An Assessment Of Potential Groundwater Contamination in Indiana

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I INTRODUCTION

Our most essential resource is being threatened by improperly buried and stored liquid wastes seeping into underground water supplies in all fifty (50) States. In an unpublished report by this Agency (Surface Impoundment Assessment), it was reported that the Nation has at least 180,000 surface impoundments of liquid waste and that 90 percent of them endanger groundwater. Moreover, many hundreds of improperly cited and improperly operated hazardous waste landfills are allowing toxic seepage to contaminate groundwater aquifers.

The nation as a whole has not yet grasped the importance of groundwater or the significance of groundwater contamination. It is literally a case of "out of sight, out of mind." Yet fully half the water America uses comes from underground supplies.

To date most of our anxiety over water quality has focused on surface waters where pollutants are anathema to the senses and also curtail water uses. Groundwater, away from sight and subject to an insidious contamination that is often odorless and invisible, is largely forgotten. Unlike surface waters, which are subject to the purifying effects of evaporation, biological degradation, and aeration, groundwater is effectively isolated from the atmosphere, and is comparatively static; thus largely lacking in the effects of the above purifying mechanisms. Its self-cleaning capacity is much lower and once contaminated can remain such, in some cases, for geologic time.

The contamination of groundwater supplies is not solely the work of "Midnight Dumpers" who illegally pour tankers of waste into ditches and fields. Much of the groundwater contamination is a result of the entirely legal disposal of liquid wastes.

Burying and lagooning, by far the most common methods of waste disposal in this country, in the long term, are most likely the least safe of all hazardous waste disposal methods currently available. This applies not only to past practices, but also to some of the most advanced techniques required under the enlightened and more stringent laws applicable today.

Billions of dollars a year are being spent by industry and government to manage huge quantities of hazardous wastes that are growing by hundreds of millions of metric tons annually. But the bulk of that waste, as much as 90 to 95 percent by some counts, continues to be placed in thousands of lagoons and landfills scattered throughout the country.

Current Federal regulations require that land burial be carried out far more carefully than in the past. Requirements include that new landfills have liners to keep the wastes inside, collection systems to remove the liquids that inevitably form, monitoring devices to detect the escape of the contents, and caps to seal off the site once it is filled. The regulations also discourage burial of most, but not all, liquids and encourage burial in solid form.

However, it is becoming increasingly apparent that even state of the art landfills with "tailor-made" liners and doubleliners are beginning to leak after distressingly short periods. Should this type of hazardous waste disposal be continued in the future - undoubtedly this will be the case assuming the disposal economics and the environmental laws are not changed - the existing threat to the Nations groundwater will remain and become more serious and ever larger in geographic and toxic scope.

This report will suggest the areas in Indiana that can be expected to have the highest potential for groundwater contamination based upon the findings of the Surface Impoundment Assessment (SIA), the data and information gathered under the Resource Conservation and Recovery Act, "Superfund" inventories, and the geology of the State. While the data of the SIA were based on "desktop" research that relied upon examination of aerial photos rather than actual site visits, and the use of Standard Industrial Codes (SIC) instead of actual sampling and laboratory analysis, the evaluations made herein can be expected to, more likely than not, accurately define conditions in Indiana with respect to areas of relatively highest groundwater contamination potential.

II GEO-HYDROLOGIC CONDITIONS

GEOGRAPHY

Indiana lies within the limits of latitude 37°46'18" and 41°45'33" north, for an extreme length of 275 miles in a north-south direction; and between longitude 84°47'05" and 88°05'50" west with a maximum width of 142 miles in an east-west direction.

At its maximum the Indiana topography is about 900 feet, with elevations ranging from about 300 feet above sea level at the Wabash River mouth (Posey County), to more than 1200 feet in the east-central area (Randolph County).

CLIMATE

Temperatures average 49°F along the Michigan State line and 56°F along the Ohio River. The average annual temperature for the entire State is approximately 53°F (See Figure 1).

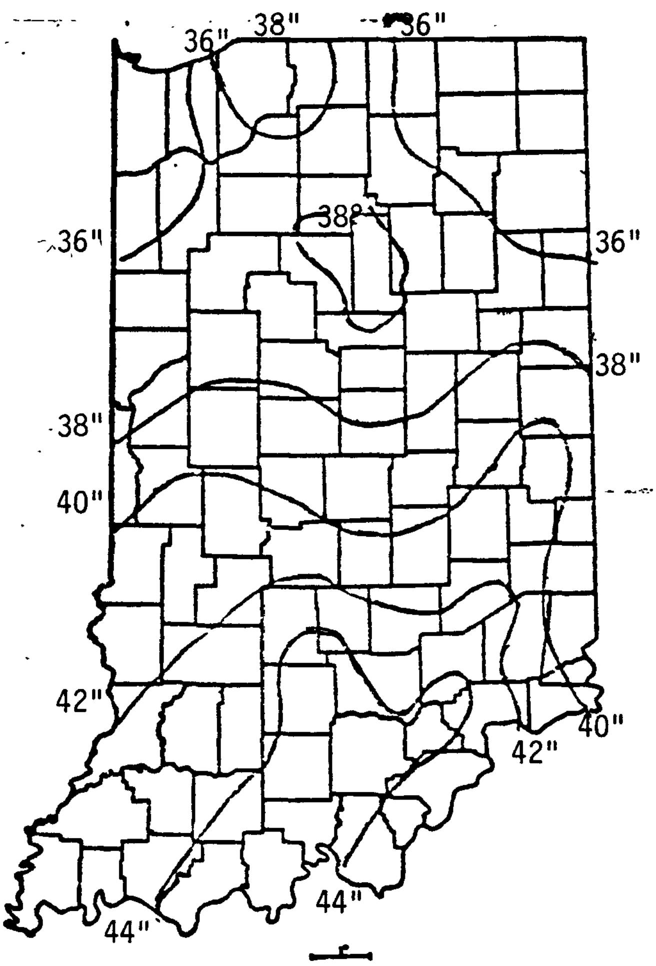
The average annual Statewide precipitation in Indiana is 38 inches, ranging from 36 inches to 44 inches, north to south (See Figure 1). With respect to snow, the annual average ranges from 70 inches to 16 inches, north to south and accounts for two to seven inches of the average annual precipitation. Approximately 59 percent of the total annual precipitation occurs between April and October, the normal growing season.

GEOLOGY

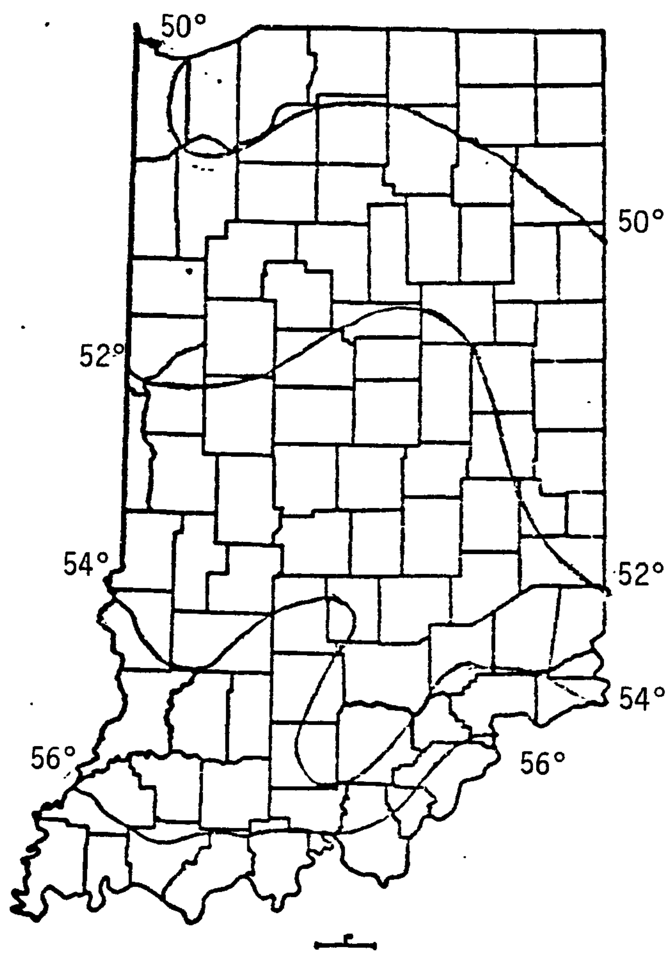
Of equal importance to the climatic character, which controls the amount of precipitation, are the geology and topography of Indiana which influence the disposition of the precipitation and its availability as a water resource. The location and availability of the Indiana water resource are intimately related to its geology and soils. The proportion of precipitation that runs off the land as surface water rather than infiltrating the soil is dependent in part upon the topography, the geologic conditions, and the soils. Moreover these same factors have much influence upon the amount and occurrence of groundwater.

The largest single influence upon the topography of Indiana has been that of glaciation. As glaciers advance and retreat under the influ-

FIGURE 1



Map of Indiana indicating the distribution of annual average precipitation.



Map of Indiana showing annual temperature in degrees Fahrenheit.

ence of climatic conditions, the topography is transformed. An advancing glacier scours the land surface while a retreating glacier leaves behind large deposits of materials previously scoured from the earths surface. Glacial drift, the rock material transported by glaciers, covers almost the entire State, the legacy of more than one glacial episode. The remaining nonglaciated area (one-twelfth of State) is located in the south-central portion and even that area shows some evidence of drainage changes related to glacial activity.

Indiana's bedrock formations are more than two hundred million years old and are associated with the Pennsylvanian, Mississippian, Devonian, and Silurian periods. These sedimentary rock formations consist mainly of sandstone, siltstone, shale, limestone, and dolomite. These are for the most part deposits from a series of inland seas that occupied what is now Indiana and surrounding States through most of Paleozoic time. In addition, terrestrial sedimentary deposits are located in parts of Indiana and include large deposits of coal, the remnants of great swamp forests.

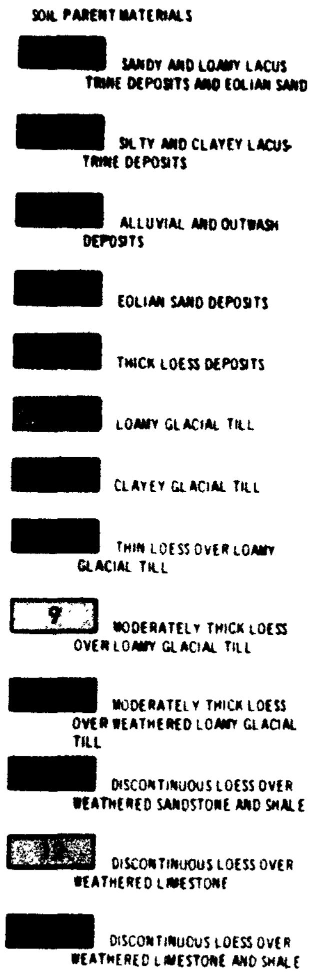
The sequence of sedimentary rock is about 3000 feet thick near Muncie, but is 5000 feet thick at the Michigan border and more than 12000 feet thick at the southwest corner of the State. Erosion has removed great thicknesses of the sedimentary rocks and also has beveled them, so that the oldest rocks (Ordovician) lie at the bedrock surface near Richmond and Lawrenceburg, and the youngest (Pennsylvanian) rocks underlie Evansville and Terre Haute.

The basis of soil formation is the gradual weathering and decomposition of soil parent materials. The basic parent materials of Indiana soils are glacial drift and various bedrock formations (See Figure 2). During the process of soil formation, vegetation is established. As the vegetational communities develop, organic matter accumulates and soil profiles are developed. With the introduction of vegetation, micro-flora and fauna also developed. Over geologic time the modern day soils were formed, each with individual characteristics and physical properties.

Soils and the underlying geologic formations create an intimate association with the water resource. Each individual soil has a distinctive permeability characteristic, which governs its capacity to absorb precipitation and to transmit it underlying geologic formations. The basic components of soil are sand, clay, and silt. The higher the content of sand, the greater the premeability of liquid through it.

MAJOR DRAINAGE BASINS

A drainage basin is an area that gathers water originating as precipitation and contributes it ultimately to a stream or other body of water. All streams, no matter what size, have associated drainage basins from which the stream's flow is derived. The two major drainage basins in Indiana are the Great Lakes and the Mississippi River basins (See Figure 3). The Great Lakes drainage consists of the Little and Grand Calumet Rivers and minor tributaries to Lake Michigan in Northwest Indiana; the St. Joseph River basin in Northern Indiana, which also drains to Lake Michigan; and the Maumee River basin in the northeastern part of the State, which drains to Lake Erie. The Great Lakes drainage portion of Indiana totals approximately 3,545 square miles, including 241 square miles in Lake Michigan.



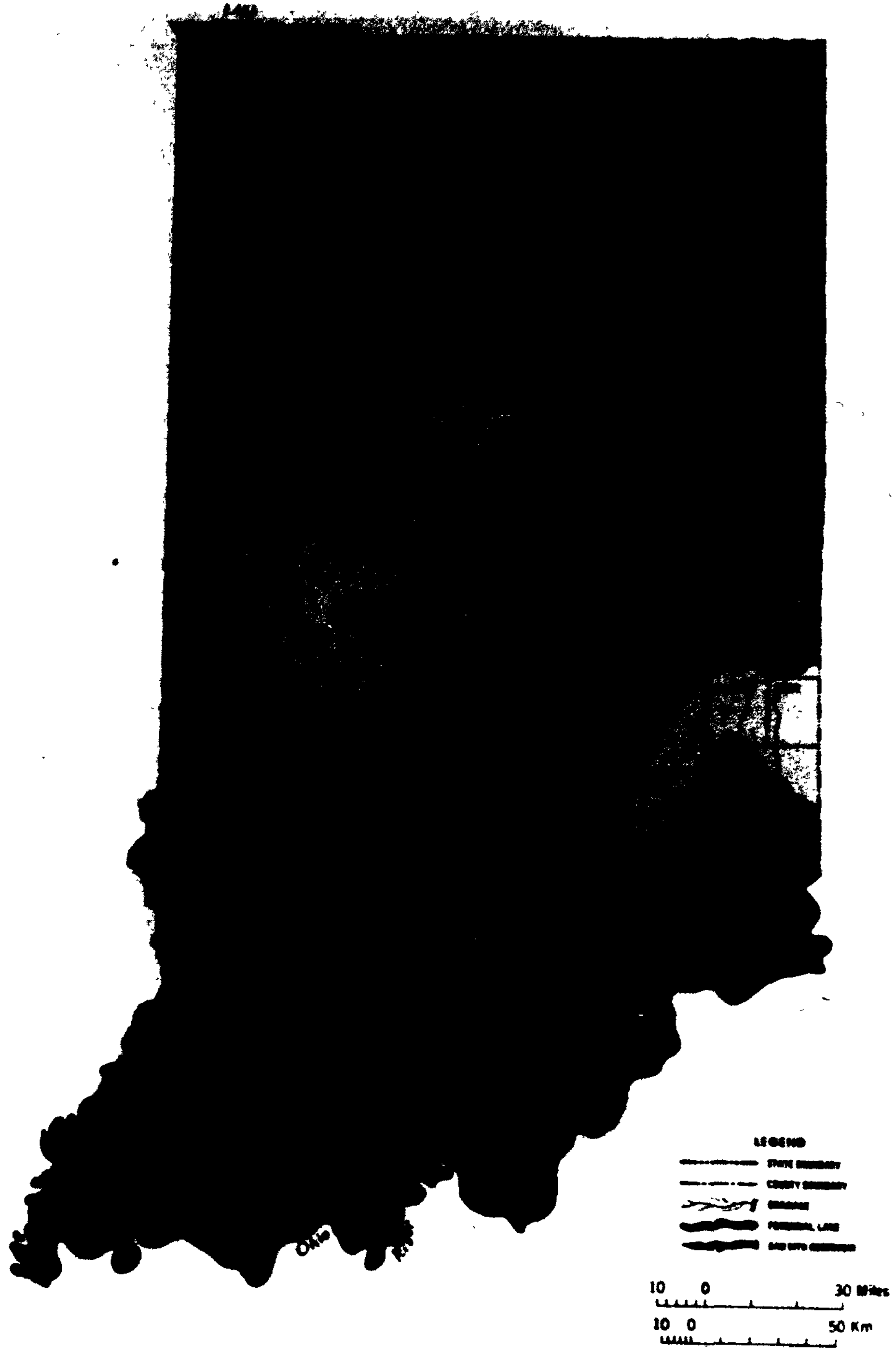
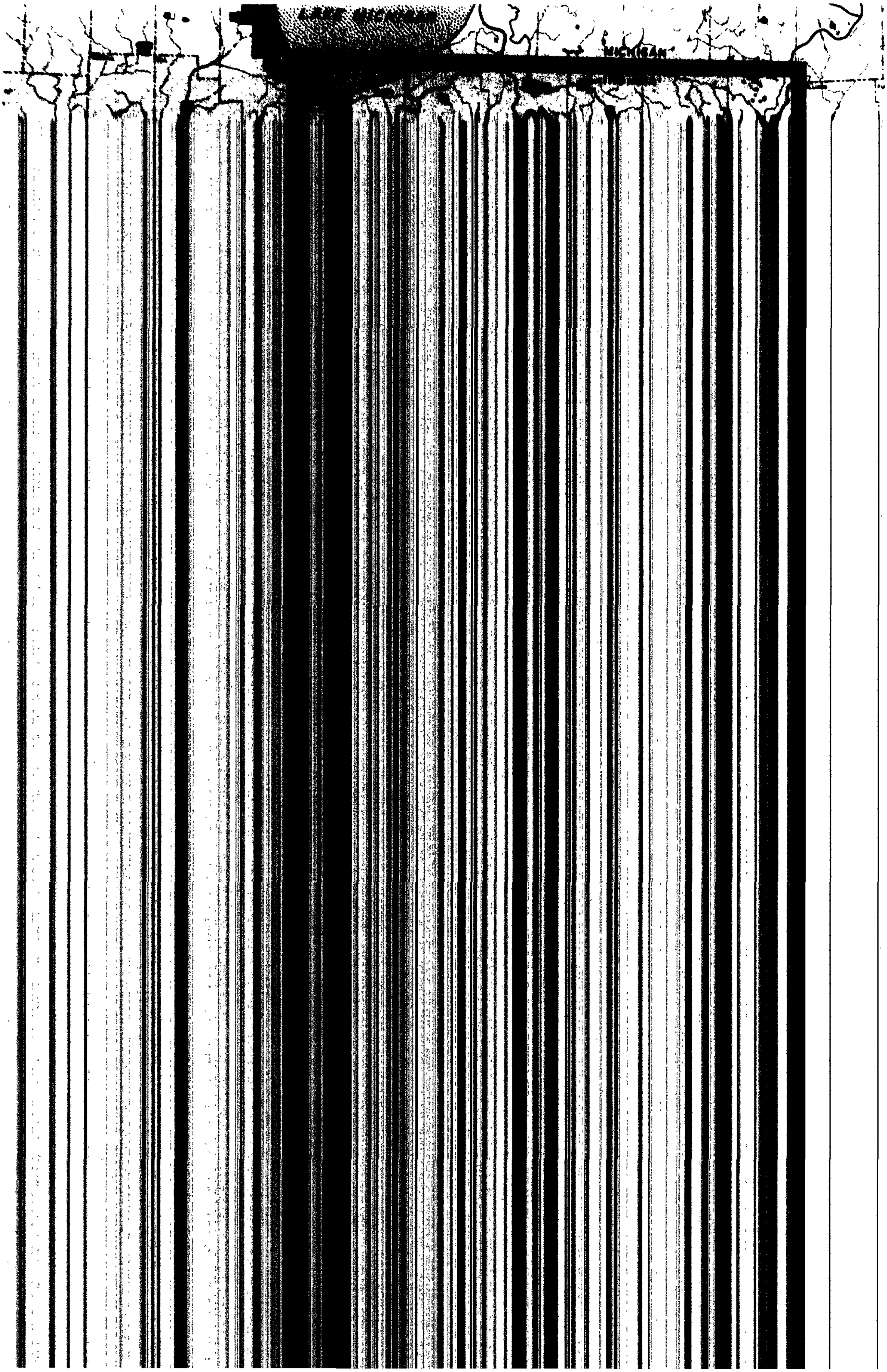


FIGURE 2

Map of Indiana showing the general location of parent materials to Indiana soils. Map courtesy of the U.S. Soil Conservation Service.


MICHIGAN

The Mississippi River drainage consists of two major areas of the State. The first of these includes the basins of the Kankakee and Iroquois Rivers, which drain westerly into Illinois and then to the Mississippi River via the Illinois River. The total area within this section is approximately 3016 square miles.

The rest of the Mississippi River drainage, which encompasses about seventy-seven percent of the State, includes the basins of the Wabash River, the Whitewater River, and a number of minor tributaries to the Ohio River along the southern part of the State. These all drain to the Ohio River and then to the Mississippi. The total area within this section is approximately 29,730 square miles.

III GROUNDWATER RESOURCE

The gross long-term supply of water to Indiana, in the form of precipitation, amounts to a Statewide annual average of 38 inches per year. However, not all the precipitation is directly available to maintain the water resource, as indicated in Figure 4. Much of the water is lost to evapotranspiration. It is estimated that approximately 69 percent or 26 inches of the average annual precipitation in Indiana is returned to the atmosphere. Therefore, of the original 38 inches of precipitation, approximately 12 inches represent the annual net supply to the water resource, both groundwater and surface water.

The distinction between the groundwater component and the surface water component is implied by their respective names. Groundwater occurs in consolidated and unconsolidated underground geologic formations. Surfacewater occurs in surface streams and lakes.

In general, groundwater is supplied by that portion of precipitation that infiltrates through the soil profile to underlying geologic formations, or aquifers, that have the ability to absorb, store, and transmit water. Although information is limited, it appears that approximately nine (9) percent of the average annual precipitation recharges, or is contributed to, the groundwater system.

Groundwater in Indiana occurs in a variety of both unconsolidated and bedrock aquifer systems. The most significant of these aquifers are the various unconsolidated outwash sand and gravel deposits associated with glacial drift, and the limestone, dolomite, and sandstone bedrock formations.

UNCONSOLIDATED AQUIFERS

The most productive groundwater aquifers are associated with glacially derived outwash - the unconsolidated deposits (See Figure 5). Sand and gravel deposits occur in the major river valleys. Drainage courses, which were cut by glacial melt waters and now occupied by a number of rivers and streams, were in many cases filled with these unconsolidated materials. These aquifers are capable of yielding 2000 gallons per minute (GPM) and more to properly constructed, large diameter wells.

Other productive groundwater aquifers are the thick, inter-till sand and gravel deposits found in central and northern Indiana. The withdrawal potential of groundwater from these unconsolidated aquifer systems ranges between 400 and 2000 GPM from properly constructed, large diameter wells.

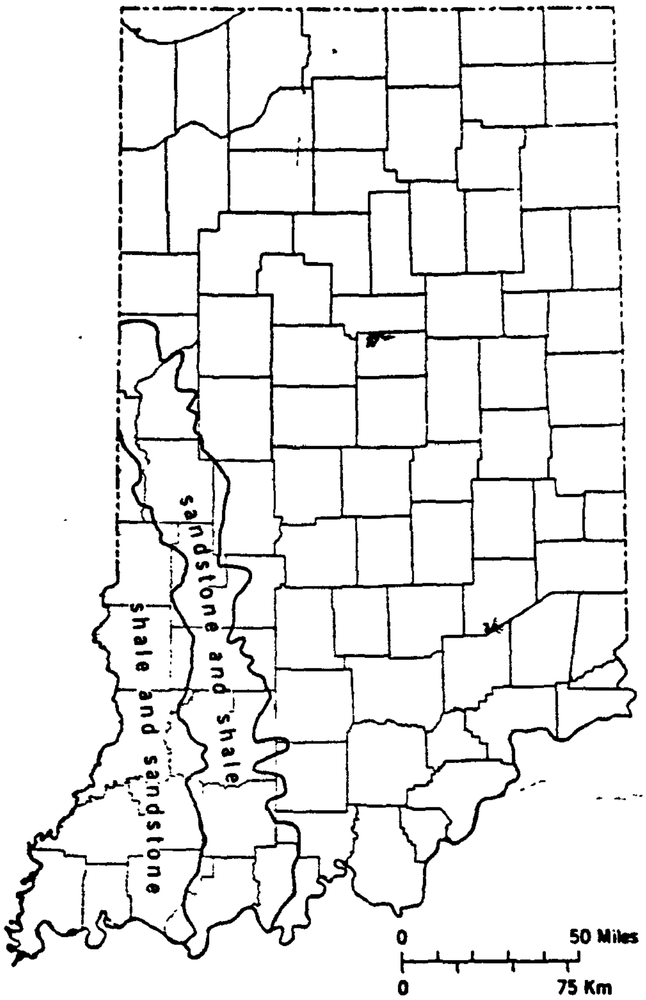
BEDROCK AQUIFERS

Like the unconsolidated deposits, the bedrock formations (See Figure 6) also have the ability to absorb, store, and transmit water. The major bedrock aquifers which occur in Indiana are the so-called Pennsylvanian, Mississippian, Devonian, and the Silurian, all of the Paleozoic era.

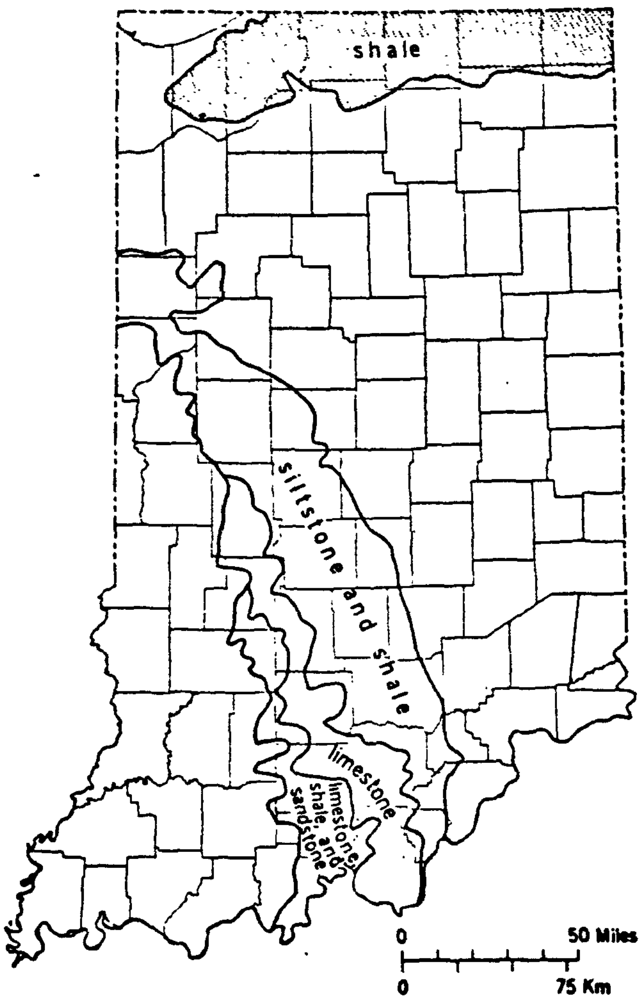
Aquifers contained within the Pennsylvanian age bedrock are generally of low yielding capacity, seldom supplying more than 20 GPM to a properly constructed well. However, their value is most significant to the homes and farms utilizing these sources in southwestern Indiana, and to those waterflood oil operations requiring fresh water for injection and re-pressurization of oil bearing formations. Those portions of Indiana with underlying Pennsylvanian age bedrock aquifers are shown in Figure 7. In general well depths are greater in the Pennsylvanian rocks than in other geologic systems of the State, and depths approaching 300 feet are common. Well casings are usually six (6) inches or greater, indicating the low yield capabilities of these aquifers. Because of the low permeability of the bedrock, the abundance of shale confining zones both above and below aquifer systems, and the limitations in available drawdown, it is seldom possible to pump large volumes of water.

The Mississippian age bedrock aquifers can be broken into three (3) reasonably distinct groups (See Figure 7). They include the uppermost alternating limestone-shale-sandstone units, which are not considered an important aquifer source and contain only small amounts of water (generally yielding less than 10 GPM); the middle Mississippian age

FIGURE 7



Map of Indiana showing those areas with underlying Pennsylvanian bedrock aquifers.



Map of Indiana showing those areas with underlying Mississippian bedrock aquifers.

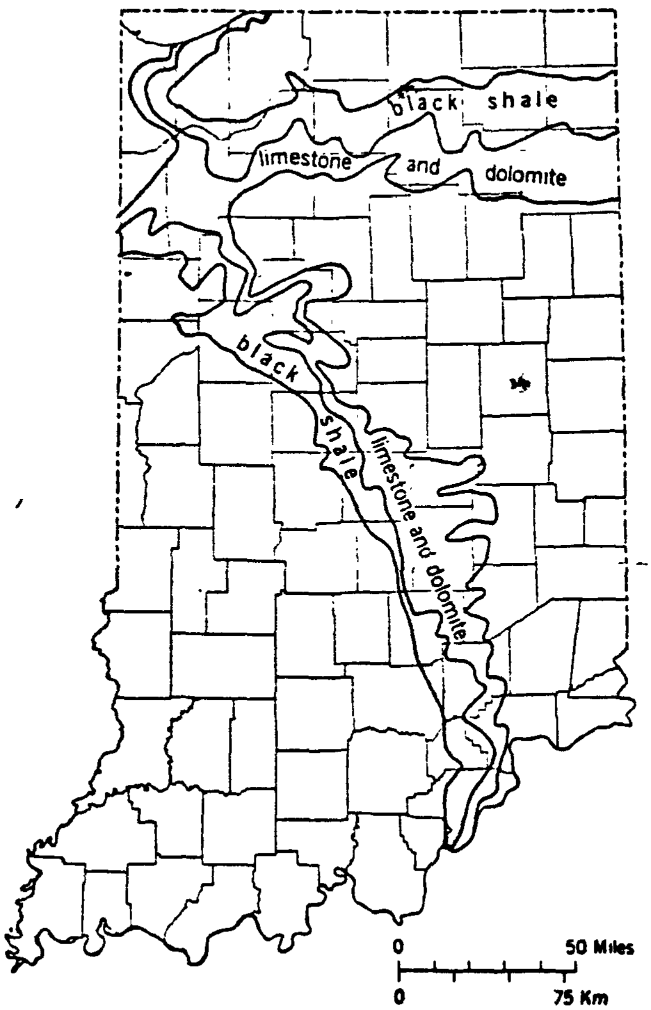
limestone sequence that is prominent in south-central Indiana, and which can, in localized areas yield up to 100 GPM, but normally yields only small amounts sufficient for home use; and finally the siltstone and shale formations that yield little groundwater. In general, the Mississippian aquifers are not considered major sources of groundwater in the State, and exclusive of anomalous conditions in Montgomery and Fountain Counties, average well yields are less than 10 GPM. Well depths vary widely, ranging from 50 to 350 feet.

Black shale, limestone, and dolomite formations are the dominant rock types of the Devonian age bedrock aquifer system in the State. Devonian bedrock aquifer locations in Indiana are shown in Figure 8. Significant aquifer sources are confined to the limestone and dolomite units and marked differences exist between the water bearing characteristics of these formations.

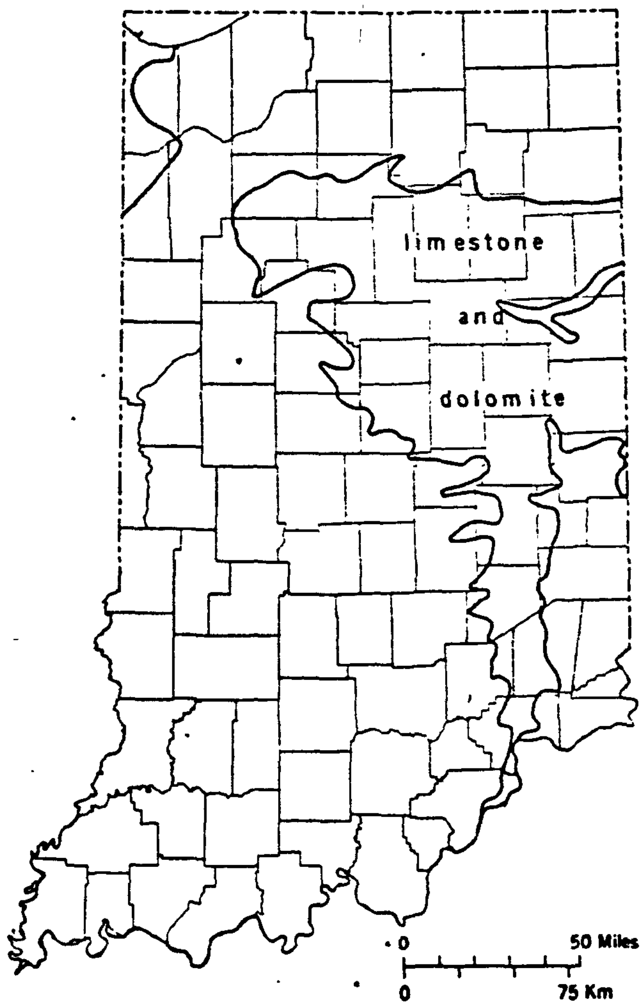
Well yields from the dolomite-limestone aquifers range from 100 to 600 GPM for the northern half of the State to less than 50 GPM for the southern sectors where most well yields will be less than 10 GPM. Well yields from the shale formations are not significant, and dry holes and wells yielding less than five (5) GPM are common.

The Silurian age bedrock aquifers shown in Figure 8, are composed primarily of limestones and dolomite with some interbedded shale. Silurian bedrock aquifers are an important source of water for many communities in the northern half of the State and are also utilized by thousands of residents served by individual domestic wells. In portions of Lake, Newton, and Jasper Counties they are tapped by

FIGURE 8



Map of Indiana showing those areas with underlying Devonian bedrock aquifers.



Map of Indiana showing those areas with underlying Silurian bedrock aquifers.

numerous irrigation wells. Yields from the Silurian aquifer system vary from 10 GPM to 600 GPM. Generally, in most of the northern portion of Indiana, the limestone and dolomite aquifers can be expected to yield up to 400 GPM from properly constructed wells. In southeastern Indiana where the glacial deposits are thinner, well yields range from 5 to 100 GPM.

IV GROUNDWATER AVAILABILITY

Groundwater capabilities vary widely in the State ranging from as little as 10 GPM or less to over 2000 GPM to properly constructed, large diameter wells. The availability of groundwater on a Statewide basis is shown on Figure 9. The various categories of groundwater yields are only a measure of the relative productivity of the several aquifer systems. These yield potentials do not indicate that an unlimited number of wells, of the specified yield, can be developed in any given location.

NORTHERN INDIANA

In general, the groundwater resource of northern Indiana can be classified as being good to excellent, and exclusive of some areas in northwestern Indiana, well yields of from 200 to 2000 GPM can be expected in most areas. Major areas of groundwater availability are found where the productive Silurian-Devonian bedrock aquifer system underlies large areas, and where deposits of glacial material up to 500 feet in thickness contain highly productive inter-till sand and gravel aquifers. A number of major outwash sand and gravel deposits are associated with the St. Joseph, Elkhart, Pigeon, Fawn, Eel, and

Tippecanoe River Valleys. These sources are capable of large groundwater production.

CENTRAL INDIANA

In the central portion of the State, groundwater conditions range from fair to good. Well yields from 100 to 400 GPM are typical. Both outwash sand and gravel, and limestone and dolomite bedrock aquifers are tapped for large production needs. Major groundwater sources occur in the valleys of the West Fork of the White, Whitewater, Eel, and Wabash Rivers, and in portions of the Valleys of Eagle, Fall, and Brandywine Creeks, and the Blue River. Bedrock aquifers in the Silurian-Devonian limestone sequence are also tapped for fairly large production. Locally, thicker inter-till sand and gravel aquifers are present that are capable of meeting small municipal and industrial need. These sources are normally capable of yielding up to 300 GPM.

SOUTHERN INDIANA

Many areas of the southern portion of the State are particularly lacking in groundwater, and only limited amounts, generally less than 10 GPM are available to properly constructed wells. In these areas, the major sources of groundwater are present in the sand and gravel deposits of the stream valley aquifers and are extensively tapped by a number of municipalities, rural water systems, and irrigation users. The valleys of the Eel, East and West Forks of the White, Ohio, Wabash, Whitewater, and main stem of the White are underlaid by thick deposits of outwash sand and gravel capable of producing over 1000 GPM to properly constructed large diameter wells.

V GROUNDWATER LEVELS

When water is withdrawn from an aquifer system the water level in the aquifer may decrease. Providing that the rate of withdrawal of groundwater does not exceed the annual average recharge to the aquifer, the aquifer system will not be "mined" or undergo a continual decrease in groundwater levels. During the long period of monitoring water levels in Indiana, there have been no discernable long term changes, in the form either of lowered or rising water levels.

In general, groundwater levels naturally follow a rather consistent seasonal pattern, reaching annual high levels in late April or early May, and then beginning a slow but continuous decline through the summer growing season. In autumn, with the onset of seasonal increases in precipitation and major reduction in evapotranspiration, the groundwater levels begin to rise.

Normal annual water level changes are typically in the range of three (3) to seven (7) feet in most aquifers. While Statewide water level trends have reflected no long term rise or decline in water levels, large groundwater withdrawals, however, have caused pronounced declines in local water levels, particularly near municipal well fields, stone quarries, and in some areas of irrigation usage.

VI WATER WITHDRAWALS

In addition to instream uses (fish and wildlife, outdoor recreation, hydroelectric power generation and commercial navigation) man has a variety of needs for water. These needs include public water supplies, irrigation, and the production of energy and energy related processes (through the extraction of coal, oil, and gas). Water is withdrawn from both the surface and groundwater compoments of the water resource by either surface water intakes or wells. Of the estimated 13,840 million gallons of water withdrawn daily from the Indiana water resource, approximately ninety-five (95) percent is returned to a supply source while five (5) percent (approximately 615 million gallons) is consumed. Water consumption includes evaporation, transpiration, transfer out of the basin of origin, and that incorporated into products.

PUBLIC WATER SUPPLY

Any public utility which distributes water for sale to customers is defined as a public water supply. The source of a public water supply is dependent upon the location and the availability of the water resource. Approximately fifty-one (51) percent of the water distributed by the Indiana public water supply utilities is derived from a surface water source: from streams, reservoirs, and lakes, particularly Lake Michigan. The remaining forty-nine percent of the water supplied by public utilities is withdrawn from groundwater. The location and source of Indiana public water supply systems are shown in Figure 10. In general, the source of water for public utilities depends upon local geological and hydrological conditions. As previously discussed, the availability of groundwater is generally greater in the northern and central portions of Indiana than in the southern part of the State. Usually only those utilities with limited access to adequate quantities of groundwater rely upon surface water sources. The four largest utilities in the State, serving the Indianapolis, Gary-Hobart, Fort Wayne, and Evansville areas, obtain at least ninety-five percent of their supply of water from surface sources.

The three (3) types of public supply systems in Indiana are the municipal, rural water, and subdivision utility systems. The municipal utility generally serves an incorporated city or town, but may serve developments outside city boundaries.

The rural public water supply systems are typically located in rural areas in southern Indiana where the water resource is limited (See Figure 11). These systems are usually formed by local residents after a period of time of dealing with undependable wells or cisterns. Due to small capacity distribution systems and higher rates, the commercial, industrial, and agricultural uses of water through the rural systems are limited.

The subdivision utility is designed to serve only the residences within a single development. Subdivision system have been developed for mobile home parks, isolated subdivisions, or industrial parks not having access to another water supply.

The customers of public water utilities may include anyone having access to the water mains, such as homes, apartments, various public and private institutions, commercial enterprizes and industry. In 1975, sixty-eight (68) percent or approximately 3,632,000 of Indiana residents were supplied through a public water utility.

INDUSTRIAL WATER SUPPLY

Industries require the use of process water, cooling and condensing water, boiler feed water, and sanitary water. Industrial water intake is composed of water derived from public water supplies or from self-supplied industrial water withdrawals. Total industrial water intake in 1977 approached 3720 million gallons per day. Of this Statewide industrial water use, approximately ninety-three (93) percent was self supplied while the remaining was purchased from public utilities.

RURAL WATER

Water used for livestock and residential purposes, and not supplied by a public water utility, constitutes a rural water use. In 1977 rural water use was estimated at approximately 147 million gallons per day, with residential use constituting the largest portion at 104 million gallons per day.

VII GROUNDWATER QUALITY (NATURAL)

CONVENTIONAL PARAMETERS

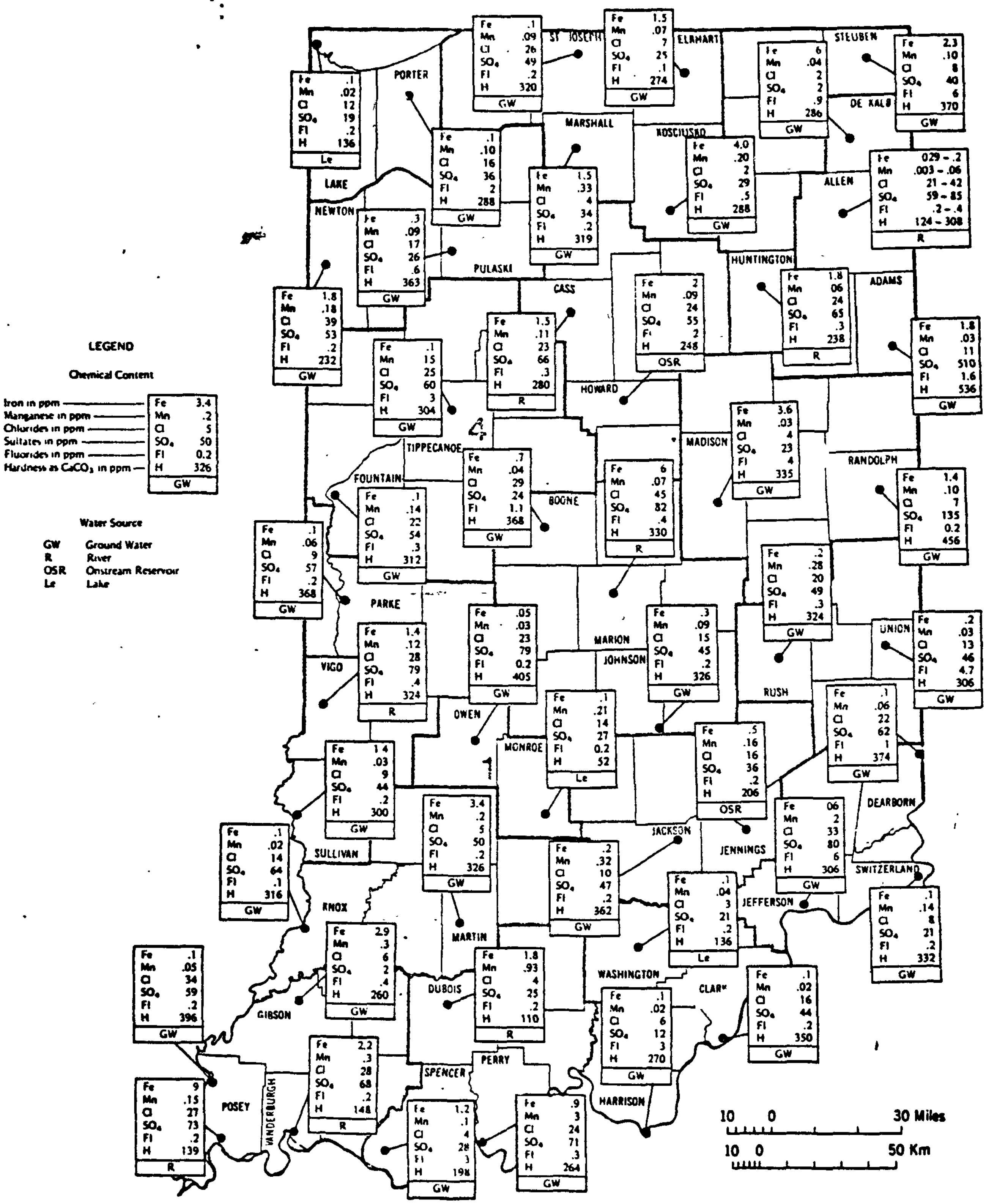
The natural chemical quality of groundwater is the direct result of the mineral composition of the formations through which it has passed. During the slow process of the movement of water from the surface downward through the earth and into the aquifer systems, it dissolves and takes into solution various chemical elements including chlorides, fluorides, iron, calcium, magnesium, carbonates, sulfates, and a number of other dissolved constitutents.

Groundwater quality throughout Indiana is quite variable depending upon the aquifer system being sampled, geologic setting, and depth of formation. For example, the hardness content of groundwater may range from less than 100 ppm to over 600 ppm. In general, the natural chemical quality of Indiana groundwater is good, meeting most of the basic requirements for household, municipal, industrial, and irrigation uses. However, the waters are normally hard, exceeding 180 ppm, and some form of iron or manganese removal treatment is required in many situations. Several key natural chemical constituents are of particular importance in assessing groundwater for general household, municipal, and industrial uses. These usually include hardness, turbidity, iron, maganese, chloride, nitrate, sulfate, fluoride and hydrogen sulfide content. Figure 12 shows selected representative regional water analyses for a number of municipal water supplies. The analyses are predominantly for municipalities with groundwater sources. However, analyses for various stream sources, water supply reservoirs, and lakes scattered throughout the State also are shown.

Hardness levels above 300 ppm are present in much of the State and portions of northeastern Indiana have hardness levels exceeding 600 ppm as indicated in Figure 13. Localized areas of high hardness also exist in extreme south-central Indiana in Harrison and Washington Counties. A region of softer water is present in the southwestern portion of the State where natural softening processes have reduced hardness levels below 100 ppm in localized areas depending upon the depth and aquifer sampled.

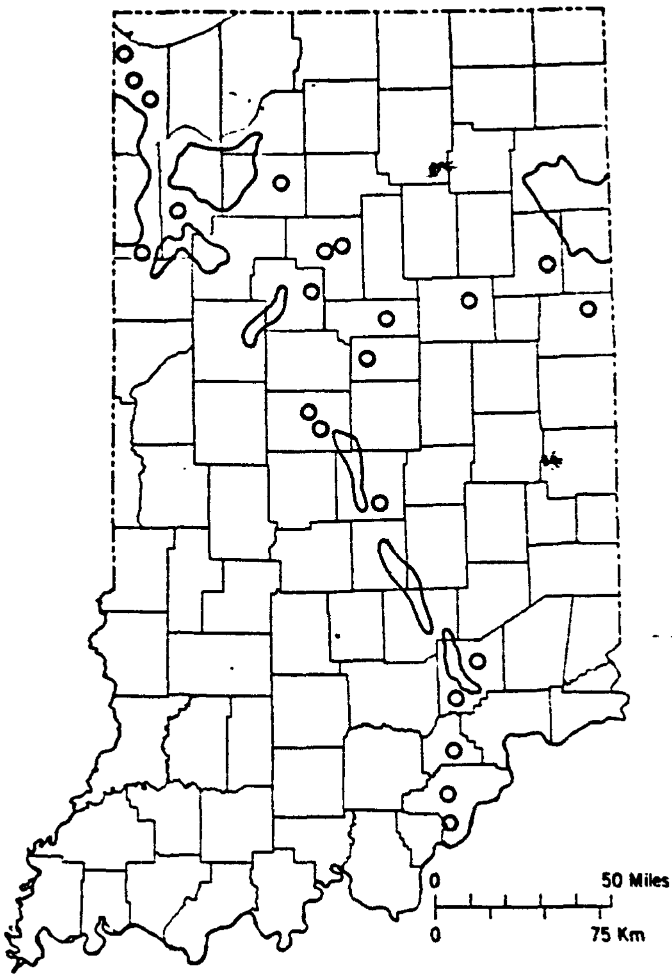
Figure 14 shows areas of low, moderate, and high iron content within the State. For the most part groundwater in Indiana contains more

FIGURE 12

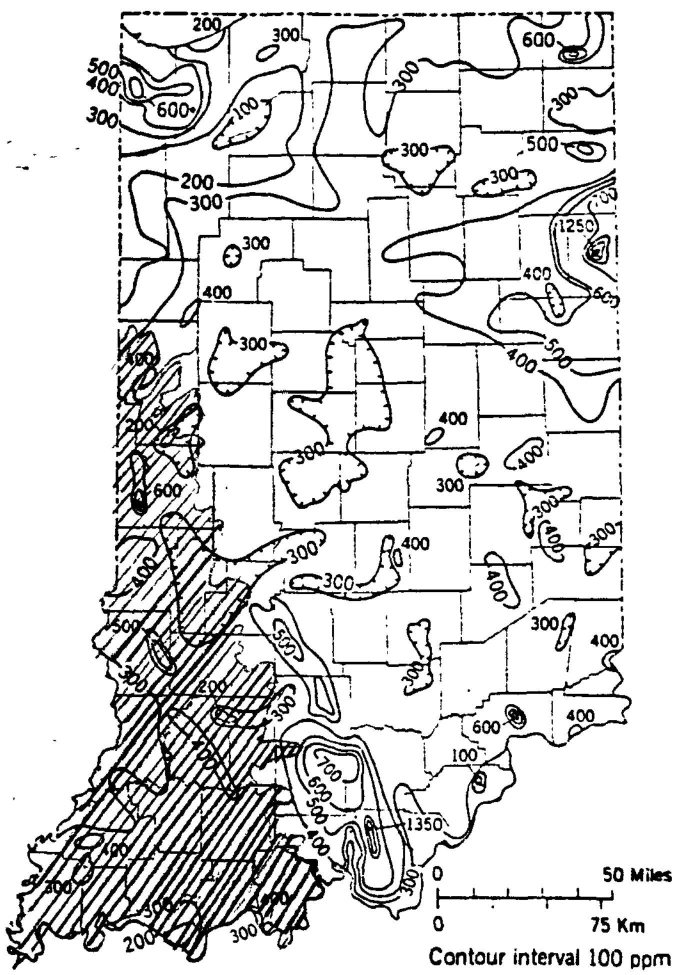


Map of Indiana showing the water quality for a number of municipal water supplies, and the sources of the supplies.

FIGURE 13



Map of Indiana showing the general distribution of hydrogen sulfide in ground water.



EXPLANATION

Outcrop area of Pennsylvanian rocks. In this area hardness levels may vary substantially depending upon depth and aquifer sampled.

Map of Indiana showing the distribution of water hardness of ground water in parts-per-million.

than 0.3 ppm of iron, the minimum concentration needed to stain plumbing fixtures and laundry.

Manganese, often associated with high iron content is a nuisance in concentrations over 0.05 ppm. The areas having the lowest manganese content in Indiana (See Figure 14) are along the Wabash River, the Whitewater River in the southeastern part of the State, and in areas underlaid by Mississippian age limestone aquifers.

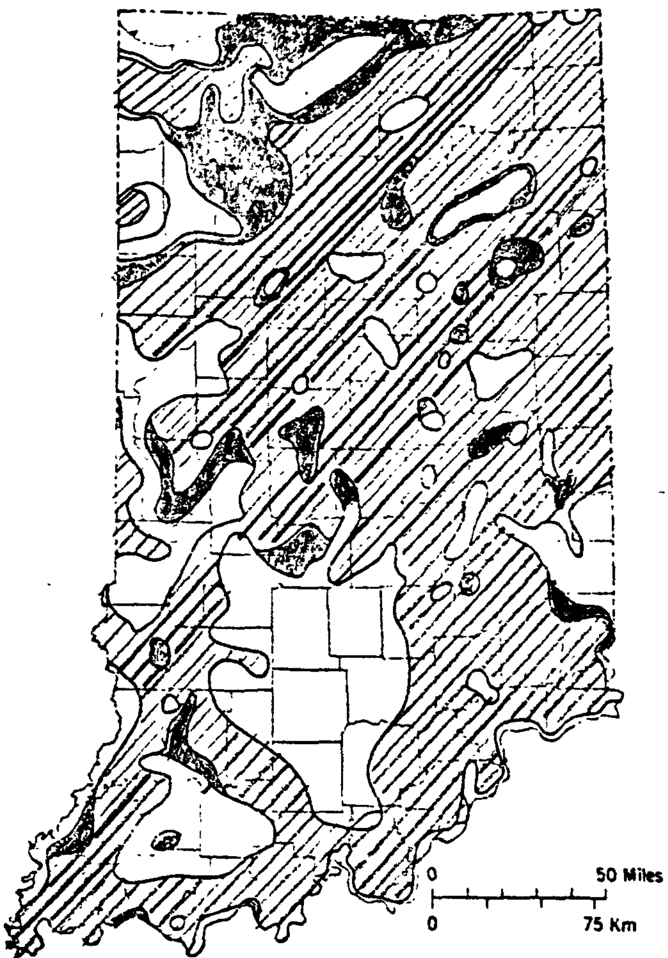
Sulfate levels vary according to the geologic deposits present in an area. In northeastern Indiana, sulfate levels in excess of 600 ppm are present (See Figure 15). Elevated sulfate levels are also found in Harrison, Orange, Vermillion, and Lake Counties. Fluoride concentrations greater than 1 ppm, the recommended level for cavity prevention, are present in much of central and northeastern Indiana and in scattered parts of southwestern, west-central and northwestern Indiana (See Figure 15). Localized high fluoride concentrations in the western sectors of the State are due to geologic factors which have substantially changed the chemistry of groundwater in these areas.

Sizeable areas in northwestern Indiana are underlaid by limestone bedrock containing water with a high level of hydrogen sulfide (See Figure 13). A shale bedrock capstone is present above the limestone in many places, and when the shale occurs at a shallow depth, it virtually eliminates all other alternative water supply possibilities.

VIII POTENTIAL GROUNDWATER CONTAMINATION

An important and historical aspect of the groundwater resource is that it has been relatively free of pollution and therefore requires

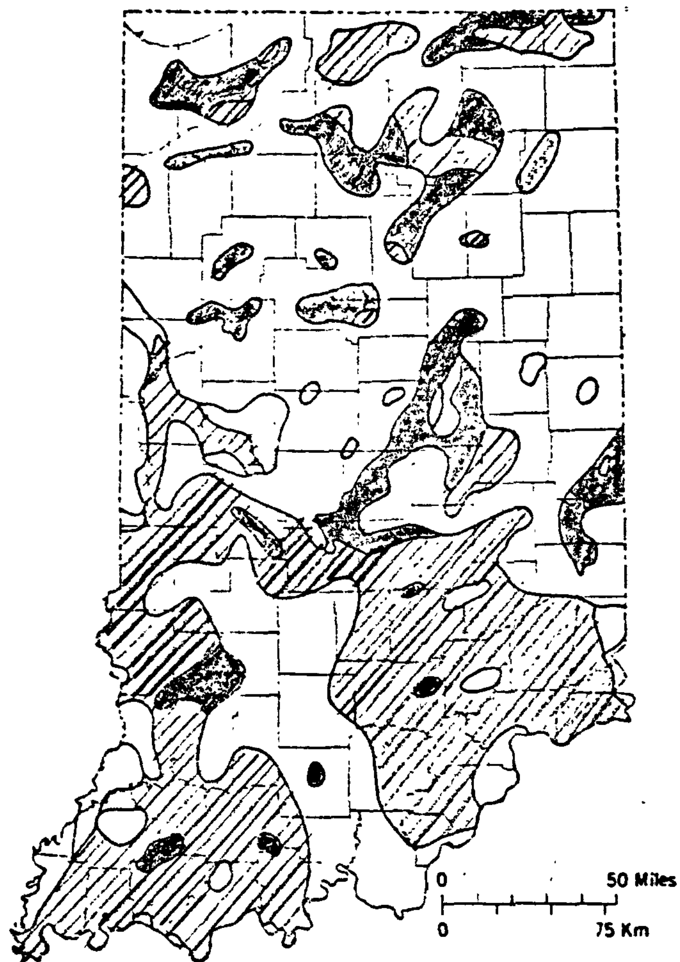
FIGURE 14



CONCENTRATION

0.5 ppm or less	0.5 to 1.0 ppm	1.0 ppm or greater

Map of Indiana showing the general concentration of iron in ground water in parts-per-million.

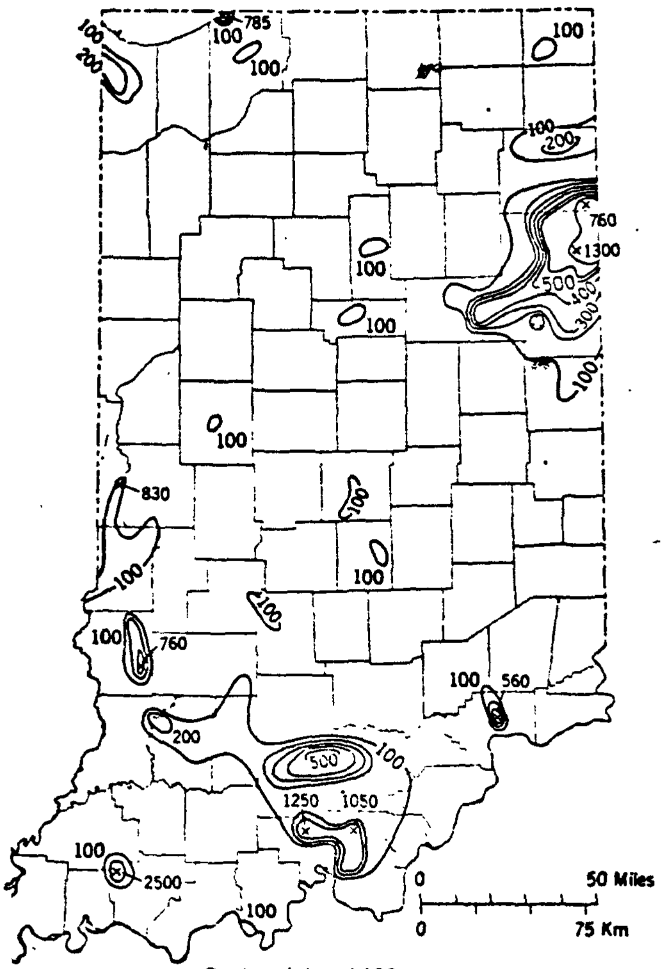


CONCENTRATION

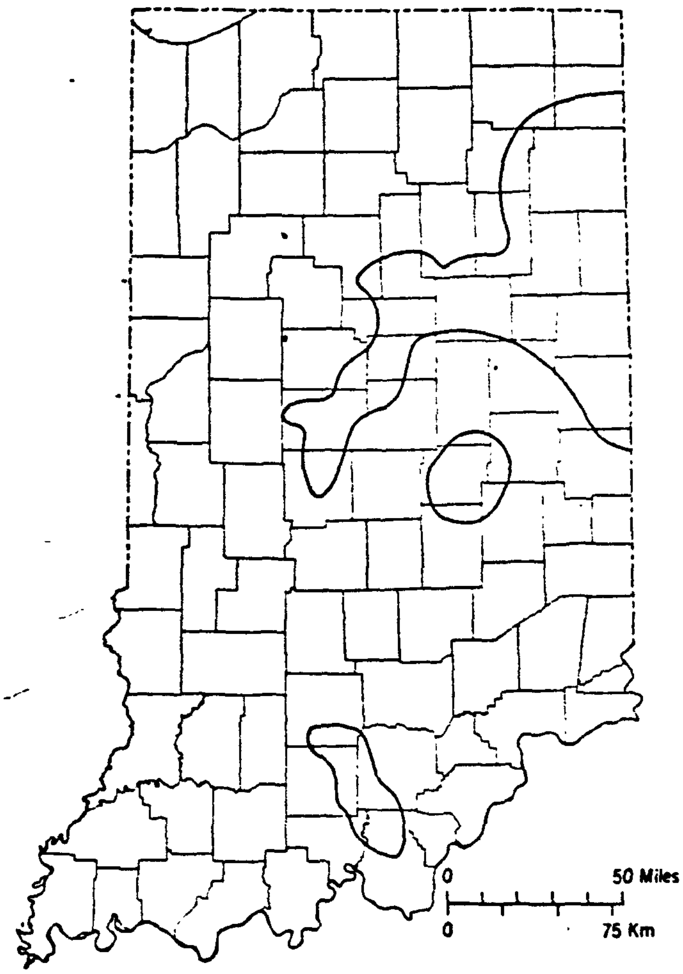
0.05 ppm or less	0.05 to 0.10 ppm	0.10 ppm or greater

Map of Indiana showing the general concentration of manganese in ground water in parts-per-million.

FIGURE 15



Map of Indiana showing the concentration of sulfate in ground water in parts-per-million.



Map of Indiana showing tne general distribution of fluoride in ground water.

very little, if any treatment before use for potable purposes. Groundwaters are purified by several natural characteristics of the soils. The efficiency of the natural ability of the soils to purify, directly relates to the nature of the soils and the pollutants. The soil phenomena affecting purification are physical, biological, and chemical. With respect to the physical, the purification mechanism is a matter of filtration or straining. Soil microorganisms thrive at or near the soil surface. Under both aerobic and anaerobic conditions, microorganisms can change the composition or structure of pollutants providing the pollutant is not of too toxic a character. Purifying chemical processes include oxidation, reduction, sorption, ion exchange, precipitation and dissolution. These processes occur throughout the ground providing appropriate conditions exist. The conditions include the presence or lack of oxygen, moisture, natural clay, dissolved gases, etc.

With the development in recent years of highly sophisticated measuring and analytical techniques, it was discovered that the nations groundwaters are not as contamination-free as historically thought. Highly toxic contaminants, too toxic to be subject to microbiological degradation and not altered by any other natural purification mechanism, are finding their way into heretofor potable groundwater aquifers. The contamination of these groundwater supplies is not solely the work of "Midnight Dumpers" who illegally pour barrels of wastes into ditches and fields. Much of this contamination is a result of the entirely legal disposal of liquid and solid wastes into improperly protected and located pits, ponds and lagoons, quarries, natural land surface depressions, improperly located and constructed underground waste injection wells and other dumps.

Discharging into dumps, waste-burial grounds, and disposal wells is a common method of waste disposal. Serious contamination of the groundwater reservoir near the dumps can readily occur if the bottom of the depressions is below the water table, or if the earth material separating the dump or lagoon from the aquifer is primarily silt, sand, or other relatively permeable material. Those parts of Indiana, or any other State for that matter, directly underlaid by permeable sand and gravel, creviced dolomite or limestone aquifers are especially susceptible to pollution from such sources. In general, impoundments have historically been sited and constructed without apparent regard for the protection of groundwater quality. In fact, until a few short years ago siting and construction were virtually unregulated, by both the Federal and State Governments, from the perspective of groundwater protection.

Studies of leachates from refuse disposal areas have shown that both biological and chemical contaminants are produced. Contaminants are leached from refuse and made available for distribution into nearby aquifers by movement of moisture through the refuse. During this movement the chemical constituents are taken into solution, and biological constituents are translocated by the seeping waters. Their flow in sand and gravel aquifers is through inter-connected pores between the rock particles comprising the water-bearing material.

In shallow limestone or dolomite aquifers, the contaminating constitutents move through interconnected networks of joints, cracks, and fissures characteristic of these bedrock formations.

In a study (Surface Impoundment Assessment) by this Agency, it was reported that thousands of pits, ponds, and lagoons around the country contain chemical wastes that pose serious threats of groundwater contamination. It was concluded that of the more than 180,000 contaminated pools, ranging from cattle ponds to industrial waste lagoons, more than 90 percent of them posed at least a potential threat of groundwater contamination. Furthermore the drinking water supplies for thousands of individual homes, and many entire rural and suburban communities are drawn by wells from groundwater. Most of the pools, according to the Surface Impoundment Assessment (SIA) are in soils that permit the liquid waste contents to drain into the groundwater, that is, the impoundments are located over thin or permeable unsaturated zones which provide limited protection to underlying aquifers. Moreover, seventy (70) percent of the industrial impoundments were determined to be unlined, as were 78 percent of the municipal impoundments, and 84 percent of the agricultural.

Subsurface flow of groundwater is very slow in comparison with that of overland water flow. Under normal hydraulic gradients, groundwater may travel horizontally only a few feet per day through sand and gravel or creviced limestone and dolomite, and only a few feet per year through sandstone and other finer grain deposits such as clay and shale. Depending upon the geology of the aquifer, contamination of the groundwater with certain synthetic toxicants can poison that water source for as much as geologic time. Figure 16 shows pits, ponds, lagoons and hazardous waste dump sites in Indiana. The hazardous waste sites are active sites and were obtained from the Waste Management Division of this Region. The pits, ponds, and lagoons were selected from the SIA. A primary objective of the SIA was to rate the contamination potential of groundwater from surface impoundments. The employed evaluation system applied a numerical rating scheme that yielded a first round approximation of the relative groundwater contamination potential from all the impoundments located. The scheme evaluated the following characteristics: quality and thickness of the unsaturated zone (area between lagoon bottom and top of aquifer), the groundwater availability, groundwater quality, and the waste hazard potential. A summation of the four (4) characteristics above produced the overall groundwater contamination potential. Finally, the distance from the impoundment to a ground or surfacewater source of drinking water and the determination of anticipated flow direction of the waste plume were used to ascertain the potential endangerment to current water supplies presented by the surface impoundment. Because of the desk-top nature of the assessment, the numerical rating (1 - 29) could not be used to assess the actual amount of groundwater contamination at the site. Rather each score was used for relative comparison with other sites only. Actual determination of groundwater contamination would require intensive on-site investigation.

Because of the huge numbers of impoundment sites located in Indiana (as is the case in the remainder of the country), it was arbitrarily decided to limit this study to only those impoundments with numerical ratings of 25 or greater. This means that of approximately 3700 impoundments of all types located by the SIA in Indiana, only the top 37 or one (1) percent of the total were considered in this report and placed in Figure 16 and in Table 1. It is possible that this arbitrary cut-off excluded some sites that are contaminating, or that have the potential to contaminate usable groundwater supplies. Therefore on-site investigations of the upper one (1) percent (sampling and appropriate analysis of public and private water supplies in the area) may point to the need to study other sites with lesser SIA contamination potential.

With respect to the hazardous waste dumps (Table 2), all 49 sites computer-programmed by the Waste Management Division were retrieved and considered in this report.

LAKE COUNTY

Examination of Figure 16 reveals that Lake County contains more by far of the hazardous waste dumps and impoundments considered in this report than any other Indiana County. Moreover all of the report-considered Lake County dumps and impoundments are located north of latitude 41°30', the northern-most 25 percent of the County.

Based upon the computer-retrieved waste and process codes, the hazardous waste dump sites contain, in all probability, practically all chemicals used in the Great Lakes basin. In a broad brush manner these sites contain at least a dozen toxic metals, refinery wastes, steel plant wastes, electroplating wastes, halogenated and unhalogenated paraffin hydrocarbons, acids, aldehydes and ketones, esters, halogenated and unhalogenated aromatic hydrocarbons with both single and fused

TABLE I
UPPER ONE (1) PERCENT OF INDIANA
IMPOUNDMENTS WITH HIGHEST POTENTIAL FOR
GROUNDWATER ENDANGERMENT
(SIA)

LOCATION COUNTY/LATITUDE/LONGITUDE			IMPOUNDMENT TYPE
ORANGE COUNTY			
38°32,05"	-	86°32'10"	
38 35 40	-	86 23 30	Agricultural
38 33 45	-	86 20 30	"
38 38 15	-	86 31 30	"
38 38 15	-	86 24 45	"
38 39 30	-	86 25 05	"
38 35 40		86 22 35	"
38 33 55	-	86 21 20	"
38 34 45	-	86 22 25	"
WABASH COUNTY			
40°40'35"	-	85°51'40"	Agricultural
40 44 25	-	85 51 20	"
40 58 15	-	85 50 55	Industrial
40 52 10	-	85 47 40	Oil and Gas
STEUBEN COUNTY			
41°35'15"	-	85°02'50"	Agricultural
WASHINGTON COUNTY			
38°38,10"	-	86°13,25"	Agricultural
38 28 45	-	86 13 30	"
HARRISON COUNTY			
38°03'10"	-	86°03'50"	Agricultural
KOSCIUSKO COUNTY			
41°21'45"	-	85°48'00"	Agricultural
41 07 50	-	86 04 15	"
41 17 00	-	85 40 45	"
41 22 20	-	85 42 10	"
41 02 50	-	85 42 10	"
41 13 45	-	85 57 15	"
41 14 00	-	85 49 55	Industrial
41 13 45	-	85 51 20	"
41 19 35	-	85 50 55	"
41 14 05	-	85 50 05	"
41 19 35	-	85 42 30	Municipal
HUNTINGTON COUNTY			
40°45'30"	-	85°24'50"	Agricultural
40 59 10	-	85 33 45	"

LOCATION COUNTY/LATITUDE/LONGITUDE			IMPOUNDMENT TYPE
40°55'15"	-	85°21'30"	Agricultural
LAGRANGE COUNTY			
41°41'50"	-	85°34'45"	Agricultural
LAWRENCE COUNTY			
38°43'20"	-	86°18'40"	Agricultural
38 56 50	-	86 23 15	Agricultural
38 52 55	-	86 28 55	Industrial
38 52 25	-	86 25 45	"
38 52 40	-	86 30 05	Mining
38 54 05	-	86 31 50	"
ELKHART COUNTY			
41°41'50"	-	85°59'20"	Industrial
41 40 50	-	85 55 00	"
41 41 35	-	85 59 15	"
41 40 55	-	85 42 00	"
41 37 00	-	85 55 15	"
41 26 45	-	85 59 10	Municipal
41 35 45	-	85 51 10	"
LAKE COUNTY			
41°37'25"	-	87°25'10"	Industrial
41 30 50	-	87 24 50	"
41 35 45	-	87 13 25	"
41 35 25	-	87 31 15	"
41 38 55	-	87 29 35	"
41 36 50	-	87 21 45	"
41 40 15	-	87 25 50	"
41 37 35	-	87 22 15	"
41 36 25	-	87 20 30	"
41 39 55	-	87 26 00	"
41 39 15	-	87 28 30	"
41 36 40	-	87 23 25	"
41 40 45	-	87 27 45	"
41 38 00	-	87 25 45	"
41 36 25	-	87 19 15	"
41 40 20	-	87 26 40	"
41 30 05	-	87 28 10	"
41 37 20	-	87 23 30	"
41 41 35	-	87 30 45	"
41 38 10	-	87 24 00	"
41 39 00	-	87 27 45	"
41 37 05	-	87 29 35	Municipal
41 37 05	-	87 28 40	"

LOCATION COUNTY/LATITUDE/LONGITUDE			IMPOUNDMENT TYPE
MARION COUNTY			
39°44'05"	-	86°12'25"	Industrial
39 44'05"	-	86 13 20	"
39 48 20	-	86 19 55	"
39 55 05	-	86 15 08	"
39 45 15	-	86 17 55	"
39 48 30	-	86 02 20	"
39 48 45	-	86 19 15	"
MARSHALL COUNTY			
41°26'50"	-	86°09'35"	Industrial
41 27 05	-	86 09 45	"
41 26 55	-	86 09 55	"
PORTER COUNTY			
41°36'45"	-	87°08'50"	Industrial
41 36 35	-	87 07 40	"
41 37 55	-	87 04 35	"
41 26 55	-	87 00 40	"
41 23 30	-	87 01 30	Municipal
WARRICK COUNTY			
37°55'40"	-	87°20'40"	Industrial
HENRY COUNTY			
39°56'00"	-	85°23'15"	Industrial
CLARK COUNTY			
38°21'55"	-	85°38'14"	Industrial
CARROL COUNTY			
40°01'45"	-	86°16'30"	Industrial
39 56 25	-	86 15 25	"
SHELBY COUNTY			
39°41'05"	-	85°43'50"	Industrial
POSEY COUNTY			
37°54'15"	-	87°55'35"	Industrial

TABLE I (Cont.)

LOCATION COUNTY/LATITUDE/LONGITUDE	IMPOUNDMENT TYPE
TIPPECANOE COUNTY	
40°27'10" - 86°52'50"	Industrial
VERMILLION COUNTY	
39°54'40" - 87°24'50"	Industrial
39 54 45 - 87 31 15	Mining
FLOYD COUNTY	
38°17'35" - 85°47'50"	Industrial
HANCOCK COUNTY	
39°45'30" - 85°47'50"	Industrial
HOWARD COUNTY	
40°28'25" - 86°09'15"	Industrial
40 27 20 - 86 06 40	"
JOHNSON COUNTY	
39°22'55" - 85°59'30"	Industrial
MONROE COUNTY	
39°22'55" - 85°59'30"	Municipal
VANDERBURGH COUNTY	
37°54'30" - 87°38'40"	Oil and Gas
SPENCER COUNTY	
	Oil and Gas
37°55'20" - 87°04'20"	
37 55 20 - 87 04 20	"
37 54 45 - 87 06 05	"
37 55 50 - 87 14 25	"
37 55 50 - 87 14 40	"
37 55 05 - 87 03 10	"
37 58 30 - 87 10 45	"
37 55 05 - 87 03 10	"
37 58 50 - 87 08 15	"
GREENE COUNTY	
39°06'25" - 86°59'00"	Oil and Gas
39 05 45 - 87 00 30	"

TABLE 2

HAZARDOUS WASTE DUMPSITES IN INDIANA

OWNER	LOCATION
Central Indiana Disposal Inc.	Ashboro
General Electric	Shelbyville
Indiana Waste Systems Inc.	Wheeler
Logansport Municipal Utilities	Logansport
Superior Sanitation Inc.	Marion
Indiana Statewide Rec. Inc.	Sullivan
Randolph County Landfill	Farmland
Bergsoe Boliden Inc.	Municie
Northern Indiana Public Service Co.	Hammond
Willcutt Landfill	Medora
Wabash Valley Reclamation Center Inc.	Wabash
Four County Landfill	Fulton
ITT-United Plastics Division	Medora
GMC Delco Remy	Muncie
National Distillers and Chemical Corp.	Indianapolis
Arvin Industries	North Vernon
Indiana and Michigan Electric Co.	Lawrenceburg
Stauffer Chemical Co.	Hammond
Wells Aluminum Corp.	North Liberty
Steel Warehouse Co.	South Bend
U.S. Steel Corporation	Gary
Federated Metals Inc.	Hammond
Vulcan Materials Co.	Gary
Mason Metals Co. Inc.	Schereville
Dana Corporation	Auburn
Dana Corporation	Angola
Corning Glass Works	Bluffton
Eli Lilly and Co.	LaFayetteon
Jones Chemical Inc.	Beach Grove
Alcoa	Newburgh
Rock Island Refining Corp.	Portage City
Interroval Corp.	Michigan City
National Steel Corp.	Portage City
Indiana and Michigan Electric Co.	Fairbanks
Conservation Chemical Co.	Gary
GK Technologies Inc.	Muncie
Howmet Turbine Components Corp.	LaPorte
Indiana Farm Bureau Corp.	Mt. Vernon
FMC Corp. (Bearing Div.)	Indianapolis
FMC Corp. (Chain Div.)	Indianapolis
Cabot Corp.	Kokomo
Northside Sanitary Landfill	Zionsville
Amland Corp.	South Bend
Gulf and Western MFG. Co.	Greensburg
Nucor Coporation	St. Joe
Bethlehem Steel Corp.	Burns Harbor
Allegheny Ludlum Steel Corp.	New Castle
Kerr-McGee Chemical Corp.	Indianapolis
General American Transportation Corp.	East Chicago

TABLE 2 (Cont.)

OWNER	LOCATION
Gary Development Corp.	Gary
Adams Sanitary Landfill	Fort Wayne
Ingram-Richardson Co.	Frankfort
Northern Indiana Public Service Co.	Wheatfield
Indiana and Michigan Electric Co.	Rockport
Ingersoll Johnson Steel	New Castle
PT Components Inc. (Link Belt Bearing Div.)	Indianapolis
PT Components Inc. (Chain Div.)	Indianapolis
Colgate-Palmolive Co.	Jeffersonville
Montgomery-Crawfordsville Landfill	Crawfordsville
Continental Steel Corp.	Kokomo
GMC (Delco-Remy)	Anderson
Gulf Oil Corp.	Milton
Fisher-Calo Chemical and Solvents	Indianapolis
Waland Disposal Co.	Shoals
ILWD Inc.	Roachdale
Newport Army Ammuition Plant	Newport
U.S. Army Soldier Support Center	Fort Benjamin Harrison
U.S. Navy Weapons Support Center	Crane
U.S. Army Ammunition Plant	Charlestown

nuclei, spent pickle liquors, herbicides, insecticides, and solvents of all kinds. In general, the hazardous waste dump sites in Northern Lake County contain most everything used in the Great Lakes Basin that is toxic, ignitable, and corrosive.

With respect to the industrial waste lagoons or impoundments, the SIA concludes that, on a national average, nearly 50 percent of the impoundments are located over thin or permeable unsaturated zones which provide very limited protection to underlying aquifers. Moreover 70 to 80 percent of both the industrial and municipal impoundments are unlined allowing for facile seepage of leachate to and through these thin and permeable unsaturated zones. Furthermore the SIA concludes that 35 percent of the industrial impoundments contain wastes which most likely are hazardous based upon the characteristics of the industry involved (Standard Industrial Codes).

As previously discussed, the unconsolidated deposits located in Lake County were formed by glacial action, wind, and shoreline processes. The thickness of these materials varies from less than 50 to over 300 feet; and the types of deposits present include lake clays, glacial till, dune sand, and outwash sand and gravel. Sand and gravel deposits serve as important aquifers in much of the area, particularly south of the Valparaiso Moraine (41°40'). Fine sand and lake clays, which predominate in areas near Lake Michigan, do not constitute a major ground water source. The underlying bedrock in Lake County is composed of Silurian and Devonian limestone and dolomite and represents an important source of groundwater especially in the southern and western portions of the county, away from Lake Michigan.

The availability of groundwater is associated with the nature and type of aquifer materials present in a given area. In Lake County there is pronounced variability in groundwater occurrence from north to south (See Figure 9). In areas near Lake Michigan, well yields are generally less than 100 GPM, and may be even lower in some localities. Shallow fine sand is the primary aquifer source in these areas and does not yield water readily. Beneath the sand are found either fine grained lake clays or glacial till deposits which do not yield water. It is in these low yield areas (near Lake Michigan) that all of the report-considered hazardous waste dumps and SIA impoundments in Lake County are located. This is a mixed blessing. The low yield groundwater aquifers, coupled with the easy accessibility of excellent quality surface waters, precludes this area from being none other than one primarily serviced by public water supplies using surface water sources. In other words, approximately 90 - 95 percent or more of the population is served from surface supplies and is not subject to groundwater sources that have an especially high potential for contamination from the many dumps and impoundments in the area. However, the low groundwater availability in the area would most likely make any potential contamination more severe because of the lesser dilution available in the pertinent aquifers. As a result, the remaining five (5) to 10 percent of the population in the area served by private wells would be subject to a greater hazard from any potential contamination adulterating the aquifer. It is imperative that a random number of private wells in Northern Lake County be sampled and comprehensively characterized. A sampling and analysis of all the private wells in the area should follow, if warranted.

Not to be lost in the discussion is the extreme likelihood that leachate from the hazardous waste dumps and SIA impoundments migrating northward, under natural drainage conditions, is contributing to the pollution of both the Little and Grand Calumet River systems and to the southern Lake Michigan nearshore.

MARION COUNTY

Examination of Figure 16 reveals that Marion County is second with respect to the number of hazardous waste dumps and SIA impoundments considered in this report. All dumps and impoundments are clustered in the center of the county with the exception of a few industrial waste lagoons that are located to the north and northeast. Metropolitan Indianapolis occupies most of Marion County .

Based upon the computer-retrieved waste and process codes, the hazardous waste dump sites contain cadmium, chromium, lead, arsenic, cyanide, volatile organic solvents such as toluene and tri and perchlorethane, herbicides, paint residues, and refinery wastes. Generally speaking, the dumpsites contain wastes that are toxic, ignitable, and corrosive, although not to the comprehensive extent characterizing those in Lake County.

With respect to the industrial waste impoundments, the conditions generalized by the SIA, and described previously under Lake County, also apply in Marion County.

All of Marion County was covered by the Wisconsinan continental glaciers that advanced through Indiana some 20,000 years ago. The deposits left by the glaciers consist predominantly of glacial till, ice contact sand and gravel, silt, lake clays, outwash sand and gravel and alluvial materials. Of particular importance are the permeable sand and gravel deposits found in the valleys of the West Fork of the White River, Fall Creek and Eagle Creek. Also contained within the glacial drift are numerous thin, intertill sand and gravel zones.

Beneath the glacial and alluvial materials to the west are sedimentary rock formations of siltstone, shale, and lenses of limestone. A black carbonaceous shale underlies western Indianapolis. Further east, the Region is underlaid by limestone, dolomite, and thin, interbedded shale and limestone.

The availability of groundwater can be determined from Figure 9. Major groundwater sources occur in the West Fork of the White River Valley sand and gravel aquifer system and the underlying limestone and dolomite bedrock aquifers. Well yields from 250 to 1500 GPM are obtained from these aquifer systems. A 1975 study by the US Geological Survey estimated that, depending on hydraulic characteristics, the sand and gravel aquifers in Marion County are capable of producing 59 to 103 MGD from a system of wells. The Marion County aquifers are easily recharged because of the porosity or permeability of the unsaturated zones and because of the adequate precipitation in the area. The permeability of the unsaturated zone allows for the quick migration through that zone of any contaminants leached from poorly placed and/or unlined hazardous waste dumps or impoundments. Fortunately most of Marion County is serviced by the Indianapolis Water Company which supplies water to approximately 85 to 90 percent of the population. While a preponderance of the water distributed by the Indianapolis Water Company is obtained from surface supplies (reservoirs), approximately four (4) percent of the total daily pumpage is obtained from groundwater supplies located in the northeastern part of the county. In addition the remaining 10 to 15 percent of the Marion County population not serviced by the Indianapolis Water Company, obtains water from approximately 15000 private wells or the public wells of the Speedway and Lawrence Water Companies. Because of the large number of hazardous waste dumps and industrial waste impoundments in Marion County, the extreme permeability of the unsaturated zone in the area, and the likely mismanagement of both dumps and impoundments (uncontrolled) relative to the needs of groundwater protection, it would be appropriate that a random number of private wells located in the periphery of Marion County, in addition to the groundwater sources augmenting the Indianapolis Water Company surface water supply, and those of Speedway and Lawrence Water Companies, be sampled and analyzed for contamination representative of the pertinent, suspected leachate materials. A sampling of all private wells in Marion County should follow if warranted.

In addition to the potential for groundwater contamination, the hazardous waste dumps and industrial impoundments located in Marion County, are likely contributing to pollution of the West Fork of the White River and to its tributaries Eagle Creek and Fall Creek.

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In addition to the potential for groundwater contamination, the hazardous waste dumps and industrial impoundments located in Marion County, are likely contributing to pollution of the West Fork of the White River and to its tributaries Eagle Creek and Fall Creek.

PORTER COUNTY

Examination of Figure 16 reveals that eighty (80) percent of the considered Porter County hazardous waste dumps and SIA impoundments are located in the northernmost twenty-five (25) percent of the county. All of the dump sites contain materials that are either ignitable, corrosive, or reactive. Organic compounds include coking operations wastes (coal tar residues), highly volatile low molecular weight chlorinated and unchlorinated aliphatic hydrocarbons, benzene derivatives such as phenol and pyridene, and petroleum refinery wastes. In addition the dumps contain pickle liquors, electroplating wastes including cyanides, chromium, and silver, and materials such as arsenic, barium, lead, mercury, and selenium. The impoundments are owned by steel, carbide, and glass industries, and according to SIC process information, most likely contain materials similar to the dump sites.

The geologic conditions described under Lake County are also applicable to Porter County. The thickness of the unconsolidated deposits varies from less than 50 to 300 feet and includes types such as lake clays, glacial till, dune sand, and outwash sand and gravel. The fine sand and lake clays, which predominate in areas near Lake Michigan, do not constitute a major groundwater source. The underlying bedrock of Silurian and Devonian limestone and dolomite represents an important source of groundwater, especially in the southern part of the county.

There is a pronounced variability in groundwater occurrence and availability from north to south (See Figure 9), with well yields ranging from less than 100 GPM near Lake Michigan to 600 GPM and more further to the south and east, and especially in the Valpariso area and in the valley of the Cobb tributary to the Kankakee River.

As in Lake County, shallow, fine sand is the primary aquifer source in the areas close to Lake Michigan. As previously mentioned, this type of aquifer does not yield groundwater readily. As a result, the towns of Portage, Ogden Dunes, and Burns Harbor, all lakeshore communities, are supplied Lake Michigan Water by the Gary-Hobart Water Company which is located in Lake County. However, the rest of the Porter County lake shore areas, and the second and third "row" of towns south of the lake shore, are served by public or private wells drilled through highly permeable unsaturated zones to high producing aquifers composed of outwash sand and gravel deposits. It appears that the groundwater sources serving the latter communities may be subject to a high potential for contamination from dumps and impoundments in the area.

The likely high contamination potential areas include Beverly Shores, Porter, and Chesterton. Furthermore, the dumps and impoundments in the area may be contaminating the Little Calumet River and the southern Lake Michigan nearshore.

ST. JOSEPH, ELKHART, KOSCIUSKO COUNTIES

Of particular importance in these three counties are the glacially derived, unconsolidated deposits which contain major sources of groundwater. These deposits consist of glacial till, inter-till sand and gravel, lake clays, dune sand, and ice-contact stratified drift.

These materials range in thickness from about 100 feet to 500 feet. Significant outwash-plain and valley-train sand and gravel deposits are located adjacent to the Valparaiso Moraine and along the Kankakee, Elkhart, St. Joseph, and Tippecanoe Rivers. Complex inter-till sand and gravel aquifer systems are present in the moraines that are located in Kosciusko and Elkhart Counties. The underlying Mississippian, Devonian, and Silurian bedrock formations which are generally composed of siltstone, shale, black shale, dolomite, and limestone, and dolomite and limestone respectively, are not considered important groundwater sources. Figure 9 indicates the maximum potential yield of the aquifers in these three counties. These yields range from 400 to 2000 GPM to properly constructed, large diameter wells. In the Kankakee aquifer in western St. Joseph County, and further east, in the extensive outwash sand and gravel aquifers in St. Joseph, Elkhart, and Kosciusko Counties, recharge rates of 500,000 GPM per square mile are applicable and describe the large available storage and the highly permeable nature of the aquifers.

The largest single utility operating in the three (3) county area is the South Bend Public Utility which withdraws approximately 28 MGD. Other large utilities are located in Mishiwaka and Elkhart, all of which pump more than five (5) MGD, and in Goshen and Warsaw which pump more than two (2) MGD. Forty percent of the Warsaw pumpage is derived from surface supplies. The three county area is serviced by another 25 smaller utilities, all deriving their supplies from groundwater and approximately another 35,000 private wells.

It is in this setting (high yield, high permeability aquifers) that over two dozen impoundments (all with an extremely high SIA potential for groundwater endangerment) and RCRA hazardous waste dumps are located (See Figure 16). The hazardous waste dumps are in the South Bend area and contain acids, organic solvents, detergents, copper, chromium, cadmium, nickel, aluminum, cyanide, paint residues, acetylaminofluorene, dichloromethane, and toluene. According to SIC information, the Elkhart impoundments most likely contain pharmaceutical wastes, chemicals and chemical preparations wastes, coating and engraving wastes, meat products, and plating wastes. In Kosciusko County, the impoundments contain paving and roofing materials, organic and inorganic acids, aluminum, cadmium, zinc, cyanide, chromium, and oils and greases. Comparable wastes are found in the St. Joseph County impoundments. Since it is highly unlikely that the impoundments and dumpsites have been properly operated and constructed, it appears likely that the potential for groundwater contamination is high in the three (3) county area especially in the areas pinpointed in figure 16. These areas include northern St. Joseph, northwestern Elkhart, and central Kosciusko Counties.

SPENCER COUNTY

Examination of Figure 16 reveals a cluster of oil and gas waste impoundments in southcentral Spencer County. Indiana has been producing oil, especially in the southwestern part of the State, since 1889. Although not a large producer compared to other oil producing States, Indiana has produced as much as 13 million barrels in one year (1953). Total State oil production in 1981 was approximately 4.8 million barrels. Spencer County in 1981 produced 150,000 barrels.

It is estimated that for every barrel of oil produced, as many as 40 barrels of salt brine must be disposed of. Under New Department of Natural Resource (Oil and Gas Division) rules and regulations, salt brine must be "deep welled" except under certain circumstances, and then only and for short periods of time. During these short-term periods, impoundments could be used. However, in earlier unregulated days evaporation pits were the vogue, since they were cheap to built and cost nothing to operate. However, they were almost completely inefficient because of the southern Indiana climate (relatively high rainfall and moderately wet soil).

Literally hundreds of these salt brine impoundments, of every size and volume, dot the southern Indiana landscape. These impoundments were built with absolutely no thought to groundwater protection. Moreover, the effluents from those impoundments with overflow mechanisms have destroyed many acres of vegetation in the oil and gas mining areas.

Groundwater availability in Spencer County is considered poor except for the sand and gravel deposits along the Ohio River (the southern border of Spencer County), and in the sand and gravel deposits contained in the old Ohio River channel in southwestern Spencer County (See Figure 9). These deposits can yield up to 1000 GPM to properly constructed wells in the former areas, and up to 600 GPM in the latter.

Spencer County bedrock is usually shallow in depth with layers of thin, weathered and broken rock overlying it. The bedrock consists of shales, sandstones and limestone which yield limited amounts of water. Wells in these bedrock deposits normally yield less than ten (10) GPM.

Spencer County is serviced by nine (9) public water supplies withdrawing approximately one (1) million gallons per day from both surface and underground sources. About 55 percent of the supply comes from underground sources. In addition, approximately 2000 private wells are the source of drinking water for another 8000 or more people in the county.

The cluster of oil and gas impoundments identified in Figure 16, unfortunately lies above aquifers of large groundwater availability. These impoundments are located in areas of highly permeable sand and gravel deposits. While more recent impoundments may have been constructed with impervious clay liners, it is more than likely that the earlier evaporation pits were merely large excavations in the ground with no attempt at bottom or side sealing. Based upon the fact that area mining companies replaced many a private drinking water well, it is fairly obvious that the brine waste waters found and are finding their way to freshwater aquifers.

Based upon the above discussion, it is recommended that a random number of private wells and all the public wells in the villages of Grandview, Rockport, and Chrisney and environs be sampled and analyzed for sodium and chloride ions and compared to natural background conditions. While a brine adulterated aquifer may become unpalatable in a short period of time, the adulteration may also be slow and insidious depending upon soil permeability, and not affect the water palatability for longer periods of time. Water consumed during these latter periods would be deterimental to a significant portion of the population, including persons suffering from hypertension, edema associated with congestive heart failure, and women with toxemias of pregnancy. The sodium intake from sources other than water recommmended for very restricted diets is 500 mg per day. Diets for these individuals permit 20 mg per liter sodium in drinking water and water used in cooking. If the public or private water supply has a sodium content exceeding this limit, persons on a very restricted sodium diet must find another source of supply.

A sodium and chloride ions definition of the groundwater aquifers in the Grandview, Chrisney, and Rockport areas would not only serve the public health interests of those on restricted sodium diets, but also give some indication to other consumers and purveyors of any imminent water unpalatability condition.

ORANGE COUNTY

Examination of Figure 16 reveals a cluster of agricultural ponds located in northeastern Orange County. These impoundments are long-term oxidation ponds for poultry and livestock (hogs, cattle) wastes with a fairly low waste hazard potential. However, their locations - short distances up-gradient from known drinking water wells and high permeability low contamination attenuation potential aquifers - have earned for these impoundments a high SIA rating for potential endangerment to water supplies. The main concern is contamination of the groundwater with nitrite and nitrate, although depending upon the geology, phosphorus, bacteria, and virus contamination is also possible. The nitrogen concern is associated with methemoglobinemia in infants and ruminants. In addition, there is evidence that high nitrate waters cause chemical diarrhea in humans, and a number of maladies in livestock, including thyroid problems, rickets, enteritis, arthritis, and general poor health. Moreover, it is theorized - and presently being researched - that nitrate and particularly nitrite might react in the human stomach with secondary amines (from cooked food) to form nitrosamines, some of which are highly carcinogenic.

Bacteria and viruses vary greatly in size and shape. This variance obviously affects their mobility in the sense of their physical filterability. In highly fractured limestone geology, it is conceivable that many microorganisms could travel great distances provided they were in an environment conducive to their survival.

Groundwater availability in Orange County is considered fair, although the largest resource is located in the northeastern part of the County. Well yields of up to 100 GPM are possible from the limestone, shale, and sandstone bedrock underlying this area. Orange County has never been glaciated and the clay soils developed from weathered limestone remain thin from erosion, being only five (5) to ten (10) feet thick.

Orange County is located in a region of typical sinkhole topography. As a result there are relatively few perennial drainage courses in this area. Run-off is rapid during periods of rainfall and escapes through sinkholes or percolates through the clay soil into the groundwater which is generally found immediately below the soils in limestone joints and solution features.

While the Confined Feeding Control Law of Indiana (1971) requires spray irrigation of impoundment contents onto farmlands with certain restrictions, the lack of adequate State regulatory resources precludes appropriate enforcement of this requirement. It is most likely confined feed lot operators do not adequately irrigate, allowing overflow of impoundments especially during periods of precipitation. As mentioned above, the run-off finds its way to neighboring sinkholes thus contaminating ground water in a karst area especially sensitive to groundwater contamination.

There are four (4) public water supply systems in Orange County serving approximately 8000 people. The 1980 population of the County numbered approximately 18,000, indicating that about 10,000 people are serviced by private wells. Of the four public water supply systems, two (2) of them use groundwater as a source of supply and one (1) of the latter, servicing the city of Orleans and environs, is located in the northeastern part of the County. Because of the extreme sensitivity of this area to groundwater contamination, it is appropriate that a random number of private wells in the northeastern part of Orange County, and the public wells of the city of Orleans be sampled and analyzed for nitrates, nitrites, and bacteria.'

VIGO COUNTY

Examination of Figure 16 reveals a variety of impoundment types, including those for industrial, municipal, mining, and oil and gas operations. While many SIA high potential groundwater endangerment lagoons are present in the county, the high density clusters of similar type of lagoons found in other suspect counties are not present in

Vigo County. Suprisingly not a single RCRA hazardous waste dumpsite is located in Vigo County, at least such a dumpsite is not logged in the Federal-State computer.

Two of the considered industrial impoundments are used to stabilize previously biologically treated pharmaceutical wastes, primarily to decrease the ammonia concentration through oxidation to nitrogen oxides. While the impoundments have discharge permits (NPDES) since they discharge to surface waters, and are regulated with respect to chemical oxygen demand (COD), ammonia, and suspended solids, the impoundment bottoms are either unlined or defective. According to the SIA, the asphaltic liner of one of the above lagoons was severly cracked most likely due to improper installation and/or maintenance.

While the exact composition of the pharmaceutical wastes entering the biological treatment plant is unknown except to company personnel, most likely these wastes include some of the following categories of both organic and inorganic compounds and their biological degradation products: anesthetics, narcotics, hypnotics, analgesics, antiseptics, protozoacides, vitamins, and hormones and other miscellaneous drugs. Moreover since many of the raw materials used in drug manufacture are derived from the by-products of coal distillation, the aromatic derivatives obtained therefrom can also be expected to be part of the pharmaceutical waste composition. Other considered Vigo County impoundments contain wastes from nitrogen fertilizer production, aluminum smelting, oil and gas production, mining operations, and municipal sewage treatment plant operations.

Incorporated within the unconsolidated deposits in Vigo County are glacial till, outwash sand and gravel, dune sand, and large clays. The thickness of the glacial drift ranges from 100 to 200 feet. The most important water bearing formations are the outwash sand and gravel aquifers associated with the Wabash River Valley and its tributaries. Properly constructed wells in the Wabash Valley sand and gravel aquifers are capable of yields exceeding 2000 GPM (See Figure 9). In most of the County, to the northwest and southeast, groundwater availability is quite limited. Most wells in these low availability areas are located in Pennsylvanian bedrock and yield less than 50 GPM, with 10 GPM being the highest expected yield in many areas.

Vigo County is serviced by seven (7) public water supply systems. All systems withdraw their supplies from groundwater sources. In addition, the largest, Terre Haute, augments its seven (7) MGD groundwater supply with two (2) MGD from the Wabash River. The (1980) population of Vigo County was approximately 113,000. The service population of the seven (7) public water supply systems is approximately 72,000, indicating that about 40,000 people in the County get their water from private wells. Most of the private wells are located in the southern part of the County.

Half of the considered impoundments are located above aquifers of large groundwater availability. These impoundments are sited in areas of highly permeable sand and gravel deposits. Since most of the lagoons are unlined, and since there may be construction/operational problems with those that are lined, and because of the location of the lagoons in highly permeable and productive areas, the water supplies serving Terre Haute and the northern half of the County should be sampled and analyzed primarily for nitrates, nitrites, and total organic carbon (TOC). If the TOC is unreasonably high, more definitive organic characterizations should be made. A random number of private wells in the southern part of the County should be analyzed for chlorides and metals.

OTHER SITES

The preceding discussion dwelled on Counties in Indiana that would have the most likely potential for groundwater endangerment based upon the number of closely proximate SIA impoundments and RCRA dumpsites present, the likely hazard of the expected wastes involved using Standard Industry Code information, and the geology of the underlying areas.

Examination of Figure 16 shows little proximity and lesser numbers of the report considered RCRA dumpsites and SIA impoundments in the remaining Indiana Counties. It is possible that groundwater contamination and/or endangerment could occur, or is present, at any of the latter sites, especially those generally located in the northern half of the State or in the valleys of the major rivers and their tributaries (See Figure 9). The geology in these areas (greater unsaturated zone permeability) allows for more facile seepage of any contaminated liquid to underlying aquifers. Since the impoundment and dumpsite density is relatively low, expenditure of investigative resources in the above areas could better await study resolution in the previously comprehensively described areas.

SUPERFUND SITES

In addition, thirteen (13) inactive (non-RCRA) "Superfund" sites (See Table 3) not shown in Figure 16, and located in Seymour, Columbia City, Lebanon, Kingsbury, Gary (3) Bloomington (2), Indianapolis, Fort Wayne (New Haven), Zionsville, and Elkhart have the potential for groundwater contamination. In fact, the monitoring wells of several of the Superfund sites have been tested positive for both organic and inorganic contaminants. Moreover five (5) of fifteen (15) wells located in the Main Street well field, which produces approximately 70 percent of Elkharts' potable water supply, have been found positive for trichlorethene.

The Superfund dumpsites in Gary, Elkhart, and Indianapolis are located in areas geologically described earlier and are proximate to other SIA impoundments and RCRA dumpsites. As such, the presence of the Superfund dumpsites enhances the significance of the observations made for these areas.

The Zionsville Superfund site is located over the Eagle Creek Valley aquifer, in an area of thick, unconsolidated glacial deposits, with a very permeable unsaturated zone and excellent groundwater availability. The Zionsville public water supply has its source in this aquifer.

On-site monitoring wells have tested positive for the volatile organic chemicals 1,1-Dichloroethane, Trichloroethene, and 1,1,1-Trichloroethane.

TABLE 3

SUPERFUND SITES*

1	Lebanon (Boone County)	-	Wedzeb Enterprizes Inc.
2	Zionsville (Boone County)	-	Envirochem Corp.
3	Columbia City (Whitley County)	-	Wayne Waste Oil
4	Seymour (Jackson County)	-	Seymour Recycling Corp.
5	New Haven (Allen County)	-	Parrot Road Dump
6	Bloomington (Monroe County)	-	Lemon Lane Landfill
7	Bloomington (Monroe County)	-	Neals Landfill
8	Kingsbury (LaPorte County)	-	Fisher-Calo Inc.
9	Gary (Lake County)	-	Ninth Ave. Dump
10	Gary (Lake County)	-	Midco 1
11	Gary (Lake County)	-	M&M Landfill (Lake Sandy Jo)
12	Indianapolis (Marion County)	-	Bragg Dump
13	Elkhart (Elkhart County)	-	Main Street Well Field

* List order has no significance

It is likely that this site is contaminating nearby Finley Creek which is a tributary to Eagle Creek. Eagle Creek leads to the Eagle Creek reservoir which is a major source of drinking water for Marion County (Indianapolis).

The Kingsbury Superfund site is located over the Kankakee River Valley aquifer with a geology very similar to the Zionsville site. The Kingsbury public water supply is located in a tributary aquifer of the Kankakee River Valley.

On-site monitoring wells have tested positive for 1,1-Dichloroethene, trichloroehene, and tetrachloroethene. Like other Superfund sites, this site is inactive (not presently being used for waste disposal). However, monitoring well analysis has shown increases of up to 30 percent in the volatile organic chemicals mentioned above in a period of about one-half year.

The (2) Bloomington Superfund sites are located in Monroe County which is nearly devoid of glacial deposits. The lack of glacial deposits has made this area one of poor groundwater resources. As a result the city of Bloomington must resort to Monroe Lake - a State owned reservoir developed by daming Salt Creek - as a source for its public water supply. Fortunately most of Monroe County is serviced by the Bloomington Water Utility or other utilities which purchase water from Bloomington.

Both Bloomington sites were used to dump electric capacitors and arrestors that are filled with polychlorinated bi-phenyls (PCB).

Available data show high concentrations of PCB in both dump site soils. In addition, PCBs were found in water samples from springs near the sites. Since this area is a karst (sinkhole) area (see page 34), the possibility of PCB contamination is fairly high.

The Fort Wayne (New Haven) Superfund site is located in an area of rich groundwater resources and availability. It is a highly glaciated area; Fort Wayne being located at the confluence of the St. Joseph, St. Mary, and the Maumee Rivers. Inspite of the excellent groundwater availability the city of Fort Wayne Public Water Supply is obtained from the St. Joseph River and the Cedarville reservoir, sources which need no treatment for hardness, manganese and iron content. Although this dumpsite is located in an area serviced by the New Haven Water utility, this utility purchases its water from Fort Wayne.

Leachate from the New Haven dumpsite was determined to contain tetrachloroethylene, benzene, fluorene, and hexachlorobenzene. A well 50 feet east of the site is contaminated. The aquifer which is approximately 20 feet below the site, is the source of water for approximately 1100 people not serviced by the New Haven Water Utility, and who live within three (3) miles of the site.

The Seymour Superfund site is located in the valley of the East Fork of the White River. Although the White River Valley is a rich groundwater source, the city of Seymour gets its water from the East Fork of the White River for reasons described above. However, the Freeman Field Utility which serves an industrial park immediately south of Seymour, and approximately 1000 persons in adjacent areas, uses the White River aquifer and withdraws approximately 630,000

GPD. The Seymour dumpsite is located in this industrial park. Initially this site was an industrial waste reclamation operation. The area contains thousands of drums of solvents, phenols, cyanides, acids, and many smaller containers of hazardous materials from chemical laboratory operations. Investigative studies performed off-site indicate contamination of the soil and groundwater.

The Columbia City site is located over the Blue River Valley (tributary of the Eel River) aquifer which is overlaid by thick, permeable, unconsolidated glacial materials. The groundwater resource and availability are excellent. The Columbia City public water supply is obtained from the Blue River Valley aquifer. In addition, there are many private wells in the surrounding area tapped into the same aquifer.

Over one (1) million gallons of waste have been disposed of on this superfund site by open dumping on surface soils, into unlined pits, and into an unlined trench. Leaking drums on-site abound. Data indicate high levels of cyanides, lead, chromium, and cadmium. The site is bordered by residences on the north and west sides, and a bend of the Blue River on the east and south sides. Three (3) municipal wells are located within one (1) mile northeast of the site. While the municipal wells appear to be up-gradient from the dump site, this has not been substantiated. The likelihood of municipal and private well contamination appears strong. In addition, it is likely that leachate materials from this site may be contaminating the Blue River.

The Lebanon site is located in Boone County as is the heretofore discussed Zionsville site. While the Lebanon Site does not contain the thick, permeable unconsolidated deposits and groundwater resources found in the Zionsville area, nevertheless Lebanon has a good groundwater resource with fairly thick deposits and a fairly permeable unsaturated zone. The Lebanon water supply taps an aquifer of a tributary of Sugar Creek. The sand and gravel aquifer is approximately 100 feet beneath the surface in the area of the Superfund site.

The Lebanon Superfund site is the remains of a warehouse destroyed by fire on May 2, 1981. The warehouse was used to store approximately 50,000 capacitors, many containing PCB. The PCB-contaminated warehouse debris was left on-site and remains on-site to the present time. Sampled rubble was determined to be as high as 24,500 PPM PCB. In addition, low levels of tetrachlorodibenzo-p-dioxin (TCDD) and tetrachlorodibenzofuran (TCDF) were found to concentrations of 500 parts per trillion (PPT). Although no aquifer contamination has been detected as yet, low concentrations of PCBs have been measured in nearby Prairie Creek.

SUMMARY

(1) Groundwater in Indiana occurs in a variety of both unconsolidated and bedrock aquifer systems. The most significant of these aquifers are the various unconsolidated outwash sand and gravel deposits associated with glacial drift, and the limestone, dolomite, and sandstone bedrock formations.

(2) Generally the most productive groundwater aquifers are in the northern part of Indiana and get progressively

less productive north to south, exclusive of major river valley aquifers.

(3) Approximately one-twelfth of the State is non-glaciated and is located in the southcentral portion. Many areas in the southern part of the State are particualrly lacking in groundwater, and only limited amounts (less than 10 GPM) are available to properly constructed wells.

(4) The contamination of groundwater supplies is not solely the work of "midnight dumpers" who illegally pour barrels of wastes into ditches and fields. Much of the contamination is the result of the legal disposal of solid wastes into improperly protected and operated ground repositories.

(5) Because of the huge numbers of impoundment sites located in Indiana, it was arbitrarily decided to limit this study to only those impoundments (37) with numerical SIA ratings between 25 and 29 inclusive (one percent of the Indiana total), with the caveat that the arbitrary cut-off may exclude some sites that are contaminating or have the potential to contaminate, usable groundwater supplies (See Table 1).

(6) Since the RCRA dumpsites in Indiana were not nearly as numerous as the impoundments, all 49 RCRA sites computer-programmed by the Region were retrieved and considered in this report (See Table 2).

(7) Because of the high degree of public health hazard potential, all thirteen (13) Indiana Superfund candidates (See Table 3), were included in this report, along with a description of

dumpsite location geology, and associated groundwater contamination problems.

(8) Lake County contains more by far of the report-considered waste repositories than any other Indiana County. Moreover all the waste repositories are in the northernmost twenty-five (25) percent of the County.

(9) The Lake County geology contiguous to Lake Michigan does not make groundwater readily available. As a result most of the Lake County population is served by public water supplies using Lake Michigan as a source. However five (5) to ten (10) percent of the population in this part of the county are on private wells. It is most likely that the groundwater supplying these have a high potential for contamination by the toxicants listed on page 21.

(10) Because of the large number of waste repositories located in Marion County, and the extreme permeability of the unsaturated zone in the area, it appears likely that the aquifers supplying the private wells in the periphery of Marion County, in addition to the groundwater sources augmenting the Indianapolis Water Company surface supply, and those of the Speedway and Lawrence Water Companies have a high potential for contamination by the toxicants listed on page 24.

(11) As with Lake County, the area contiguous to Lake Michigan in Porter County does not yield groundwater readily. As a result most of the larger Porter County Lake Shore communities are supplied Lake Michigan water by the Gary-Hobart Water Company. However, the remaining Lake Shore areas, and the second and third "rows" of towns south of the immediate Lake Shore are supplied by public and private wells drilled through highly permeable unsaturated zones

to high producing aquifers. Because of the large number of waste repositories located in the area, and the geology as described above, it appears that the aquifers serving the Beverly Shores, Porter, and Chesterton areas have a high potential for contamination by toxicants listed on page 26.

(12) For the same reasons described above, the groundwater aquifers supplying the private and public wells in northern St. Joseph, northwestern Elkhart, and central Kosciusko Counties have a high potential for contamination by the toxicant types listed on page 29.

(13) Because many unlined brine waste lagoons are located above highly permeable unsaturated zones and high yield aquifers, it appears likely that the aquifers which serve the villages of Grandview, Rockport, and Chrisney and environs are becoming more saline daily.

(14) Because Orange County is a karst (sinkhole) area, and because inadequate State regulatory resources result in the illegal operation of feedlot oxidation ponds (inadequate irrigation of effluent leading to pond overflow especially during periods of precipitation), the aquifers serving rural water supplies in the northeastern part of the county, and the municipal wells of the city of Orleans have a high potential for contamination by nitrites and nitrates.

(15) Since most of the impoundments in Vigo County are located over highly permeable and productive areas, and since most of the impoundments are unlined, and because there may be construction/operational problems with those that are lined, the water supplies

serving Terre Haute and the northern half of the county appear to have a high potential for contamination by the materials listed on page 37.

(16) Other Indiana Counties not discussed in this report could have problems with groundwater contamination, especially those to the north. However, since the waste repository density in these counties is much less, groundwater contamination potential would be much less. Investigation of these sites should await problem definition in the sites with greater densities.

(17) Based upon location geology, and the fact that these sites are considered the most hazardous in Indiana, the Superfund sites at Zionsville, Kingsbury, New Haven, Seymour, Columbia City, and Lebanon most likely have a high potential to contaminate groundwater aquifers. Because of unsaturated zones with little permeability and little groundwater availability, any potential groundwater contamination at the two (2) Bloomington Superfund sites will affect relatively few people, since most of the area population is serviced from surface sources. The Superfund sites at Gary, Elkhart, and Indianapolis augment RCRA and SIA waste repository contamination described earlier.

REFERENCES

1) Clark, G.D., The Indiana Water Resource, Indiana Department of Natural Resources, Indianapolis (1980)

2) Brady, N.C., The Nature and Properties of Soils, MacMillan Publishing Co., Inc., NY, NY, (1974)

3) Freeze, R.A., Cherry, J.A., Groundwater, Prentice-Hall Inc., NY, NY, (1979)

4) Krauskopf, K.B., Introduction to Geochemistry, McGraw-Hill Book Co. NY, NY. (1967)

5) Press F. Siever, R., Earth, Freeman and Co., San Francisco, California (1973)

6) Water Resources Research Center et. al., An Inventory of Groundwater Data and Aquifer Assessment for Indiana. US EPA (1980)

7) Cargo, D.N., Mallory, B.F., Man and His Geologic Environment, Addison-Wesley Publishing Co., Reading, Mass. (1974)

8) Tank, R., Focus on Environmental Geology, Oxford University Press NY, NY (1976)

9) Carpenter, G.L., et. al, Oil Development and Production in Indiana in 1981, Indiana Department of Natural Resources, Bloomington, Indiana (1982)

10) Division of Oil and Gas, Rules and Regulations, IDNR, Indianapolis Indiana (1980)

11) SCS Engineers, Surface Impoundment Assessment in Indiana, US EPA (1980)

12) Read, W.T., Industrial Chemistry, John Wiley and Sons, NY, NY (1946)

13) Claussen, C.A., Mattison, G., Principles of Industrial Chemistry, John Wiley & Sons, NY, NY (1978)

14) Riegel, E.R., Industrial Chemistry, Van Nostrand Reinhold Co., NY, NY (1974)

15) McNabb, J. et., al., Nutrient, Bacterial and Virus Control as Related to Groundwater, US EPA (1977)

16) OWS-OSWMP, Waste Disposal Practices and Their Effects on Groundwater, US EPA (1977)

17) NAS-NAE, Water Quality Criteria, US EPA (1972)

18) OAWP - Groundwater Pollution From Subsurface Excavations, US EPA (1973)

19) K-U Associates Inc., Groundwater Survey-Seymour Hazardous Waste Site, US EPA (1980)

20) Walker, W.H., Where Have All The Toxic Chemicals Gone, Illinois State Water Survey (1972)

21) Walker, W.H., Groundwater Contamination and Refuse Disposal, Illinois State Water Survey, (1972)

22) Harrington, W.M., Sanitary Landfill Design Considerations to Protect Water Supplies, AWWA (1970)

23) American Petroleum Institute, Primer of Oil and Gas Production, Dallas Texas (1979)

24) Personal Communication, Mr. Richard Bates, Lake County Health Department, March 15, 1983

25) Personal Communication, Mr. Tim Baumgartner, Indianapolis Water Co., March 16, 1983

26) Personal Communication, Mr. Jeff Meyers, Marion County Health Department, March 16, 1983

27) Personal Communication, Ms. Karyl Schmidt, Indiana State Board of Health, March 16, 1983

28) Personal Communication, Mr. Dennis Gillespie, SCS Engineers, April 4, 1983

29) Personal Communication, Mr. Homer Brown, Indiana Department of Natural Resources, April 4, 1983

30) Personal Communication, Mr. James Traylor, Indiana State Board of Health, April 21, 1983

31) Personal Communication, Miss Beverly Kush, US EPA, April 26, 1983

32) Personal Communication, Mr. H. Lipner, Fort Wayne Water Co., April 27, 1983

33) Personal Communication, Mr. Paul Boyd, Spencer County Health Department, April 13, 1983

All figures used in this report (except Figure 16) were taken from The Indiana Water Resource published by the Indiana Department of Natural Resources and edited by G.A. Clark.