study revealed that syndets have appeared in wells as deep as 95 feet and as much as 500 feet from their source. One of the significant findings of the report is the fact that detergents known to have been discharged several years before the study did not deteriorate or stabilize to less objectionable compounds. The conclusions contained in the report and which probably would be valid also in Michigan are as follows:

1. When individual wells and sewage disposal systems are placed on relatively small plots it may be anticipated with some certainty that syndets will appear in the wells.

2. Increased depths of wells and distances from cesspools may delay, but it is certain will not prevent, the appearance of syndets in well water.

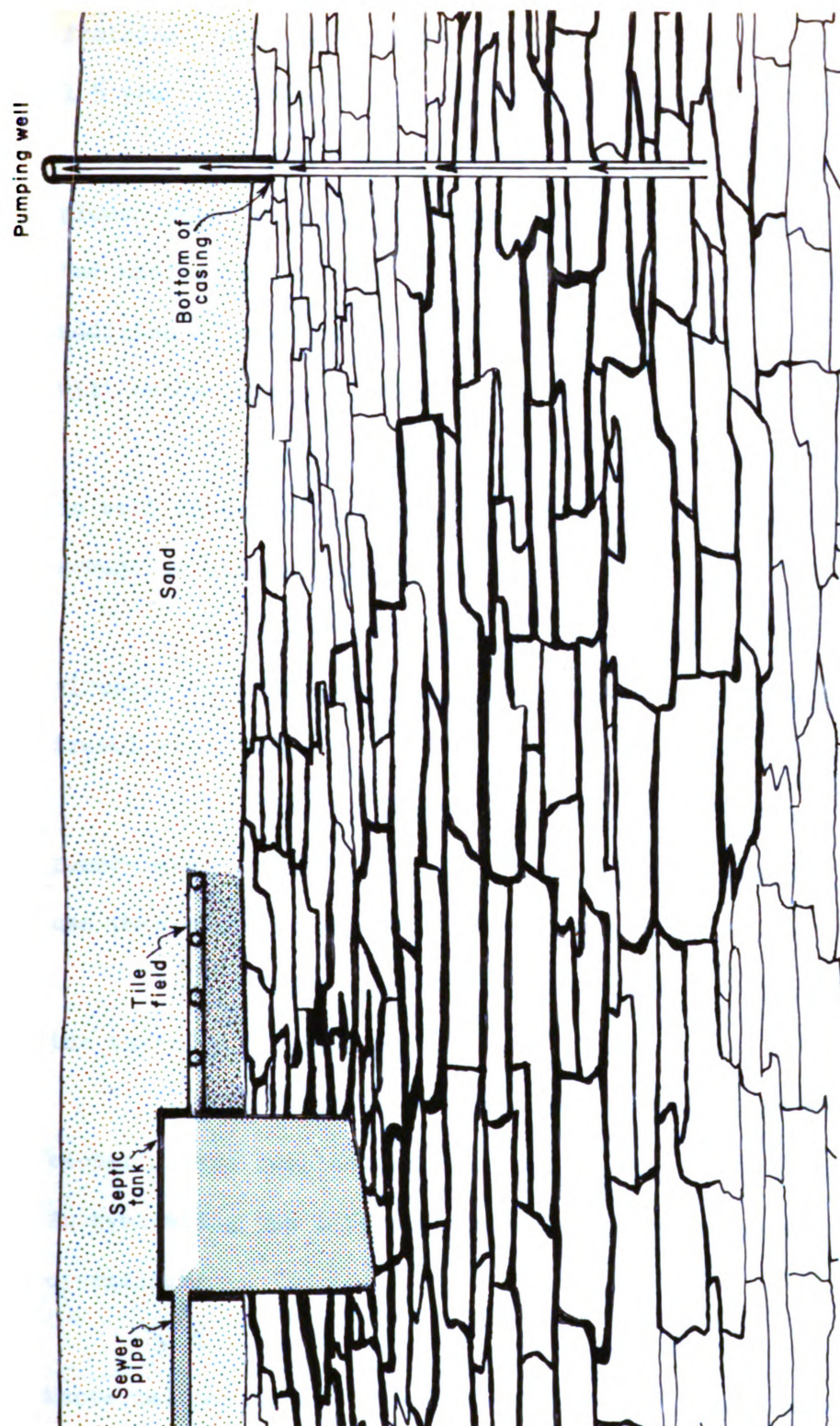


Figure 13. Diagram showing movement of contaminants from surface source through secondary openings in limestone or dolomite

3. The presence of syndets in water causes unpleasant taste and frothing. Most persons detect the taste when the syndet concentration is 1.5 ppm or higher. Frothing appears at about 1.0 ppm.

4. The average homeowner may add 100 pounds of syndets to the ground water each year. These syndets do not appear to deteriorate and the wastes tend to remain concentrated with little dilution. With continued addition of syndets year after year, the amount will build up and the problem will become more acute each year.

5. Syndets originate only in sewage discharges and their presence in well water definitely establishes contamination by the homeowner's own sewage or his neighbors'.

6. The significance of syndets as a vehicle to transport bacteria, viruses, or other pollutants greater distances than they might normally travel is unknown.

7. The phosphates present in most detergents may increase the number and survival time of bacteria in ground water, as some bacteria can use phosphates as a food.

8. There appears to be little information available relative to the toxicity of syndets.

Butler, Orlob, and McGauhey (1954) studied movement of both bacterial and chemical pollutants and made a number of conclusions important in evaluating the potential hazard of aquifer contamination 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. Where the water table is near the effluent source, "it must be presumed that coliform bacteria will enter the ground water through such means of access as porous soil, root channels, or rodent holes."

4. Chemical pollutants travel farther and faster than bacterial pollutants in ground water, although instances of travel of coliform organisms with ground water through distances of 10-232 feet have been reported.

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

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

Free circulation in carbonate rocks in the Manistique-Gulliver area

In the Manistique-Gulliver area of 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. 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, but because

of the absence of an adequate soil or sediment layer to serve as a filtering medium at many sites, essentially raw sewage spills directly into the water contained in the Burnt Bluff and Manistique formations which are the most important aquifers in the area. Many cases of poor bacteriological quality have been reported, although the water is of generally good chemical quality.

Hepatitis epidemic at Posen

During the summer of 1959 a severe epidemic of hepatitis affecting several hundred persons at Posen in Presque Isle County was investigated by personnel of the State Department of Health and State Geological Survey. Preliminary findings left little doubt that the hepatitis (a severe liver ailment) was caused by ingestion of polluted ground water. The source of the polluted water was the Traverse limestone of Devonian age, which is quite permeable due to the presence of fractures and solution cavities. The investigation showed also that numerous septic tanks were located less than 50 feet from domestic wells in the area, and in one case only 8 feet from a well. In addition kitchen sinks, sump holes, and ditches drained directly into the formation.

According to the Michigan Geological Survey hydrogeologist who investigated this case, "One thing was very apparent from inspection of well installations. This was the almost total disregard for established principles of good sanitary engineering. Inadequate isolation of wells from sources of pollution and poor well construction practices were commonplace, and a properly constructed and isolated well was the exception rather than the rule. The consequences of this disregard for sanitary engineering

principles was dramatically illustrated after the results of water analysis were known. Out of 72 water samples tested, 40 percent were bacteriologically unsafe. Of these 72 samples, 20 were selected for chemical analysis and 65 percent of the 20 samples selected showed the presence of nitrates, nitrites and/or detergents.

"Poor well construction practices are not unique to the Posen area, but are found in many other areas in Michigan and the nation as well. The problem is accentuated in the Posen area, however, because the limestone bedrock, from which water supplies are obtained, is found at or near the ground surface. In many cases, it was necessary to make a hole in the limestone to set the septic tanks below grade. Many of the wells were not cased deep enough to seal off the contaminated zone in the upper saturated portion of the limestone and some wells had no casing at all. Most of the wells had no seal on the top of the casing, and the casings were terminated below grade in many instances.

"The geology in the Posen area is such that any contamination on the ground surface could be readily flushed down to the ground water by precipitation or snow melt. Contaminated surface runoff can readily penetrate the limestone bedrock through crevices or fractures extending to the ground surface or directly into poorly constructed wells."

Almost half a century ago, Matson (1911) who was dealing with 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. This practice, which is by no means uncommon, is often defended by the assertion that the water in limestone channels beneath a city is unfit for drinking even without the sewage. The correctness of this assertion cannot be disputed, but there are persons who are ignorant of the danger and who continue to use the underground water. Moreover, those living at some distance from the city may use water from the underground channel which receives the sewage. For these reasons any city which proposes to convert an underground watercourse into a sewer should be forced to trace the channel to its destination so that others may be protected."

Septic tank discharge to a thin aquifer in Wayne County

According to data obtained by the Michigan Geological Survey an important question concerning ground-water supply arose following construction of a large subdivision in Sumpter Township, Wayne County. The water supply for each house is obtained by individual domestic wells from a surficial sand layer about 18-20 feet thick, but in addition, each house is equipped with a septic tank discharging effluent to the top of the sand aquifer. This sand aquifer is the only source of fresh ground water for the area as the underlying glacial drift is of very low permeability and the water present in the bedrock formations is too highly mineralized for domestic use. The water level in the sand aquifer prior to any pumping in the subdivision was about 5 feet below land surface.

A test conducted on the aquifer indicated that a supply adequate for all of the domestic wells could be obtained from this aquifer, although a way of protecting the supply from contamination by septic tank effluent had to be devised.

In an attempt to eliminate the health hazard which would result from pumping of bacterial pollutants from the top of the aquifer, the County Sanitarian required that each well be driven to the top of a clay layer underlying the sand, and that a screen be installed in the basal portion of the sand. Further, to prevent septic effluent from percolating downward along the side of the well casing to the screen, each well was constructed with a 4-inch outer casing to a depth of $10\frac{1}{2}$ feet.

Bacterial analyses which were made on water from a number of wells which had been in use for 1 to 2 years showed the quality to be satisfactory. Because of the fact that the water-yielding zone of the aquifer is so close to the area of discharge of septic tank effluent, however, the constant potential hazard makes it imperative that the quality of water used in the subdivision be observed closely. Water levels in the aquifer should also be observed, as declining levels would directly reduce the separation between the bacterial effluent and the well screens. The effect of the septic effluents on the chemical quality of the water must also be considered, as chemical pollutants are known to travel faster and further and generally persist in a noxious state longer than bacterial pollutants. In addition, consideration must be given to the fact that the thickness of the effluent layer tends to increase with time, and that recharge from precipitation is to the top of the aquifer, and must percolate through a contaminated zone before reaching the various well screens.

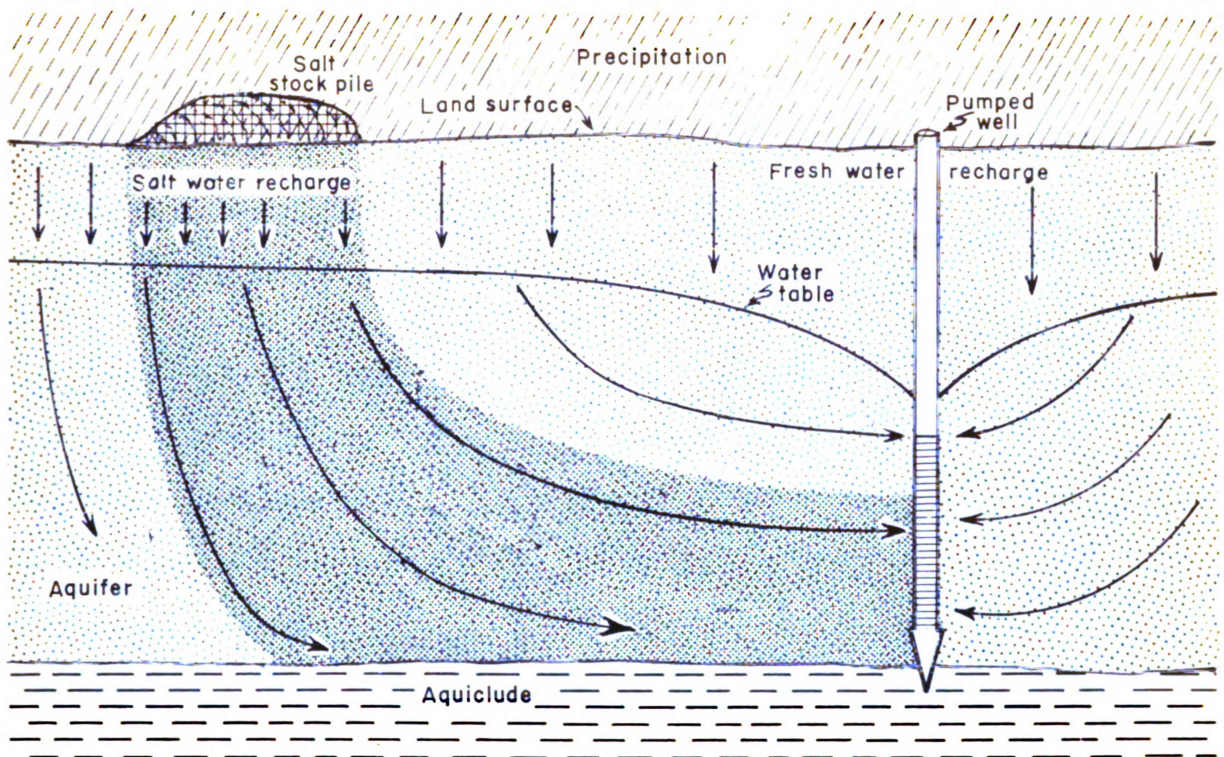
Contaminants Percolating or Leached from the Land Surface

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 (fig. 14). Liquid wastes disposed of, spilled, or stored on the land surface will adversely affect the quality of ground water by subsequent percolation to an aquifer. Any type of solid material which contains soluble contaminants and through which water may percolate to an underlying aquifer presents a potential hazard. 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.

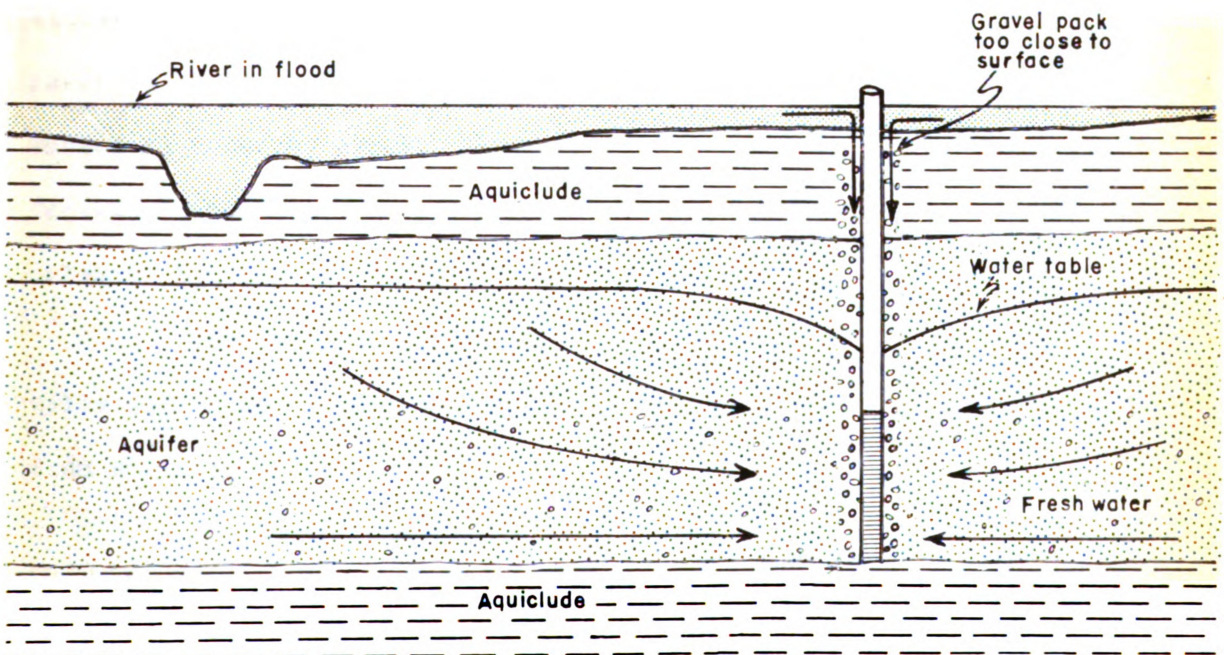
The various instances of ground-water contamination resulting directly from migration of harmful substances from the land surface described below illustrate that special precautions to protect ground waters, especially in shallow aquifers, must be taken because of the fact that such hazards may not be anticipated or fully understood by the public.

Pickle brines at Edmore

In 1949, a municipal well tapping the glacial drift at Edmore in Montcalm County began to produce water with a distinctly salty taste. Laboratory analysis by the Michigan Department of Health showed that the water contained 1,900 ppm of chloride compared to a chloride content of 34 ppm as determined by a routine analysis of water from this well in 1943. Investigation by the Water Resources Commission revealed that brine



A. Leaching of surface solids by recharge



B. Floodwater entering well through improperly sealed gravel pack

Figure 14. Diagrams showing movement of contaminants to aquifers from the surface

spilled on the ground several hundred feet from this well by a nearby 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.

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 Michigan Geological Survey, whey and milk wastes from a local cheese plant polluted at least 15 or more of the private wells in the vicinity of the plant. The polluted wells, all of which tapped shallow fractured and creviced limestones and dolomites 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 appears that it was either spilled on the ground or discharged to a clogged or defective sewer following a State Health Department order to cease discharging the wastes to a nearby creek. The important consideration, however, is the fact that the wastes moved readily through openings in the limestone and dolomite aquifer and resulted in serious contamination.

The Michigan Department of Health noted also that many of the wells were also contaminated by coliform organisms which 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 limestones, 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 proper 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 material in liquid form used for the manufacture of fertilizer is transported by railroad tank cars and stored in tanks mounted on platforms at the site. The liquid in one tank was found to be unusable and was therefore 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 as the sand aquifer is the only source of fresh ground water in the area as it overlies the Coldwater shale of Mississippian age which does not yield potable ground water in the area. Further aggravating the situation was the fact that it was not feasible to dewater the aquifer inasmuch as the nearest stream which could be used for surface disposal was several miles distant. The company requested advice of the Michigan Geological Survey concerning methods of obtaining a new potable water supply or of removing the fertilizer from the aquifer. Information as to how this problem was resolved, however, is not available at the date of the present report.

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 a case of serious contamination of wells at Indianapolis, Ind., by garbage liquors from a disposal site 500 feet away. This case is significant inasmuch as the possibility of contamination was studied prior to 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 ft. away, causing considerable increases in the hardness and the total solid content of the water. Lang and Bruns (1941) noted a case where picric acid waste traveled underground for three miles in 4 to 6 years. They also cited an instance where garbage dumped in a sand pit continued to pollute wells 2,000 feet away 15 years after dumping had ceased. The latter case is especially significant in Michigan, as it is not an uncommon practice for persons, especially riparians, to attempt to reclaim low-lying swampy land by soliciting dumping 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 quite 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, of course, the soluble salts may be readily leached 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 portions of the Black River limestone at Rock by this practice. Litigation in this matter is impending. Storage of salt stockpiles in sheds, or perhaps even covering of 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.--A number of instances of pollution of roadside domestic wells were 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 many 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 as producing salty water by the owner. Analysis of the water revealed that it contained 4,400 ppm of chloride. As the U. S. Public Health Service Drinking Water Standards recommend that not over 250 ppm of chloride be present, this well was abandoned and another well drilled to a greater depth to avoid the salt contamination.

In another case salt appeared in drinking water along the highway near Parkdale as a result of its use on the roads for snow removal. Investigation revealed that here 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 as to why some of the snow along the roadsides 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 of county residents concerning rapid corrosion of automobile bodies caused by application of the salt. This happened to be 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, resulting in prompt discontinuance in use of chromium-treated salt.

Chromium compounds contained in land fill at Grandville

A unique case of contamination of ground-water supplies by chromium occurred in the city of Grandville west of Grand Rapids. In this instance the city installed a public-supply well in the glacial drift deposits along the Grand River. In order to overcome the possibility of flooding of this well during periods of high water in the Grand River, the casing was extended several feet into the air, and the land surface was raised by filling the area with sand and gravel. In time the presence of chromium was detected in the water by a firm of consulting engineers. This resulted in considerable consternation on the part of responsible officials as there was no apparent source of chromium contamination in the vicinity. Investigation by the Grandville Superintendent of Water revealed that the sand and gravel fill used to raise the land surface at the site of the well was taken from a former dumping grounds for electroplating wastes! Infiltration of rainwater and snowmelt to the aquifer through the fill had leached the chromium compounds contained in the fill and carried it into the well.

Percolation of leached nitrates into shallow aquifers

In 1945, the Michigan Department of Health received a number of requests for nitrate determinations on well water samples submitted by doctors who were trying to find the cause of cyanosis or methemoglobinemia in infants. The disease, referred to commonly as "blue

babies" is apparently limited to children under six months of age and 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 where infants with cyanosis were involved showed nitrate contents of 243 to 975 parts per million. An inspection of these water sources proved them all to be shallow dug wells with improper construction and several with improper location. The nitrates in the water were leached from decaying human and animal excreta. According to the Michigan Department of Health, a public health sanitarian would have condemned all of the wells by inspection alone, without the necessity of taking samples for bacteriological examination.

The nine source wells for the analyzed samples were located in Saginaw, Bay, Gladwin, Wayne, Macomb, and Washtenaw Cos. in the southeastern part of the Southern Peninsula of Michigan. In this area fresh groundwater supplies commonly are obtainable only from shallow glacial drift deposits. Wells tapping these aquifers are especially susceptible to contamination from nitrates leached from sanitary wastes at the surface or from other solid or liquid contaminants present over the area.

Comly recommends that water used for feeding of infants possess a nitrate content no higher than 10, or, at the most, 20 ppm expressed in terms of nitrogen, or 44 to 48 ppm when concentrations are reported as NO_3 . Hem (1959, p. 234) 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 may also result in noxious liquids entering an aquifer, if the sewer is in or above the saturated portion of a shallow aquifer. If the earth material in which the sewer is laid is of very 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 two-week period in 1952, six employees of a small industrial plant in the Lansing area became ill. They had complained that the water from the semi-public water system serving the plant tasted and smelled like sewage. Analysis of the water by the Ingham County Sanitarian confirmed their suspicions. The water was grossly contaminated with coliform bacteria. The Ingham County Health Department immediately posted the supply as "unsafe for drinking," and began an investigation to determine the source of contamination. The lavatory, toilet stool, and water pump were all in the same room. Investigation showed that a leaded joint in the soil pipe sewer had parted--apparently from frost-heaving, as the pipe was only 1 foot below land surface--and also that the pipe had a slight rise in grade toward the septic tank allowing the sewage to leak into the ground. In addition, the seal between the well cap and casing consisted only of common putty which permitted the sewage to enter the well. The County Health Department reported that construction of the water system was in violation of State regulations and the sewage system was constructed in violation of county regulations.

This contamination was abated by laying the sewer on a proper grade and extending the well casing 1 foot above land surface and relocating the pump.

Leaking municipal sewers at Sturgis

During World War II, the Michigan Department of Health recommended that the city of Sturgis, in St. Joseph County, abandon its wells or install a chlorination system because of the proximity of sewers to the 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, as 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 were made to clear up the contamination by chlorinating the wells, but to no avail, 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, in Ionia County, part of the city's water formerly was taken from a shallow infiltration system in the glacial drift, consisting of dug wells used as collectors fed by a network of infiltration tiles. In January 1955 water from this system developed a most objectionable taste, although water from wells tapping the glacial drift at depth had no such taste. Investigation by the Superintendent of Water revealed that the taste originated in water from only one of the collectors, which when valved off the system, abated the nuisance.

It was found upon further examination 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 which are poor in chemical or bacteriological quality are still another potential source of contamination in areas where such waters may be recharged to aquifers. In addition, flood waters or pools of stagnating water lying on the surface after floods, storms, or spring thaws, some of which might ultimately enter underlying aquifers, also are potential sources of contamination. Recharge of such waters may occur naturally by percolation through permeable materials such as sand and gravel or by flow through fractured and creviced limestone and dolomite. It is likely, however, that the greatest hazards of aquifer contamination by objectionable surface waters results from infiltration induced by nearby pumping (fig. 15). The threat of aquifer contamination by surface waters spilling or backflooding into wells has been described above under the section entitled "Injection into Wells."

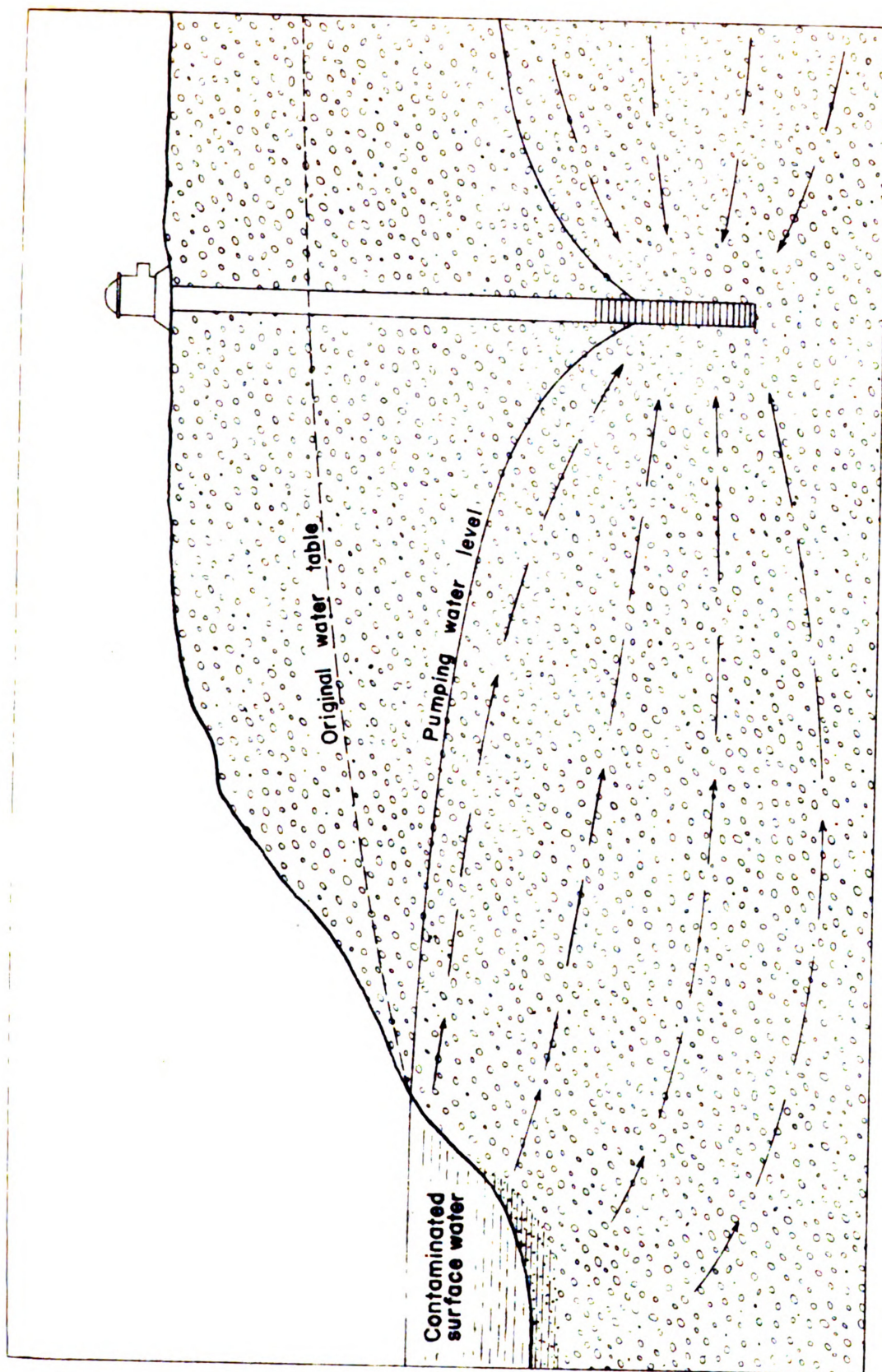


Figure 15. Generalized diagram showing how water can be induced to flow from a surface source of contaminated water to a well. (adapted from Ferris and others, 1954)

Discharged softening-plant effluent in Paris Township

In Kent County, the Water Resources Commission investigated a case of salt contamination of an aquifer tapped for water supply by Wyoming Township. In this instance the report of the study showed that neighboring Paris Township operated a zeolite softening plant for the water-supply system. Spent brines from the system were discharged to a creek which flows by Wyoming Township's 32nd Street well field. It was found that pumping by Wyoming Township induced infiltration of the softening plant effluent from the creek through the aquifer into the public water-supply system.

Discharged mine water at Ironwood

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

Analyses of the water made from these wells before World War II by the Michigan Department of Health showed a range in total hardness of 120-162 ppm and a chloride content ranging from 13 to 58 ppm. During the war, however, the mines were deepened considerably and the mine-drainage water discharged to the creek increased in hardness and chloride content. The increase in hardness and salinity of the creek water, which

was being recharged by induced infiltration to the aquifer, resulted in deterioration of the quality of Ironwood's ground-water supply. The U. S. Public Health Service (1954, p. 17) reported that a hardness of about 900 ppm and chloride content of 1,100 ppm for the ground-water supply resulted primarily from mine-dewatering operations. 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 chemical quality of the water naturally resulted in strong protests from consumers and the city relocated its well field. The mine-waste pollution continued, however, threatening the new supply and prompted the State Water Resources Commission to take action which led to the diversion of the mine drainage to another watershed.

Sewage-contaminated creek at Norway

White Creek (locally known as Sewer Creek) near Norway in Dickinson County had 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, indicating that the aquifer tapped by his well was recharged at least in part by water from the creek.

An interesting sidelight to this case developed later when the Michigan Water Resources Commission ordered the city of Norway to build a sewage treatment plant because of the gross contamination of White Creek. Because of the city's difficulties in financing such facilities, the Commission granted temporary 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 also to keep the mine in good condition in the event mining operations were resumed. Following introduction of the mine-drainage water into White Creek, an unanticipated fish kill occurred. Subsequent investigation by the Michigan Water Resources Commission demonstrated that the mine water was almost devoid of dissolved oxygen, and concluded that this resulted in the fish kill and "a temporary reduction in abundance of bottom animals in Sewer Creek." The fish had literally drowned in the mine-water diluted creek.

Bacterial contamination in collector system at Grand Haven

The city of Grand Haven in Ottawa County is supplied by three "collector" systems situated in Lake Michigan close to the shoreline. The collector systems consist of vertical caissons sunk to about 30 feet below the lake bottom from where 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 in order to eliminate the filtration plant which is normally used when surface waters are utilized 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. Subsequent leaks, although not of a serious nature, occurred.

The temporary bacterial contamination of part of Grand Haven's water supply is not, of course, a case of aquifer contamination, but illustrates the hazards involved by accidental mixing of raw surface waters with water which has been naturally filtered and purified underground.

Stagnant floodwaters at Benton Harbor

The following newspaper article concerning dangers to water supply as the result of flooding was published in the Benton Harbor News-Palladium on June 9, 1950: "Residents in the Marquette Woods area of Lincoln Township (Berrien County) 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, which is self-explanatory, points out the necessity of maintaining proper drainage of an area, especially after a flood if groundwater supplies are to be protected against entry of polluted flood waters through unsealed wells, or by induced infiltration caused by pumping. This is especially important as floodwaters almost always are grossly contaminated and frequently carry disease-causing organisms.

Airborne Wastes, Insecticides, and Herbicides

Until recent years, scant attention had been given to the possibility that airborne wastes, insecticides, or herbicides might adversely affect the quality of ground water. Airborne wastes have been suspected as the source of ground-water contamination in only one known instance of ground-water contamination in Michigan.

However, in view of the increasing use of insecticide and herbicide sprays in recent years, the possibility of ground- and surface-water contamination resulting from use of these pesticides should be studied.

Electroplating wastes in Wyoming Township

For a number of years Wyoming Township in Kent County had difficulty in obtaining water free from chromium contamination in its 50th Street well field. Two of the Wyoming Township wells are finished in sand and gravel glacial drift deposits and two in the Marshall sandstone. Water from the latter formation, however, is reported to be high in natural chloride content. A metals factory situated on adjacent property which uses electroplating machines was the apparent source of the chromium contamination. Accordingly, the metals firm retained a consulting engineering firm to study the problem and report on the possibility of further contamination and of means of abatement (Williams and Works, 1956).

The study concluded that the chrome was introduced to the aquifer by one or more of the following routes:

1. A cyclone tank and fan on the chrome ventilation system permitted drippage of water containing dissolved chromium compounds to the soil

below where it accumulated until rainfall washed it down to the water table. A general relationship between precipitation from February through May 1956 and chromium contamination in the Township's well was shown.

2. A dry well at the site, into which water from the roof of the plant drained was thought to be another source of intermittent contamination. Chrome-laden dust was discharged through ventilators on the roof. Some of the dust was thought to have been washed out of the air and onto the roof by precipitation, flowed down rain spouting into the dry well, from where it infiltrated to the aquifer, and subsequently migrated to the well in response to pumping.

3. It was deemed possible also that flooded or leaking sewers carrying chrome wastes may have contributed to ground-water contamination. One sewer was found to have a small leak and on several occasions when the sewage pumping station was out of service the sewers flooded, and minor additions of chrome to the aquifer may have occurred.

In addition, the Michigan Geological Survey reported that empty chromate containers had been left in the yard where rain water could rinse the chrome powder residue onto the ground and into the aquifer.

Insecticides and herbicides

No instances of contamination of ground-water supplies 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 should certainly merit consideration at least.

Nicholson (1959) weighed the question as to 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 which has 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 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 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.

An indication, however, that certain insect-killing sprays might prove to be no problem insofar as ground-water contamination is concerned is provided by Eno (1959) who noted that chlorinated hydrocarbon insecticides are absorbed and retained by the soil. Chlorinated hydrocarbons are the most widely used of the various synthetic insecticides. They tend to accumulate, however, because they are resistant to decay, and hence might have adverse effects on the soils. Eno reports that for the most part, they 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, which have great potential value in various phases of soil and water conservation, are also in widespread use, and the use of these materials is rapidly growing. Unlike pesticides these materials do not tend to accumulate to toxic amounts as repeated use is needed to control growth of undesirable plants, indicating that they deteriorate or stabilize to non-toxic compounds. At the time of the present report, however, information concerning

the effects or potential effects on man and other animals of applications of a large variety of insect- and plant-killing sprays or their decay products on the ground-water resources of the State is not available.

Contaminants Induced From Natural Sources

Fresh ground waters in Michigan have been contaminated not only by the introduction of various deleterious substances from the surface but also indirectly by encroachment of natural waters of objectionable quality in response to a variety of man's activities. Well drilling, pumping, dewatering, and construction activities have resulted in local changes of the ground-water regimen in ways which have caused migration of waters of inferior chemical quality into various fresh-water aquifers. The contaminants induced to flow into fresh ground-water sources include brines, and other waters 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 waters are described in detail by Hem (1959). Hence, only brief mention of these items is made herein.

Vertical Leakage Through Open Holes

Extensive contamination of fresh-water aquifers in Michigan has been caused by vertical leakage of highly mineralized waters 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 they are drilled 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 waters as may be afforded by confining beds of very low permeability, such as shale or unfractured beds of limestone, dolomite, or siltstone, is hence 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. 16).

Saline waters commonly are encountered 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, is not great enough to prevent saline water from occupying shallow aquifers or discharging into surface streams. The water table in the shallow fresh-water aquifers in these areas is commonly below the piezometric surface of the deeper saline-water aquifers. Thus, uncased test holes allow saline water to move upward and migrate into the shallow fresh-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 17. A map showing areas of heavily mineralized shallow waters in Southeastern Michigan (fig. 18) was prepared by Lane (1899, pl. 4).

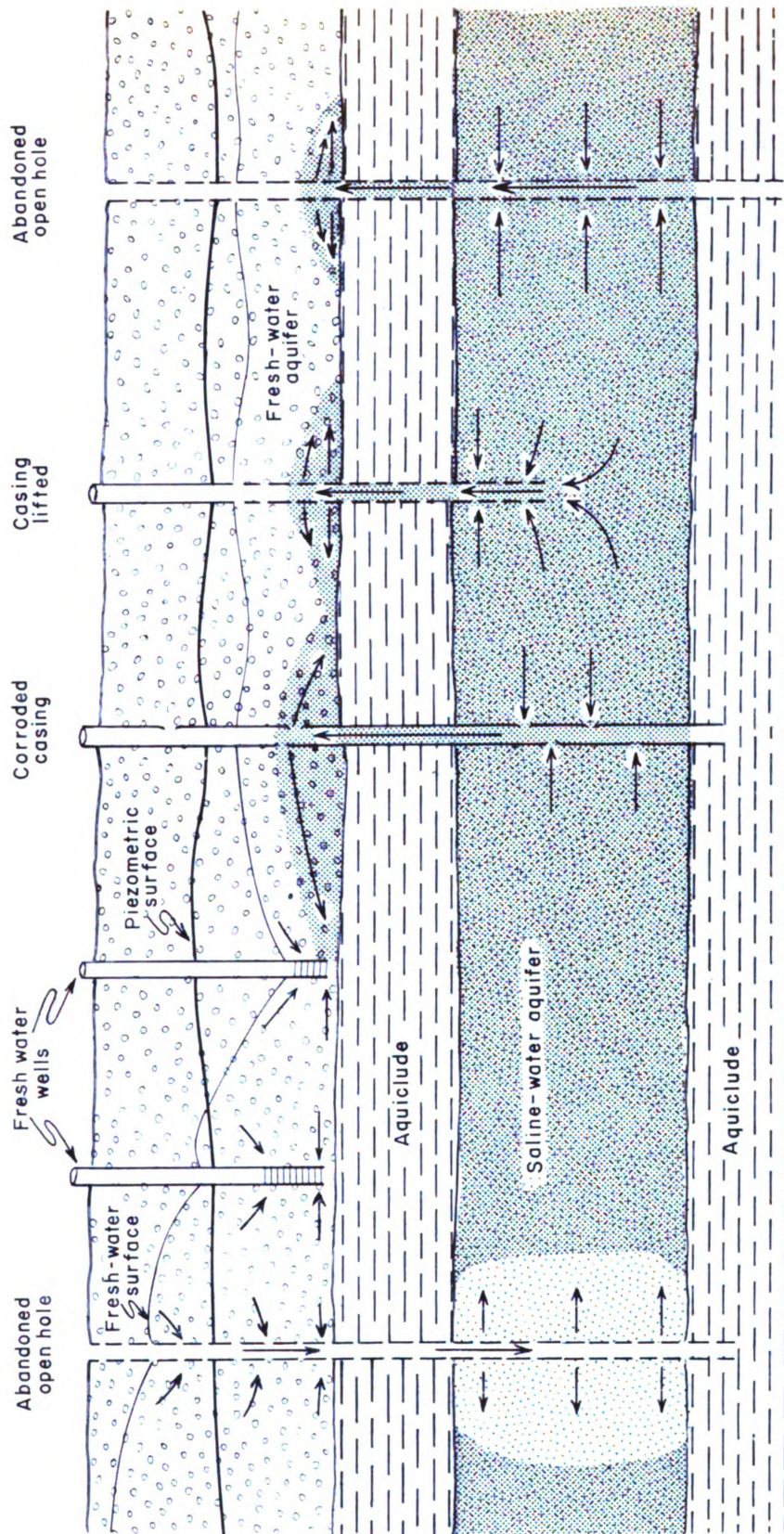


Figure 16. Generalized diagrams showing interformational leakage by vertical movement of water through open holes

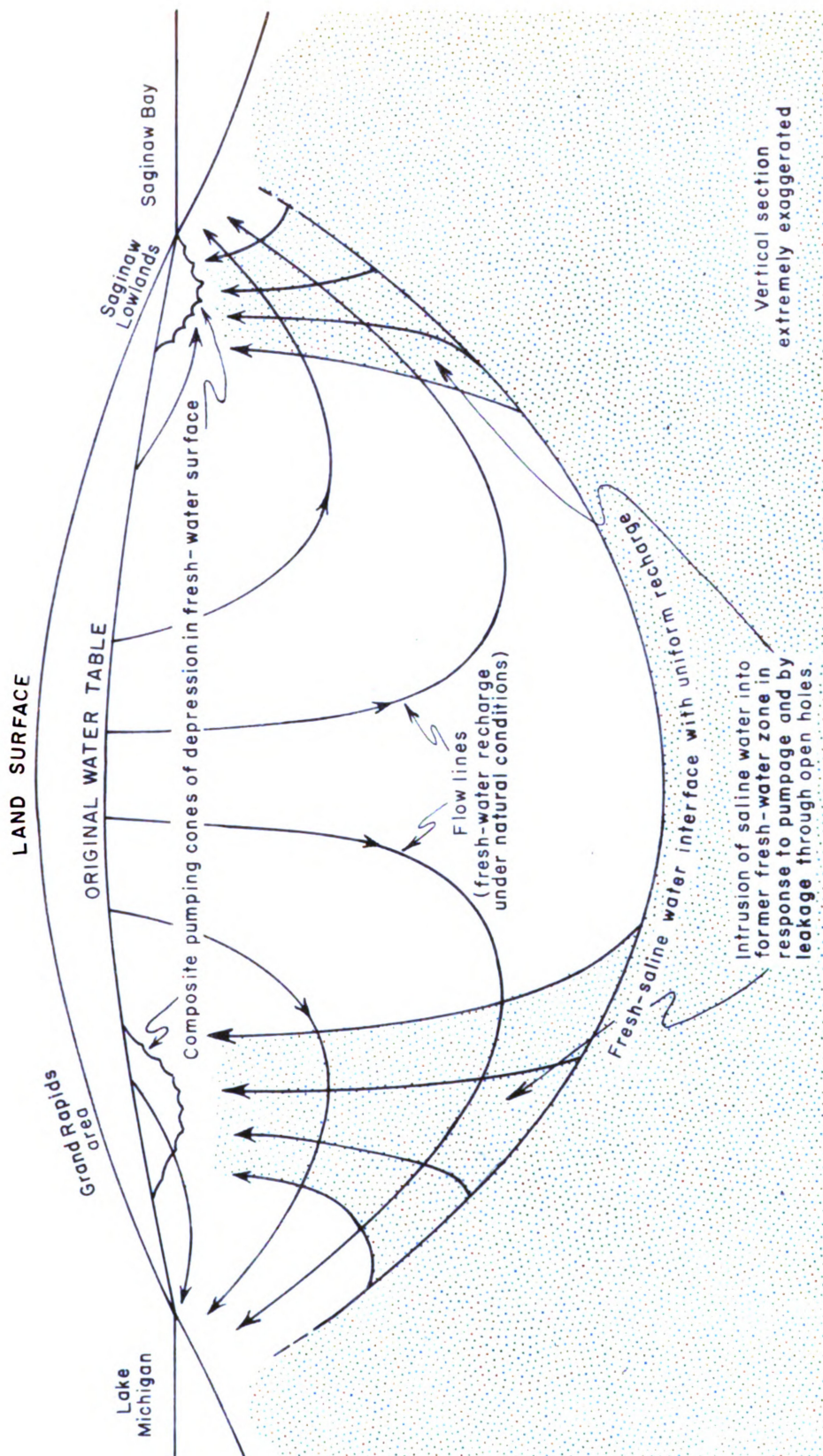


Figure 17. Hypothetical section across the Southern Peninsula of Michigan showing fresh- and saline-water interface relationships assuming a single homogeneous aquifer and uniform recharge.

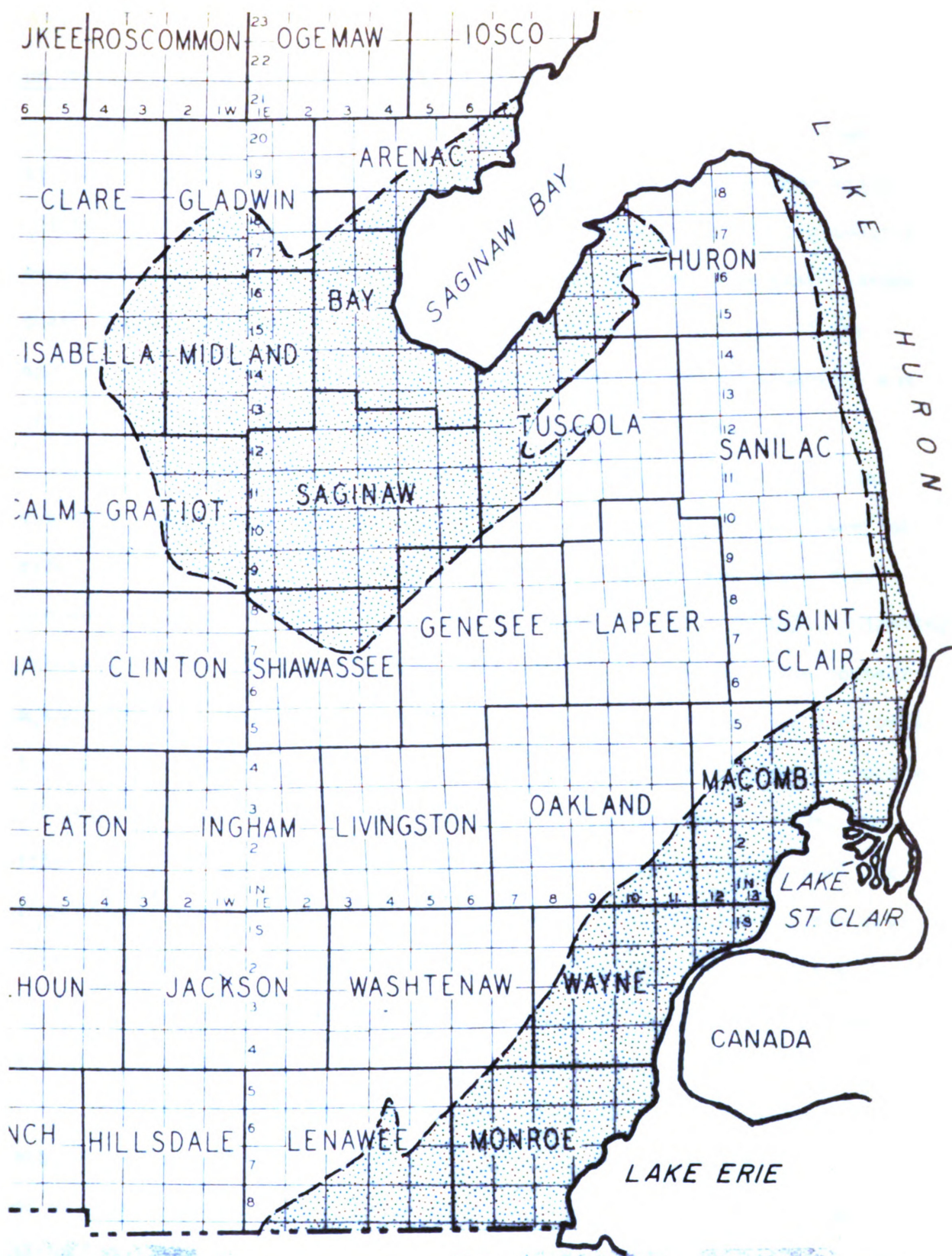


Figure 18. Map of southeastern Michigan showing areas of heavily mineralized shallow water (after Lane, 1899)

Brines from oil wells and test holes at Lowell

Chloride contamination of the fresh water supply at the village of Lowell in Kent County is an example of one of the effects of vertical migration of brines flowing upward through wells and entering an overlying aquifer. For many years Lowell has been supplied with water obtained from gravel deposits present along the Flat River approximately one-half mile north of the village limits; first by 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 analyzed the chloride content of a water sample from the latter well and recorded only a "trace" of chloride. In the period 1935-37 a number of oil wells and test holes were drilled about 1/2 mile upstream from the water-supply wells. In 1939, following complaints about the taste of the water, the village had the chloride content again analyzed. By that time the chloride content of water from the deep well had increased to 775 ppm, which far exceeds the amount considered to be tolerable (250 ppm). In 1945 the chloride content reached 925 ppm. In 1941 the chloride content in the shallow dug well reached 225 ppm indicating 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 brines from the Traverse or the Detroit River formation at great depth and from shallower sandstones of the Marshall formation (table 2). Records of the oil wells and tests reveal that water was encountered 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 should ultimately flush out the chlorides, and pumping should accelerate the natural flushing action. Periodic sampling of water for chemical analysis from the contaminated wells would determine trend in chloride content.

Saline waters in the Saginaw Lowlands

Widespread and very serious impairment of fresh-water aquifers in Michigan resulting from leakage of natural contaminants is known to have occurred in large areas of the Saginaw Lowland. Bowman (1906, p. 94) attributed the deterioration in quality of water from the Saginaw sandstone 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 man-made operations, and state that natural migration of brines to fresh-water beds also has occurred.

Saline water in the Grand Rapids area

In the Grand Rapids area, Kent County, sandstones of the Marshall formation comprise the only bedrock aquifer that yields large quantities of water. The water pumped by most wells tapping this aquifer may be classified as saline inasmuch as the dissolved solid contents are generally well in excess of 1,000 ppm. Historical evidence (Winchell, 1861, p. 91) indicates that the present mineral 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 (upper) members of the Marshall formation was fresh although the term "fresh" is merely relative and the mineral content of the water at the time of his study is not known.

The increase in mineralization which is believed to have occurred since the time of Winchell's study has been attributed to the fact that many old brine wells were not properly sealed. Nellist (1906, p. 272) stated that there were flowing wells in the area which penetrated to the Marshall sandstone 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 Group, which had been previously 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, Wisler, and Laird (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 mineral 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 well in the central part of the city of Lansing for additional water supply. The well tapped the Saginaw formation which is 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 of the water increased rapidly and after two months of pumping the chloride content was in excess of 900 ppm. This concentration of chlorides was very unusual for water from the Saginaw formation in the Lansing area. The engineering staff of the Board of Water and Light immediately started an investigation to determine the source of the chloride.

It was concluded that a probable source of the chlorides was highly mineralized water flowing upward through a well tapping one or more underlying saline-water aquifers. A study of U. S. Geological Survey records revealed that in 1867 a well had been drilled nearby in search of a supply of commercial salt brine. The well, which was drilled to a depth of 1,400 feet, yielded highly mineralized water and initially flowed 1,600 gallons per hour. The brine was not of a quality suitable for commercial salt, but eventually the water was used for mineral baths, and a mineral pool at a spa and hotel which were built at the site. The hotel and spa were destroyed by fire in 1879 and were never rebuilt. A chemical analysis

of the water from the well was published in U. S. Geological Survey Water-Supply Paper 31 (Lane, 1899, p. 58, no. 242) and revealed that the sodium chloride content of the water was 4.575 parts per thousand (4,575 ppm). From the above data it became readily apparent that the source of the high chloride water in the Saginaw formation was the "old mineral well."

The investigation then turned to the problem of locating the old mineral well, which, fortunately, was found. It was buried beneath a garage at the site of the destroyed hotel. In January 1957 the well 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.

It appears from the chemical records that 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 will be successful. However, it is apparent that a large part of the aquifer was contaminated and that it will take considerable time to restore the aquifer to its original condition.

This case also reveals one of the benefits of a program of basic-data collection. Without these records 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 waters at Grand Ledge and Eaton Rapids

Several years ago village officials at Grand Ledge in 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; hence, the project was dropped. On the other hand, 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 in 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 declining trend 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 (fig. 19). Permitting unrestricted or excessive flow from an artesian well results in similar effects.

Numerous geochemical data show that overpumping has resulted in deterioration in quality of water pumped from aquifers in various parts of the State, and further, that pumping from the fresh-water aquifers which have been penetrated by test holes tapping saline-water aquifers will aggravate the conditions cited above. It is believed by the author that contamination of portions of various important aquifers in Michigan by vertically migrating saline waters induced by pumping seriously threatens ground-water supplies in some of the important urban areas of the State.

Intrusion of high-chloride waters

Royal Oak area.--Ferris and others (1954, p. 136-7) studied the effects of pumping on the sodium and chloride content of water from a number of 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, which in this area is charged with sodium chloride. They provide data showing that the chloride content determined from a water sample collected in 1926 from a well at Royal Oak was 365 ppm. In 1930, when the City decreased pumping from this well and purchased additional

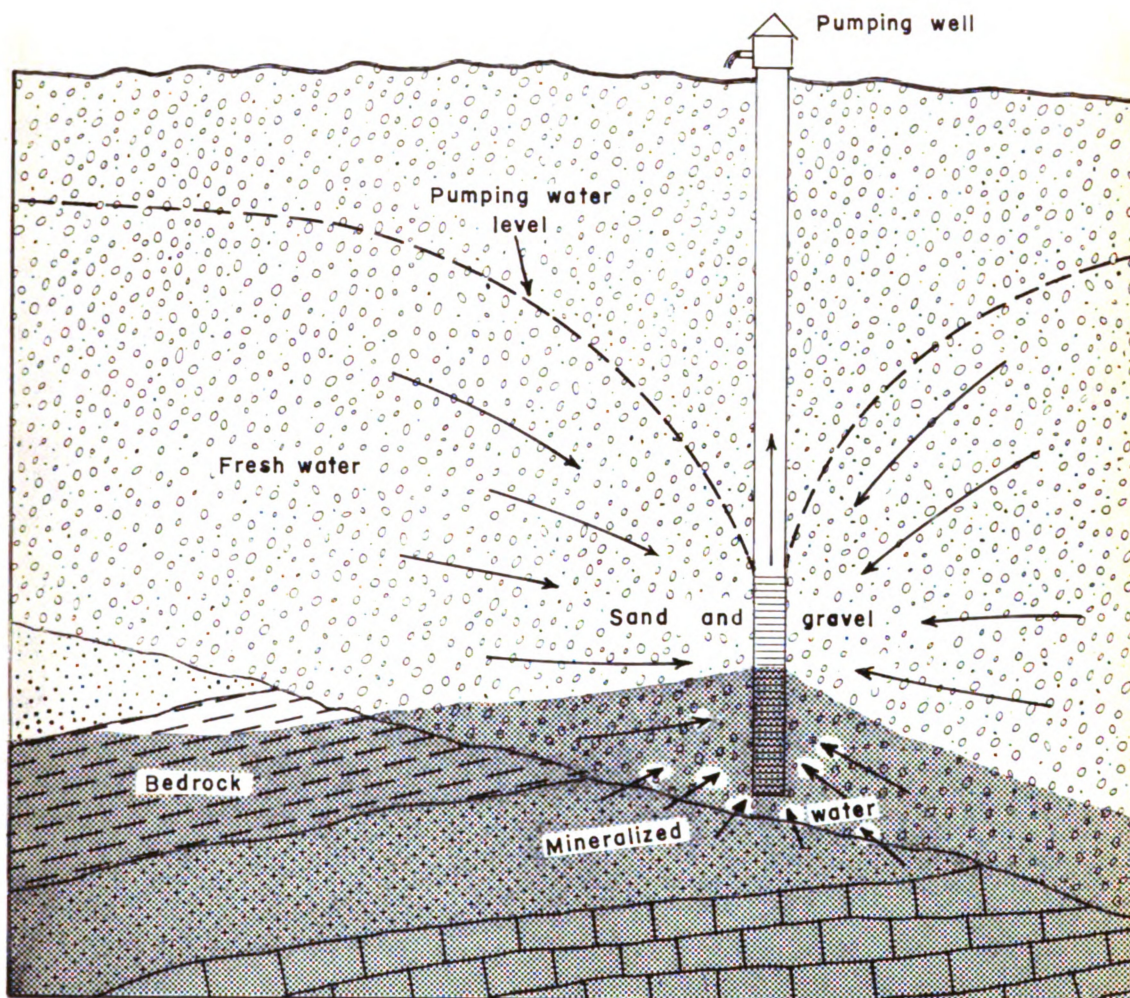


Figure 19. Generalized diagram showing how a fresh-water well may be contaminated by highly mineralized water from underlying rocks (after Wisler and others, 1952)

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.

A marked difference in effects on chloride content caused by pumping of various wells in the vicinity was noted, and two possible explanations for unusually high chloride concentrations were offered: 1. Induced migration of mineralized water might be accentuated by leakage from wells drilled to the salt-water formations. 2. Bedrock formations in areas where the chloride content of the drift is high might be more permeable than others, thus providing better hydraulic connection between the fresh-water drift aquifer and the saline-water bedrock aquifers.

The authors of the report noted also that in the Royal Oak area chlorides are not the only potentially deleterious substances which might migrate from bedrock formations into the glacial drift aquifers. They reported that one well had been known to produce appreciable quantities of gas, presumably from the Antrim shale, until the gas was accidentally exploded and wrecked the pumphouse enclosing the well.

Flint area.--Wiitala, Vanlier, and Krieger (1960) considered the problems caused by overpumping in their evaluation of the water resources available in the Flint area, which includes all of Genesee County. They noted that overdrafts from the Saginaw sandstone are commonly indicated by deterioration in the quality of the water caused by increasing chloride content. They stated further that lowering of the piezometric surface and resultant upward migration of saline water effectively limits the amount of fresh water that can be withdrawn from the area. 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 sandstone as its main source of water supply.

The steady increase in chloride content of Burton Township well No. 2 tapping water from the Saginaw formation is shown by the following analyses of samples collected since 1946:

<u>Date collected</u>	<u>Chloride (ppm)</u>
November 5, 1946	135
February 11, 1953	190
August 18, 1953	230
June 13, 1955	240
December 12, 1956	375

Intrusion of high-sulfate waters

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. Instances of contamination by sulfate-bearing wastes from the land surface were not found. The source of the ground-water supply is the glacial drift, which is generally 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. Further analysis 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 had experienced increasing sulfate concentrations in its water supply before the city abandoned its well system in favor of a Lake Michigan water supply (Deutsch, Burt, and Vanlier, 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 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 low, as shown by an analysis of 19 ppm made in 1922 by the Michigan Department of Health. The sulfate content rose steadily as water levels declined, and by 1943 reached 156 ppm. By 1945 water levels in the field were about 60 feet below land surface, and by 1957 water levels declined an additional 50 feet or more. Unfortunately, after 1943 chemical analyses were not made on samples from the well previously sampled. It was assumed that the increase in sulfate is due to migration of water from the underlying Coldwater shale and that the lowering of water levels after 1943 probably resulted in continued increases in sulfate concentration, perhaps to amounts greater than 250 ppm, which would be considered objectionable.

Manistique.--Some of the residents of the city of Manistique in Schoolcraft County obtain water supplies from artesian wells finished in the Burnt Bluff formation. Water from this formation generally is hard to very hard, 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 is high in sulfate content, which is not characteristic of water from that formation. It is apparent from the results of a study made by Sinclair (1959) that water yielded by these

wells is contaminated by upward leakage of calcium sulfate waters 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 discharging of water by pumping or unrestricted flow from wells tapping the basal part of the Burnt Bluff formation. Sinclair pointed out the fact that wells tapping shallower permeable zones in the Burnt Bluff do not yield water high in calcium sulfate, and suggests avoidance of drilling into the Cataract formation in order to prevent contamination of the Burnt Bluff 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. 20). Excavation of a hole in a confining layer may accelerate encroachment of saline waters either by draining all or most of the fresh ground water in the area or permitting lowering of the fresh-water head floating on the lower saline water. The danger of contaminating fresh-water aquifers as a result of dewatering operations is especially great in parts of the Saginaw Lowlands

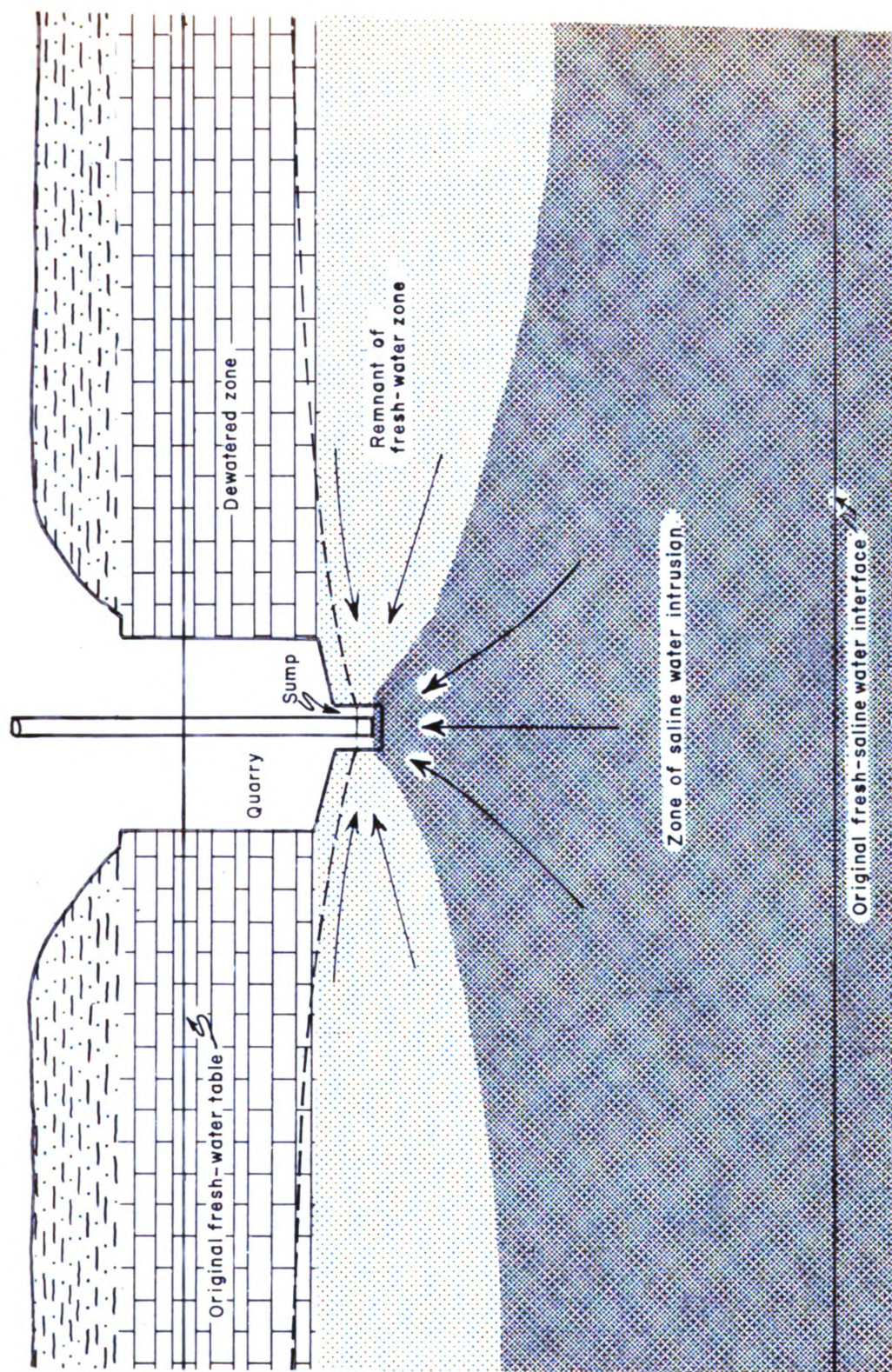


Figure 20. Diagram showing migration of saline water caused by dewatering in a fresh-water aquifer overlying a saline-water aquifer

and southeastern Michigan where relatively shallow artesian aquifers commonly contain saline water.

Sulfide water at Flat Rock

Owners of a number of domestic wells at homes adjacent to a limestone quarry along the Huron River near Flat Rock in Wayne County complained that water in their wells turned black and developed an obnoxious odor as a result of blasting in the nearby quarry. Although there is little geologic or hydrologic basis to support the contention that the actual 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.

The geologic section in this area as revealed in the quarry consists of: (1) the Sylvania sandstone, at the base of the quarry; (2) a 15-foot section of the Amhurstburg 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 actual elevation of the saline-fresh water interface, or its rate of encroachment due to conditions of pumping in the area prior to the dewatering operations at the quarry. Analysis by a commercial laboratory

of a water sample collected from one well in the area prior to dewatering operations at the quarry reportedly showed that the water was very hard and high in sulfate content. This report 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 were present, including iron sulfide which would result from chemical reaction of the hydrogen sulfide and iron. 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 indicates that hydrogen sulfide in ground waters is not uncommon along the lower reaches of the Huron River. Records of "sulfur" water antedate 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" (Amhurstburg) 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 relationship of the sulfates to the sulfides, is completely known. Hem (1959, p. 224) reported that sulfates could be reduced by hydrogen released by decomposition of organic matter by anerobic

bacteria. As the ground waters in the area contain 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

If a river is dredged and deepened, or if a canal or drain is constructed in a manner so that the water level is below the water level in the aquifer which it drains, the water level in the aquifer will be lowered in the vicinity of the drain. Resultant lowering of fresh-water heads in aquifers connected hydraulically with underlying saline-water aquifers may also tend to cause encroachment of saline waters (fig. 21) in much the same manner as caused by overpumping or dewatering operations. Each lowering of one foot of the fresh-water head may permit rises of saline water of as much as several tens of feet in aquifers connected hydraulically to the fresh-water aquifers.

In 1954 the U. S. Army Corps of Engineers planned flood control projects in various areas in southeastern Michigan, including the Sanilac Flats and Shiawassee Flats areas. In these areas, in large parts of which heavily mineralized water is at shallow depth (fig. 18), it is believed by the author that partial dewatering of streamside aquifers with attendant lowering of the fresh water head might result in the encroachment of the saline water into parts of the Marshall formation which are used as a source of fresh-water supplies. It was agreed by all concerned with the proposed

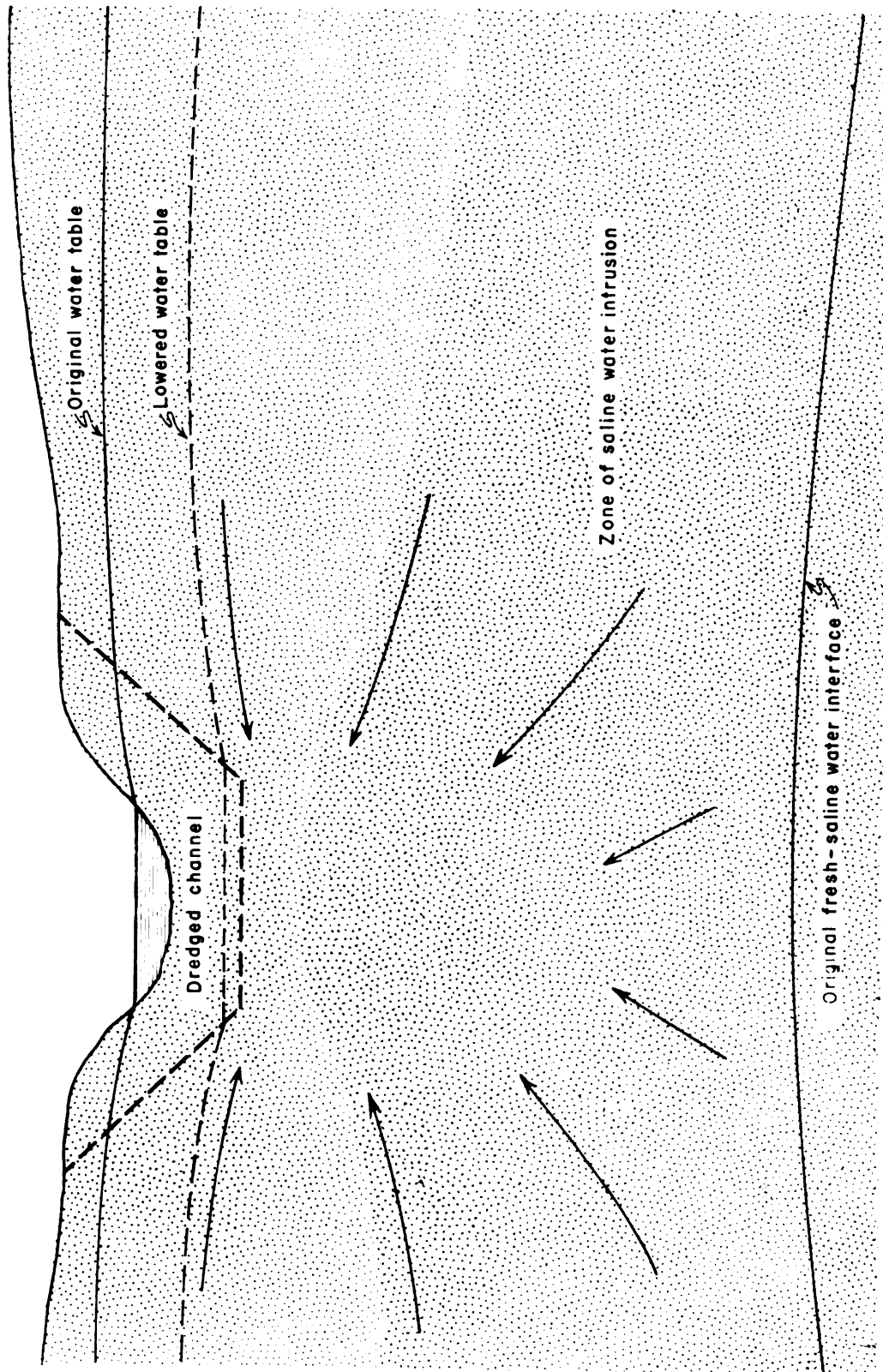


Figure 21. Schematic diagram showing migration of saline water caused by lowering of water levels in an effluent stream and streamside aquifer overlying a shallow hydraulically-connected saline-water aquifer

projects, however, that a great deal of study and observation would have been required to ascertain the possibility of detrimental effect on ground-water quality from the changes in hydrologic regimen contemplated.

LEGAL SAFEGUARDS AGAINST GROUND-WATER CONTAMINATION IN MICHIGAN

Olds (1952), who studied the legal aspects of ground-water contamination, found that not many courts in the United States have been called upon to deal with the subject. He found that most of the few courts which have ruled on such cases, however, favored a doctrine based on "correlative rights" or reasonable use, so that if damages are caused the party responsible for the damage may be held liable. The correlative rights doctrine has been preferred by the courts over the English rule, which holds that a property owner has absolute rights to the uses he makes of his property and hence is not responsible for damages to his neighbor, or to the concept that negligence causing contamination of underground water thus bringing financial injury to a neighbor must be shown.

Lauer, King, and Ziegler (1958) after their study of the same problems concluded that, although the position of the Michigan Supreme Court had been uncertain in upholding the power of the Water Resources Commission to control pollution of ground water, the court has in effect introduced the doctrine of reasonable use into Michigan law.

Legislative authority which would be used to abate ground-water pollution has been granted to various other agencies of the State as early as 1889. On the basis of currently existing legislation, the U. S. Public Health Service (1954, p. 22) reported that "The water pollution control laws of (Michigan) 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 of the State Health Department also have been delegated related water-pollution control functions.

Actions of the Michigan Supreme Court

Relatively 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 sub-surface 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) it was alleged that the complainant's 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), it was alleged that the defendant had 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 on grounds denying violation of Act 117 of the P. A. of 1949. The court held that the commission had 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, King, Ziegler (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, the Act being deficient in that it did not include control of underground 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 very effective in abating contamination of ground-water supplies in cases which have been brought to its attention. In addition, the commission has denied applications for new uses of the waters 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 them 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 so injured." Although this act probably was designed to protect nearby flowing wells from undue loss in head which might cause the flow to cease, the encroachment of sulfate waters into the Burnt Bluff formation at Manistique cited above, illustrated how loss in head might also result in deterioration of chemical quality of the water. No case of application of this law to prevent contamination, however, is known to the author.

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, Stramel, and Laird (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 inasmuch as the law has never been utilized. However, if sufficient engineering data were available to prove conclusively that loss in head was directly attributable to increase in mineral content of the water, as, for example, in the case of Manistique cited above, and that damages had been done to neighboring wells, the law probably could be invoked for abatement of pumping or unrestricted flow, or at least for collection of damages.

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 stated "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- or other mineral-bearing formation penetrated.

Section 25 of the same act exempts most holes drilled for exploration or extraction of water and all other minerals from the general regulations 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 (the Director of Conservation) 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.

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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, inasmuch as 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

Act 245 creating the Michigan Water Resources Commission and Act 219 of the Public Acts of 1949 are the most important Michigan statutes protecting the ground waters of the State from pollution. Act 219 provides for supervision and control by the State Health Commissioner over waterworks systems--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 specifi-

cations 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 which 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 of watertight construction. Further, these wells must not be in areas 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 Laws

The first comprehensive Federal legislation in the pollution control field was the Water Pollution Control Act of 1948 (P. L. 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 pollution problem resulted in the new Federal Water Pollution control Act of 1956 (P. L. 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." The 1956 law includes boundary waters in this policy declaration.

The U. S. Public Health Service (1957) summarized the authorizations in the Federal Water Pollution Control Act as follows:

1. Authorizes continued Federal-State-interstate cooperation in the preparation and development of comprehensive programs for controlling water pollution.

2. Encourages cooperative activities by the States in
 - a. The prevention and control of interstate water pollution.
 - b. The enactment of improved laws to control pollution.
 - c. The establishment of interstate compacts.
3. Authorizes increased technical assistance to States, a broader research program, the establishment of research fellowships, and the use of contract research and research grants.
4. Authorizes the collection and dissemination of basic data on water quality and other information relating to the prevention and control of water pollution.
5. Authorizes appropriation of \$3 million per year for 5 years for grants to State and interstate agencies to assist in their pollution-control activities.
6. Authorizes Federal grants of \$50 million a year (with an aggregate of \$500 million) for the construction of municipal sewage-treatment works.
7. Authorizes the establishment of a Water Pollution Control Advisory Board appointed by the President.
8. Modifies and simplifies procedures governing Federal abatement action against interstate pollution.
9. Authorizes 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 insofar as water law is concerned 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, however, 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. Reduction of contamination of ground water due to introduction of sanitary and industrial wastes may be expected to result from 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 has virtually been eliminated since enactment of the laws directing the Department of Conservation to supervise construction and operation of wells so as to protect the water resources from hazards of contamination.

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 again become usable. Where aquifers have been contaminated, the waters 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 which are recharged by septic tank effluent will ultimately be contaminated also by chemical wastes. 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 tends to aggravate the situation.

Other remaining major hazards to the ground-water resources of the State are, in the opinion of the author, overpumping and other changes in the ground-water regimen which induce waters high in sulfate, chloride, or other mineral constituents to flow into fresh-water aquifers. There are several reasons for this opinion. First, it is not clear how present Michigan laws would deal with such cases. Act 107 of the Public Acts of 1905 presumably could be applied to cases of overpumping--as for example, in the case of Manistique cited above--but the law has never been used, and apparently in most cases prescriptive rights would have long since been gained by the present users. Secondly, a wealth of geochemical and hydrologic data is needed even to recognize encroachment of saline waters, and probably even more data would be needed to offer conclusive legal proof of contamination from natural sources. Subsurface encroachment of natural saline water has been identified mainly in areas where the saline water occurs at shallow depth. Figure 18, which shows such areas in southeastern Michigan, was

prepared in 1899 (Lane, 1899, pl. IV), and 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, but several basic weaknesses in the control programs exist. A considerable amount of public education will be required to promote understanding as to how aquifers might be safeguarded. If needed, specific statutory authority should be vested in an appropriate State agency to control migration of natural saline waters 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 legally control migration of saline waters 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 be effectively utilized by the appropriate regulatory agencies. 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."

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