SUBSURFACE INJECTION IN ONTARIO, CANADA

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Abstract

Underground injection has been used in Ontario for decades to dispose of brackish waters and brines that are produced from oil and gas wells. The first injection well for liquid industrial waste was completed near Sarnia in 1958. In the next few years, a number of additional industrial injection wells were drilled near Sarnia. The majority of the wells were completed in the Detroit River Formation at depths generally less than 1,000 feet (304 m). This area was the site of intensive exploration for gas in the overlying Dundee Formation, and many cable-tool holes had been drilled to the top of the Detroit River Formation early in this century. In the late 1960's, several events occurred where industrial waste and/or brine flowed to the land surface through abandoned and inadequately plugged boreholes. As a result of these problems, industries in the Sarnia area voluntarily decreased their injection rate. Ultimately, regulations were passed which prohibited industrial waste injection into the Detroit River Formation.

Since December 31, 1976, only brine has been injected into the Detroit River Formation. In order to evaluate the effects of brine injection, a regional assessment of injection of brines to the Detroit River Formation was undertaken by the Ministry of the Environment. This project included an inventory of all injection wells in the Province, calculation of aquifer parameters from injection tests and drill stem tests, collection and review of chemical analysis of native brines, and a review of past operating practices. Data collected during the study suggested that continued injection into the Detroit River Formation could be safely accomplished by reducing wellhead operating pressures to prevent displacement of brines into freshwater aquifers.

Introduction

Underground injection is considered the perferred method to dispose of brackish waters and brines that are produced from oil and gas wells. The operation of tens of thousands of salt-water disposal wells throughout North America illustrates the dependency of the petroleum industry on these wells (Lewelling and Kaplan, 1959). The most commonly utilized alternative to injection has historically been by discharge to surface waters or by disposal in "evaporation" pits, which has frequently resulted in contamination of shallow ground water and is now prohibited in many areas. Surface storage and discharge to surface waters have been common in Southwestern Ontario, but are now discouraged where an air or water pollution potential exists.

In addition to oil and gas waste, disposal wells have been used in southwestern Ontario to dispose of brine from development of storage caverns in bedded salt, and industrial waste from the petrochemical industry. The majority of the disposal wells were completed in the Detroit River Group of Devonian Age. The locations of injection wells in Ontario are indicated in Figure 1.

Industrial Waste

The first industrial disposal wells in Ontario were completed by Imperial Oil Limited at Sarnia between 1958 and 1960. Five disposal wells and one observation well were drilled on refinery property. In the next few years, a number of additional disposal wells were drilled by other industries in the Sarnia area. Most of the wells were completed in the Detroit River Group of Formations, at depths of 600 to 900 feet (182 to 273 m). A total of 18 industrial waste injection wells were operated in the Lambton County area during the period from 1958 to 1974. All but two wells were completed in the Detroit River Group. The other two injected into a leached salt cavern. During the period from 1958 to 1974, over 63,717,330 BBLS (10,131,055 m^3) of industrial waste were injected into the Detroit River Group.

Cavern Waste

Brine which has resulted from the creation of storage caverns is classified differently from brine used in the operation of caverns. The brine used in cavern operation ("ballast" brine) may contain a few tens of parts per million of product hydrocarbon, the concentration depending largely on the solubility and vapor pressure of the product stored. The volume of ballast brine is a small fraction of the quantity of brine from dissolution of salt to form the caverns. On occasion, ballast brine ponds become filled due to precipitation and some of the liquid must be removed for disposal. Ocean disposal has been utilized and some ballast brine has been used as a dust suppressant for roads. The acceptability of disposal of these slightly contaminated brines into the Detroit River Formation, along with cavern washing brine, is under consideration.

As of 1980, there were 63 active liquid hydrocarbon storage caverns at Sarnia and three at Windsor. The caverns are developed in the Salina formation and range in size from 40,250 BBLS (6,400 m^3) to 1,140,340 BBLS (181,300 m^3). Much of the waste brine produced during the creation of storage caverns has been injected into disposal wells. By the end of 1980, 13,926,900 BBLS (2,214,200 m^3) of salt cavern storage

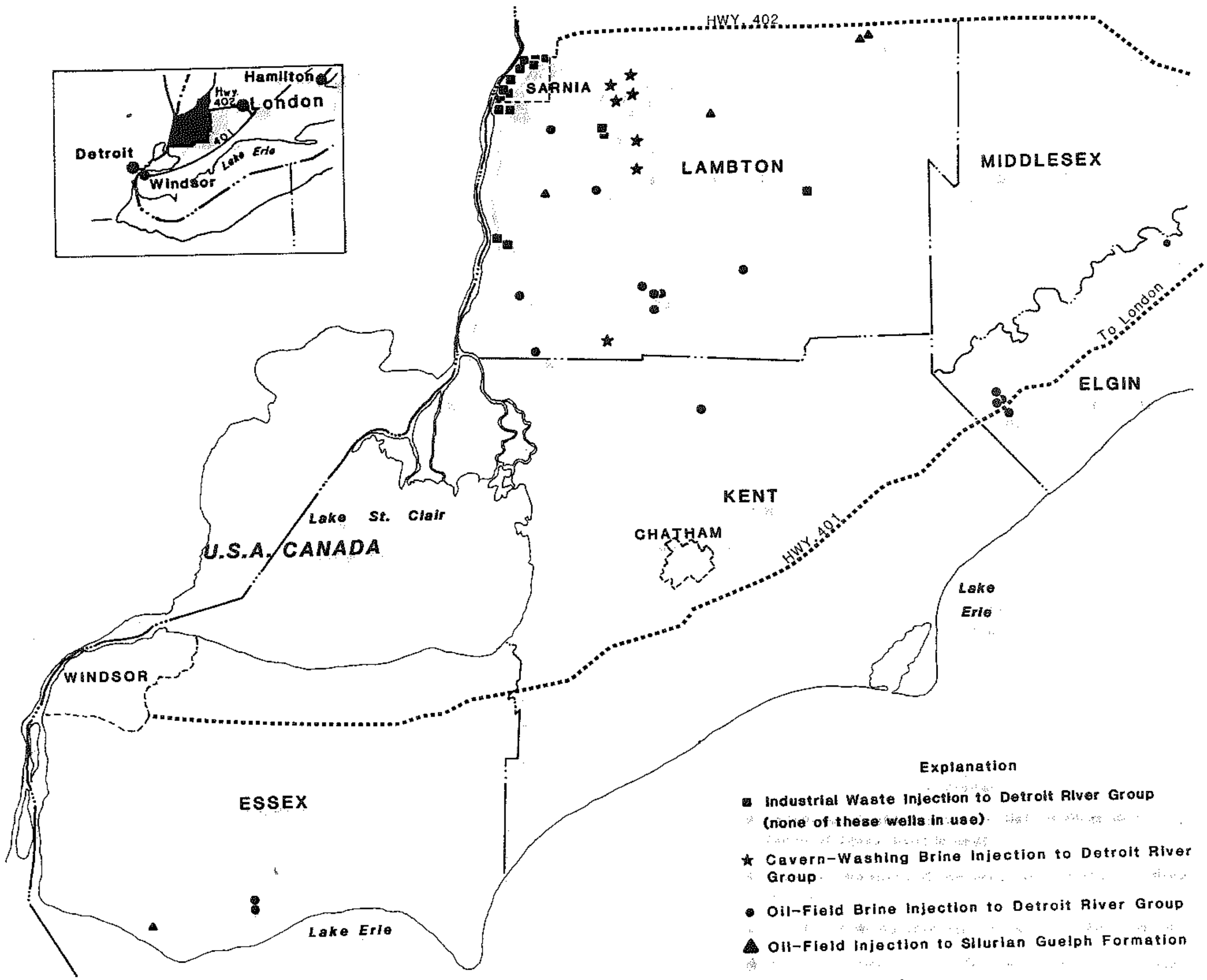


Figure 1. Locations of Waste Injection Wells in Ontario

space had been created in southwestern Ontario (Booth-Horst and Rybansky, 1982). Records show that in the period from 1970 to 1980, over 52 million BBLS (8.3 x 10^6 m^3) of cavern washing brine were injected into "lost circulation" zones in the Lucas Formation of the Detroit River Group through five wells owned and operated by Cambrian Disposal Limited (CDL). A typical brine disposal well is shown in Figure 2.

Oil Field Waste

Oil field brine is native brine produced along with the hydrocarbons. It may contain trace amounts of organic compounds. The production of oil field brines is not as centralized as the production of cavern-washing brine, but is distributed throughout southwestern Ontario. It is desirable to locate disposal facilities as close as possible to the industries they serve. Besides the economy of short transport distances, the installation of remote disposal sites or pipelines may involve difficulties in obtaining local permits or rezoning of property. Unfortunately, the properties of the disposal formations are different in different areas, and injection may not be geologically feasible at the site where it is most needed.

Sixteen wells were reportedly used for oil field brine disposal into the Detroit River Group and seven for disposal into the deeper Guelph Formation between 1970 and 1981. Some were used continuously through that period. Records of the MNR indicate that four new brine disposal wells were completed in 1981. If oil and gas production rates do not change significantly, then the amount of brine wastes injected into the Detroit River Group in the future should be similar to past amounts.

Environmental Problems of Waste Injection

In the late 1960's, several incidents occurred where industrial waste or brine flowed to the land surface through abandoned and inadequately plugged boreholes. In 1966, high-pH phenolic wastes emerged beneath a building on the property of Imperial Oil Enterprises Limited in Sarnia. An old borehole was located and plugged. In 1967, another well on the property of Imperial Oil began to flow. The well was found to be obstructed at a depth of 190 feet and was plugged. In 1967, eleven old wells in Port Huron, Michigan began to flow and were subsequently plugged. Soon afterwards, several other wells began to leak. One sample of the water was analyzed by Michigan authorities and was reported to contain 15 ppm of phenol, 820 ppm of H_2S, and a pH of 8.7. Previous samples of native waters from the Detroit River Group reportedly had not detected phenols or H_2S.

The breakout problems were reviewed by the Ministry of Mines and Northern Affairs in 1970, with the assistance of the staff of the Ontario Water Resources Commission. This review resulted in a notice to industry that wells utilizing the Detroit River Group were to be phased out within two years in the area along the St. Clair River, that the volume of waste injected in this area should be voluntarily reduced, that research into alternate methods of disposal should be accelerated, and

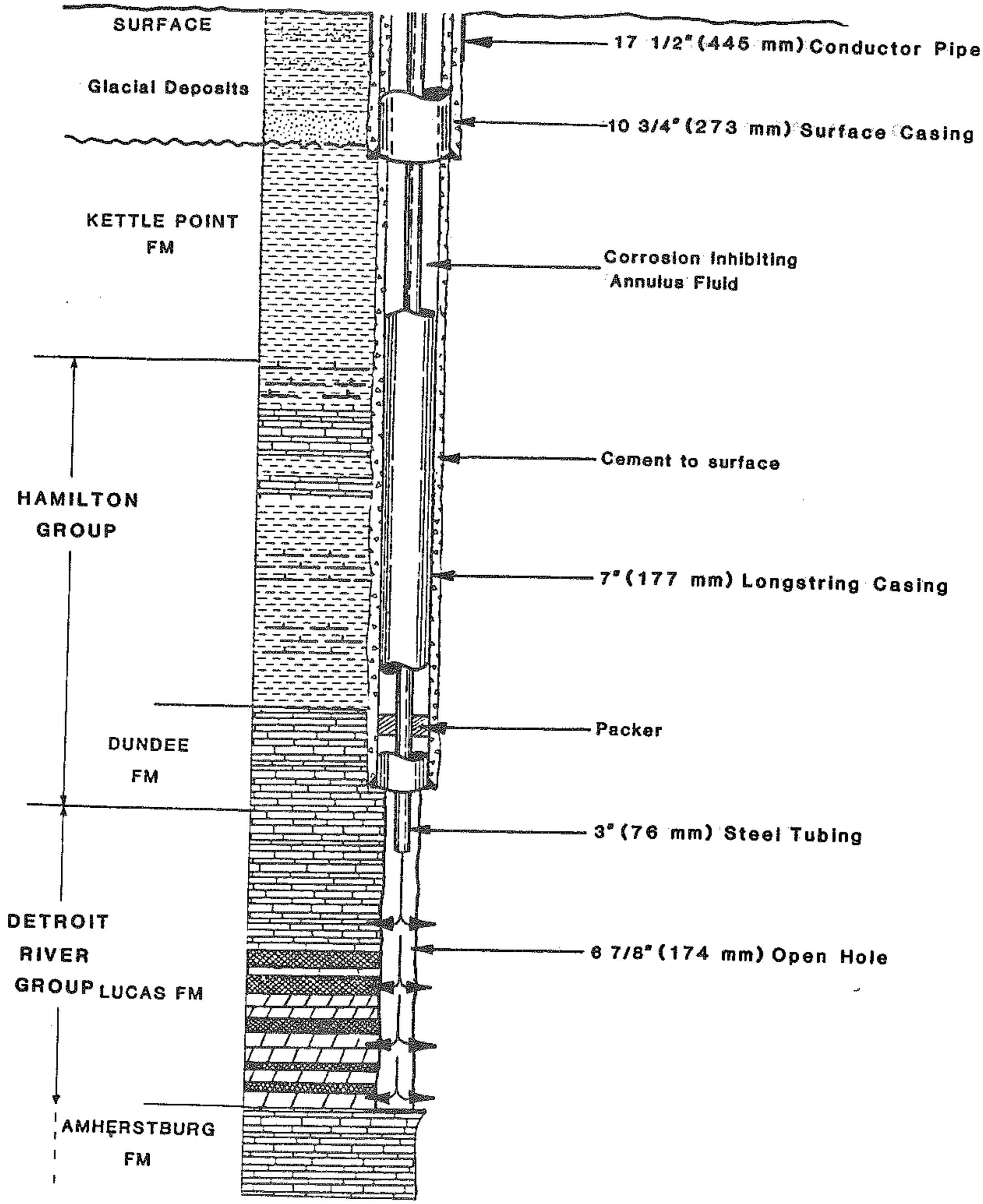


Figure 2. Schematic Diagram of a Typical Injection Well

that Cambrian-age formations should be evaluated as an alternative to the Detroit River Group. Wells completed into high-permeability or "lost circulation" zones in the Detroit River Group in locations to the east of the industrialized area along the St. Clair River were to be allowed to operate under gravity drive on a year-to-year basis, subject to annual review. Since December 31, 1976, only brine has been injected into the Detroit River Group.

Regional Geology

Southwestern Ontario is located on a structural flexure between two Paleozoic-age continental basins, the Michigan Basin to the northwest and the Appalachian Basin to the southeast. The northeast-southwest trending flexure is made up of three elements: the Findlay and Algonquin Arches, and the Chatham Sag, formed by the plunge of the two arches toward a common area centered near Kent County (Figure 3). Southwestern Ontario is underlain by essentially flat-lying or gently dipping sediments, depending on location. The Sarnia area is located on the edge of the Michigan Basin, and in this area the rocks dip to the northwest into the Michigan Basin at a rate of 50 ft. per mile (9.5 m per km). A structure map of the top of the Detroit River Group is shown in Figure 4.

The structural attitudes of the formations have locally been affected by other processes in addition to tectonic deformation. In some areas, the beds have been affected by collapse as a result of dissolution of salt beds, and/or by drape over reefal structures (Brigham, 1971). Maximum thickness of sediments in the Michigan Basin is about 14,000 feet (4,267 m) (Brigham, 1971). The stratigraphic sequence for the Michigan Basin is illustrated in Figure 5.

The Lucas Formation of the Detroit River Group is the most important zone used for injections in Ontario. The Lucas Formation consists principally of dolostone and limestone, though the section is relatively complex and contains a number of different lithologies. Evaporitic beds become thicker and more numerous toward the center of the Michigan Basin, where an aggregate thickness of 1,000 feet (304 m) of halite and anhydrite occurs (Briggs, 1959). In some areas, anhydrite beds have reportedly been dissolved by natural processes, creating vuggy or cavernous "lost circulation" zones of high permeability. The Lucas Formation occurs at a depth of approximately 600 feet (183 m) at Sarnia.

The Dundee Formation overlies the Detroit River Group. The Dundee is a fine-grained limestone that contains scattered chert nodules. A lenticular zone of high porosity dolostone ("lost circulation zone") occurs near the base of the Dundee. The Dundee is approximately 160 feet (50 m) thick near Sarnia. The Dundee is overlain by the Hamilton Formation, which is a calcareous shale and limestone; the upper part is a limestone interbedded with calcareous shale. The thickness of the Hamilton in southwestern Ontario varies from about 150 feet (45 m) in the south to 650 feet (198 m) to the north.

The Kettle Point Formation unconformably overlies the Hamilton and forms the bedrock throughout much of Kent and Lambton counties. The

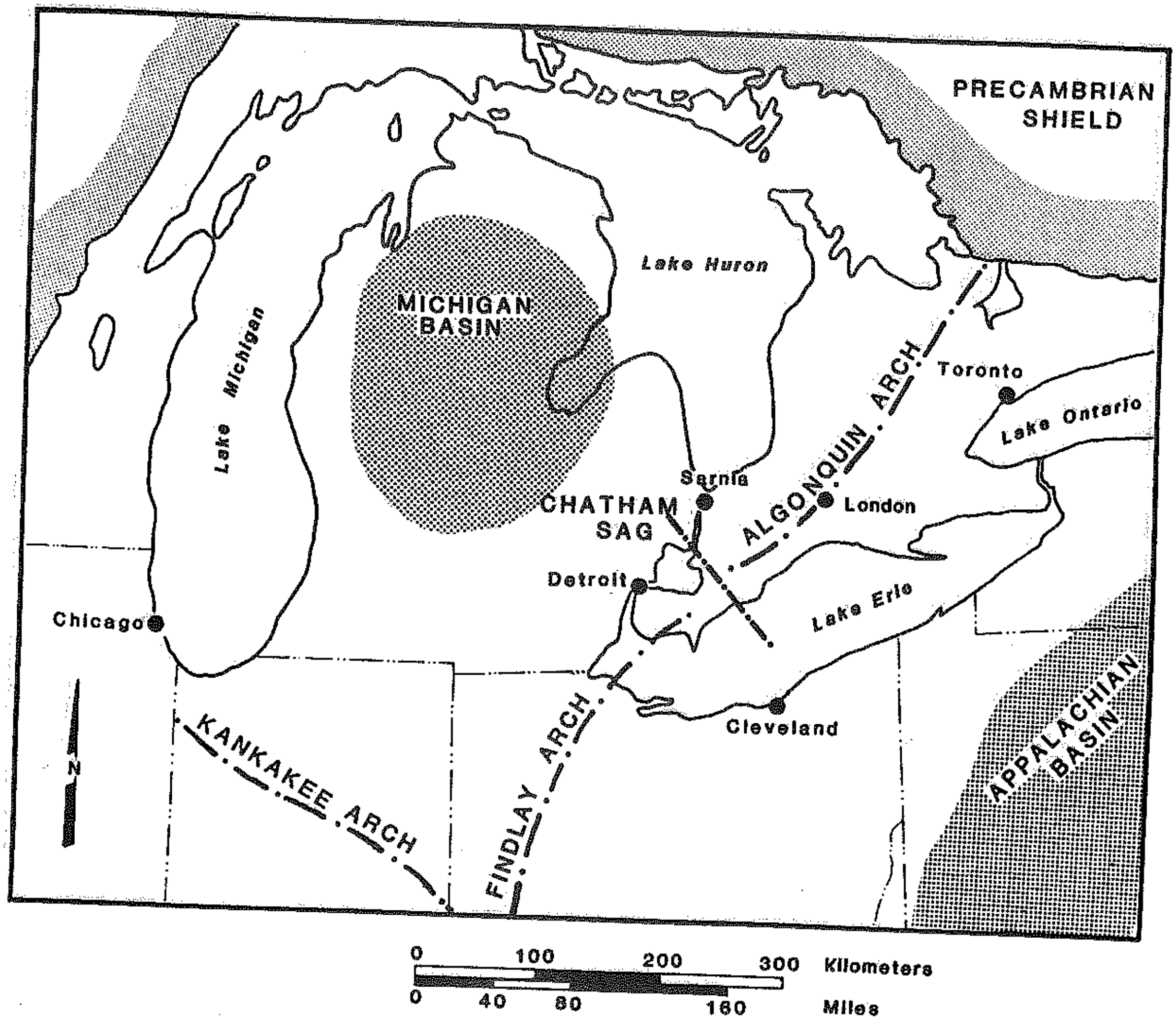
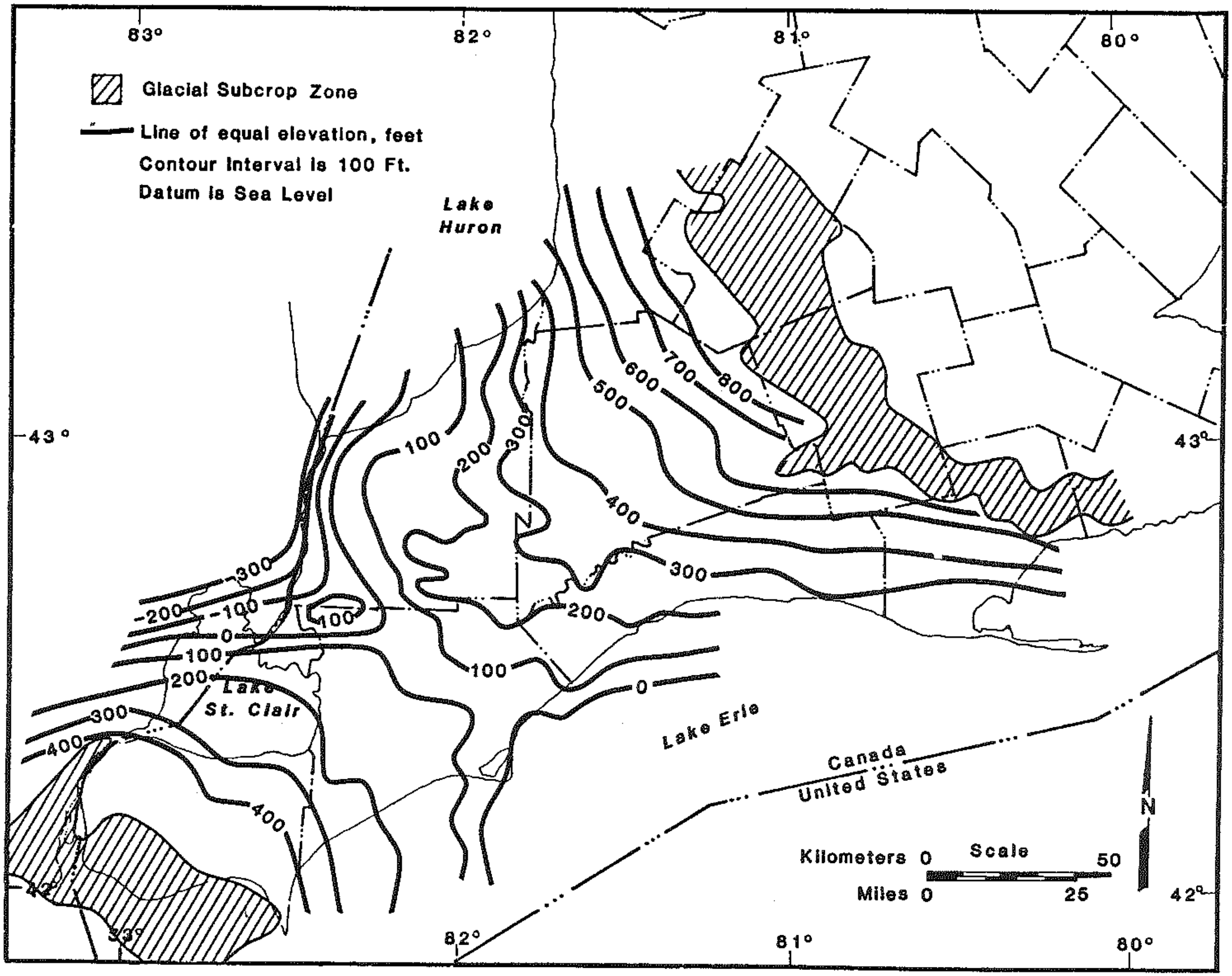


Figure 3. Structural Elements in the Southwestern Ontario Region.



(Modified after Brigham, 1971)

Figure 4. Structure Contours of the top of the Detroit River Group

ERA	SYSTEM	GROUP	FORMATION	PRIMARY LITHOLOGY	APPROX. DEPTH in LAMBTON CO. Ft. (m)
Cenozoic	Pleistocene		Glacial Till	Sand, Clay	0
Paleozoic	Devonian	Port Lambton		Shale	Missing at Well site
			Kettle Point	Shale	170 (52)
		Hamilton	Ipperwash	Limestone	320 (98)
			Widder	Shale and Limestone	
			Hungry Hollow	Limestone and Shale	
			Arkona	Shale	
			Rockport Quarry	Limestone	
			Bell	Shale	
			Marcellus	Shale w/Limestone	
			Dundee ● ☼	Limestone	580 (177)
		Detroit River	Lucas ●	Dolomite	715 (218)
			Amherstburg	Limestone and Dolomite	950 (290)
			Bois Blanc	Dolomite and Limestone	1115 (340)
			Oriskany	Sandstone	
	Silurian		Bass Islands	Dolomite	1180 (360)
			Salina ● ☼	Halite, Anhydrite, Limestone, Dolomite, Shale	1330 (405)
			Guelph-Lockport ● ☼	Dolomite	2510 (765)
		Amabel	Queenston ☼	Dolomite	2540 (774)
		Cataract	Grimsby ● ☼	Sandstone	2625 (800)
			Cabot Head	Shale	
			Manitoulin	Dolomite	
			Whirlpool ● ☼	Sandstone	
	Ordovician			Shale	2820 (860)
			Meaford-Dundas	Shale	
			Blue Mountain	Shale	
			Collingwood	Shale	
		Trenton	Cobourg ☼	Limestone	3440 (1049)
			Sherman Fall ● ☼	Limestone and Shale	
			Kirkfield	Limestone	
		Black River	Coboconk ☼	Limestone	3925 (1196)
			Gull River ☼	Limestone	
			Shadow Lake	Shale	
	Cambrian		Trempealeau	Dolomite	4450 (1356)
			Eau Claire ● ☼	Dolomite and Sandstone	
			Mount Simon	Sandstone	
Precambrian				Igneous Rocks	4520 (1378)

Depths from electric log of Imperial Moore No. 49 R.F., Moore Township

Adapted from Geol. Surv. Canada, 1969, McLean, 1968, and Booth-Horst and Rybansky, 1982

● Oil ☼ Gas

Figure 5. Stratigraphic Succession in Southwestern Ontario

Kettle Point is a thin-bedded dark shale and attains a maximum thickness of 200 to 300 feet (61 to 91 m) in eastern Michigan.

The Port Lambton is the youngest Paleozoic formation in southwestern Ontario. It occurs in a small area in the vicinity of Mooretown and Sombra along the St. Clair River. The Port Lambton is composed of shale with minor sandstone and siltstone.

Although there are areas in southwestern Ontario where bedrock outcrops at surface, the majority of the region is covered by substantial thicknesses of glacial materials. The thickness of the glacial materials is related to both the relief of the underlying bedrock surface and the surface physiographic features. Thicknesses of 100 feet (30 m) are common in the region but more than 400 feet (121 m) have been recorded in bedrock valley areas.

Most of the glacial materials are made up of a sequence of stacked till units. The tills may be separated by layers of sand, silt, or clay. The stratigraphy will, of course, differ from place to place according to the glacial history of the region. In very general terms, the stratigraphy adjacent to Lakes Erie, St. Clair, and Huron and extending inland almost to London is dominated by silt-clay tills and glaciolacustrine materials. North of Goderich-London-Woodstock the glacial stratigraphy is complex and variable. Numerous complex landforms, buried sand units, and multiple till sequences have been formed by the interaction of several ice lobes. The thickness of glacial materials gradually decreases to the north and east as one approaches the lip of the Niagara Escarpment. Most of the fresh ground water in southwestern Ontario is produced from glacial materials.

Natural Resources

Injection of waste liquids into the subsurface should be permitted only in cases where it can be assured that resources such as fresh water, oil and gas, and other subsurface resources can be protected. Protection of these resources requires knowledge of their location and adequate hydrogeologic study of the reservoir strata.

Ground Water

Many communities in southwestern Ontario rely on abundant surface water resources. However, in rural areas, the most accessible supply of water is shallow ground water in the glacial deposits or in the upper part of underlying bedrock deposits.

The glacial deposits in Lambton County are underlain by shale of the Kettle Point Formation and by shale and limestone of the Hamilton Formation. About 90% of the water wells in Lambton County obtain water from the sand and gravel near the top of the bedrock. The thickness and grain size of these deposits determine the productivity of wells. The bedrock surface in Lambton County slopes toward the St. Clair River. The thickness of the till is approximately 60 to 150 ft. (18 to 45 m) (OWRC, 1969). Water level data suggest that water moves from east to west toward the St. Clair River and Lake Huron, in the direction of the slope of both the land surface and the bedrock surface.

Oil and Gas

The first commercial oil production in Ontario began at Oil Springs in 1857 (Harkness, 1931). The presence of evidence of a former oil spring on the ground surface ("gum beds") led to drilling in this location and the subsequent discovery of oil in several shallow horizons, including the glacial deposits and a dolomitized zone in the Dundee at a depth of 360 ft. (110 m).

Many thousands of exploratory holes were drilled in Lambton County in the late 1800's and early 1900's in search of oil and gas in the Dundee Formation. Most of the records of wells drilled prior to 1930 no longer exist and the locations and plugging status of most of them are unknown. These artificial penetrations of the confining beds allowed the breakout of injected waste in western Lambton County in the 1960's. Operators are now required by the Ministry of Natural Resources (MNR) to submit an application for a permit to drill or deepen oil and gas wells and, upon completion of drilling, are required to submit a well history summary card and cuttings samples taken at 10-foot (3 m) intervals. These records have been combined with older data to form a computerized geologic information system known as the Ontario Well Data File. When a well is abandoned, it must be plugged according to MNR regulations.

The primary oil and gas production trends in Ontario can be grouped according to geographical area and productive formation. In the counties north of the eastern part of Lake Erie, and in the lake itself, wells produce gas from shallow Silurian sands. The reefs of the Guelph Formation produce oil and gas along a trend that approximately parallels the shore of Lake Huron. Cambrian sands produce oil and gas from stratigraphic and structural traps found near the zero-isopach trend that parallels the north shore of Lake Erie. Dolomitized zones in deformed Ordovician rocks of the Trenton and Black River groups produce oil and gas in widely scattered locations.

A number of oil reservoirs occur in Devonian rocks in southwestern Ontario. Most of the oil occurs in the Lucas and Dundee Formations. Two of the Devonian oil fields also produce gas. These are the Kipp Field in Kent County and the Plympton-Sarnia Field near Sarnia in Lambton County.

Salt and Brine

A number of companies in southwestern Ontario mine salt from the Silurian Salina Group of formations. The salt occurs in five major beds totalling as much as 700 ft. (213 m) in thickness. The salt beds thicken toward the northwest. The salt is easily dissolved by water and so has been mined hydraulically at Windsor, Sarnia, and Goderich, as well as by conventional underground techniques at Windsor and Goderich. Mined brines are used as feedstock for chemical manufacturing in the Sarnia and Windsor areas.

Storage Media

Underground space in southwestern Ontario is presently used for recoverable storage of two types. Liquid hydrocarbons are stored in cavities made in salt beds, and natural gas is stored in natural pore space in carbonate rocks and in sandstones.

A number of industrial firms store Liquid Petroleum Gas (LPG) and other liquid hydrocarbon products in over 60 caverns in salt in the Sarnia and Windsor areas. The caverns are formed in salt beds of the Salina Formation at a depth of approximately 2,000 ft. (609 m) in the vicinity of Sarnia. Total capacity in 1980 was 13,926,900 BBLS (2,214,200 m^3) (Booth-Horst and Rybansky, 1982).

Evaluation of Waste Injection

The environmental implications of disposal of brines to the Detroit River Group of Formations can be determined by subdividing the potential impacts into two classes. The first class consists of those processes that may result in local escape of injected fluid or poor-quality native brines from the disposal formation during the operating life of a well. This may result from failure of the well itself, or failure of the geologic media to contain the wastes, during the period when fluid pressures in the receiving formation are increased due to injection. The second class of potential concern is the fate of the slug of injected fluid after the well has ceased to operate. When the increased pressure due to injection dissipates, movement of the slug will be influenced by natural, regional circulation in the sedimentary basin. It would be desirable to estimate flow rates and the locations of regional discharge zones. Desirable properties of the regional system include slow rate of migration, large degree of dispersion and dilution, and low-flux discharge. The scope of this paper is primarly concerned with the short term, local effects of injection.

Containment of Waste

Upward movement of waste or poor-quality native water out of a disposal zone is more likely to occur in the area relatively near the well than at great distances, since the imposed increase in hydraulic head is greatest at the well. Injection wells should be engineered and the site selected to ensure that the well structure is competent and that the confining beds have sufficiently low permeability and high integrity within the area of increased heads so that upward escape is unlikely. The nature of the porosity of the disposal reservoir will determine the extent and shape of the area of greatest concern, where pressures are above some critical level.

The Detroit River Group is overlain, in ascending order, by the Dundee Formation, the Hamilton Group, and the Kettle Point Formation. This sequence of rocks consists of fine-grained or microcrystalline limestone that contains occasional chert nodules, calcareous shale, shaly limestone, and crinoidal limestone. The thickness of the interval is approximately 400 to 700 feet (122 to 213 m) in Lambton County. Early cable-tool borings were made without encountering free water in this interval, suggesting that permeability is very low. In some areas, oil and gas have been found in thin, porous zones in the Dundee. The petroleum reservoirs in the Dundee are reportedly produced by "depletion drive," which indicates that no appreciable repressuring of the reservoirs by inflow of water has occurred. This interval appears to furnish an excellent confining layer, where it is intact. However, the presence of oil and gas in the Dundee Formation resulted in the historical exploration activity during which thousands of holes were drilled through this sequence of sediments. It has been estimated (McLean, 1968) that about 10,000 wells drilled in southwestern Ontario and eastern Michigan before and around the turn of the century were never properly plugged and the records have been lost, hence the locations of these wells are unknown.

There is other evidence that the confining beds have been breached by natural processes in some locations. Oil and gas have migrated, at some time in the past, through the Dundee/Hamilton/Kettle Point sequence to the glacial deposits above bedrock. Oil is now found in the glacial deposits in the vicinity of Oil Springs and Petrolia. Drilling at these locations has shown that the oil probably moved upward from deeper accumulations in rocks of Detroit River age.

Concept of Area of Review. Elsewhere in North America, regulations that control underground injection have adopted the concept of an "area of review" or "zone of endangering influence." This area lies within a circle that is centered at the disposal well and has a radius determined by calculation or, in some cases, a standard radius. Within this area, the applicant for a permit must obtain the completion or plugging records for all borings ("artifical penetrations") that have been drilled into the proposed injection zone. The applicant is responsible for ensuring that all such boreholes or wells are properly plugged.

The radius of the area of review is defined as that lateral distance from an injection well in which the pressures in the injection zone due to operation of the well may cause the migration of the waste or native fluid into an underground source of drinking water. If the radius is calculated, the procedure is to find the radius within which the pressure increase due to injection causes the head in the injection zone to equal or exceed the head in an overlying source of drinking water. Differences in density of fluids may be taken into account. The distribution of pressure increases in the injection zone around the well are calculated using the nonequilibrium method. The nonequilibrium method uses the solution to the problem of transient radial flow of a compressible fluid from a line source in a homogeneous, isotropic, confined reservoir of infinite areal extent (Theis, 1935). The aquifer parameters required to perform this calculation are termed permeability, thickness, and porosity-compressibility product in the oil industry, and are analogous to the quantities hydraulic conductivity, thickness, and storage coefficient in the water industry.

Although the concept of area of influence is attractive because it is technically sound, in practice it is not always applicable because the native head in the injection zone may be equal to or greater than the head in the zone of fresh water. In this case, the concept of a distance from the well where the heads are equal or where the head in the injection zone is lower than that in the overlying aquifer has no meaning.

In southwestern Ontario, the hydraulic head in the disposal zone is generally lower than that in the freshwater aquifers in the glacial materials or upper bedrock. Thus, it would appear that the concept of area of review, using a calculated radius, would be applicable here. Unfortunately, the existence of a large number of unrecorded and unplugged exploratory boreholes in some areas may make this calculation irrelevant in the context of defining the area within which wells are to be plugged. An area of review can be calculated, but the records or location of all boreholes within this area cannot be obtained. It is apparent, then, that the radius of endangering influence would have to be reduced to zero, by keeping operating liquid levels low, in order to completely eliminate the risk of movement of undesirable fluids into the overlying fresh water. Well testing followed by calculation of the geographic extent of the theoretical zone of "endangering influence," which has not been done in the past, would aid greatly in determining the relative risks of allowing heads in the disposal zone to rise to various levels above heads in the freshwater zone, assuming that the locations of abandoned wells are scattered randomly throughout the region.

Failure Pathways. The route of pressurized fluids from an injection well to a water well consists of several links. The water must first travel through the disposal zone to a point of weakness or conduit in the confining beds such as a fracture or abandoned, unplugged borehole. If a vertical conduit exists through the confining beds and the conduit intersects a high-permeability disposal zone near the injection well, the pressure increase in the conduit may be large enough to cause upward migration of waste or native fluids. (The pressure "front" extends farther from the well than the waste "front.") Cross-formational flow can occur if the conduit has an outlet to a permeable stratum with lower hydraulic head. The fluid could also pass through an "intermediate" reservoir by discharging from a conduit into a porous and permeable lens in the confining beds, and then into a second conduit that penetrates the lens.

An outlet from a conduit to the land surface or to the freshwater zone in the glacial deposits or in the upper bedrock is the most undesirable situation and represents the primary failure scenario leading to environmental impairment. Unfortunately, the presence or absence of unplugged holes or moderately permeable fractures that penetrate the disposal zone cannot be unambiguously determined from hydraulic well tests and/or detailed geologic mapping.

Flow of waste or formation brine to the land surface may be readily observed, but flow into a freshwater aquifer may go undetected for years or decades, due to the slow rate of migration through granular deposits and the low density of wells which can be sampled to detect the foreign waters. It is not economically feasible to install an extensive array of monitor wells for the purpose of rapidly detecting the arrival of contaminants in glacial aquifers if the area to be monitored is large. However, nearby municipal and domestic wells can be sampled regularly in order to protect these users. Wells that have high average production rate should be included in a freshwater monitoring program because they sample a relatively larger part of the aquifer. Also, since the greatest pressure increase in the injection zone is near the injection well, a shallow well completed in the freshwater aquifer could be installed at the disposal site in order to provide monitoring where the driving force is highest.

Potential Consequences of Different Operating Pressure Limits. There is probably some limit to flowing bottom-hole pressure that would virtually guarantee that vertical migration in conduits in the confining beds could not occur. On the other hand, this limit might be unnecessarily restrictive in areas where the injection zone is capable of dissipating wellbore pressures in a short distance, or where the hydraulic character of freshwater aquifers or patterns of usage of local groundwater resources are not conducive to establishment of major sinks that could induce cross-formational flow.

The risks associated with different operating pressure and the resulting pressure distributions near injection wells can be evaluated by converting pressures to equivalent water levels using the density of native formation brine. These water levels are then compared to the static water levels in the overlying freshwater aquifer. If the water levels in the disposal zone are kept below those in the freshwater aquifer, upward flow can occur only in the near vicinity of pumping water wells.

Figure 6 shows the results of such a calculation based on the assumption that the disposal zone is homogeneous, isotropic, and of large areal extent. Although the storage coefficient has not been measured in Detroit River Group reservoirs, one has been chosen to represent worst-case conditions. Two profiles show the range of fluid levels that could be generated in conduits through the confining beds, depending upon the density of the injected fluids. The injection well is assumed to operate solely on gravity drive.

When salt-saturated brine is considered to be present in an abandoned borehole (saturated brine would be present in the disposal zone near the injection well), the radius of endangering influence is virtually zero under the conditions depicted in Figure 6. When fluid with the density of native brine is considered, water levels in the disposal zone would be above the base of fresh water with approximately 500 feet (150 meters) of the injection well. Within a smaller area, water levels in the disposal zone would be above potentiometric levels in the aquifer. Although the high-permeability zones in the more desirable injection well locations would have larger zones where injection zone heads would exceed aquifer heads, this could be estimated on a case-by-case basis if adequate well testing is performed. Given knowledge of the theoretical radius of endangering influence and assuming that artificial penetrations are randomly located, the risks would be proportional to the area of influence.

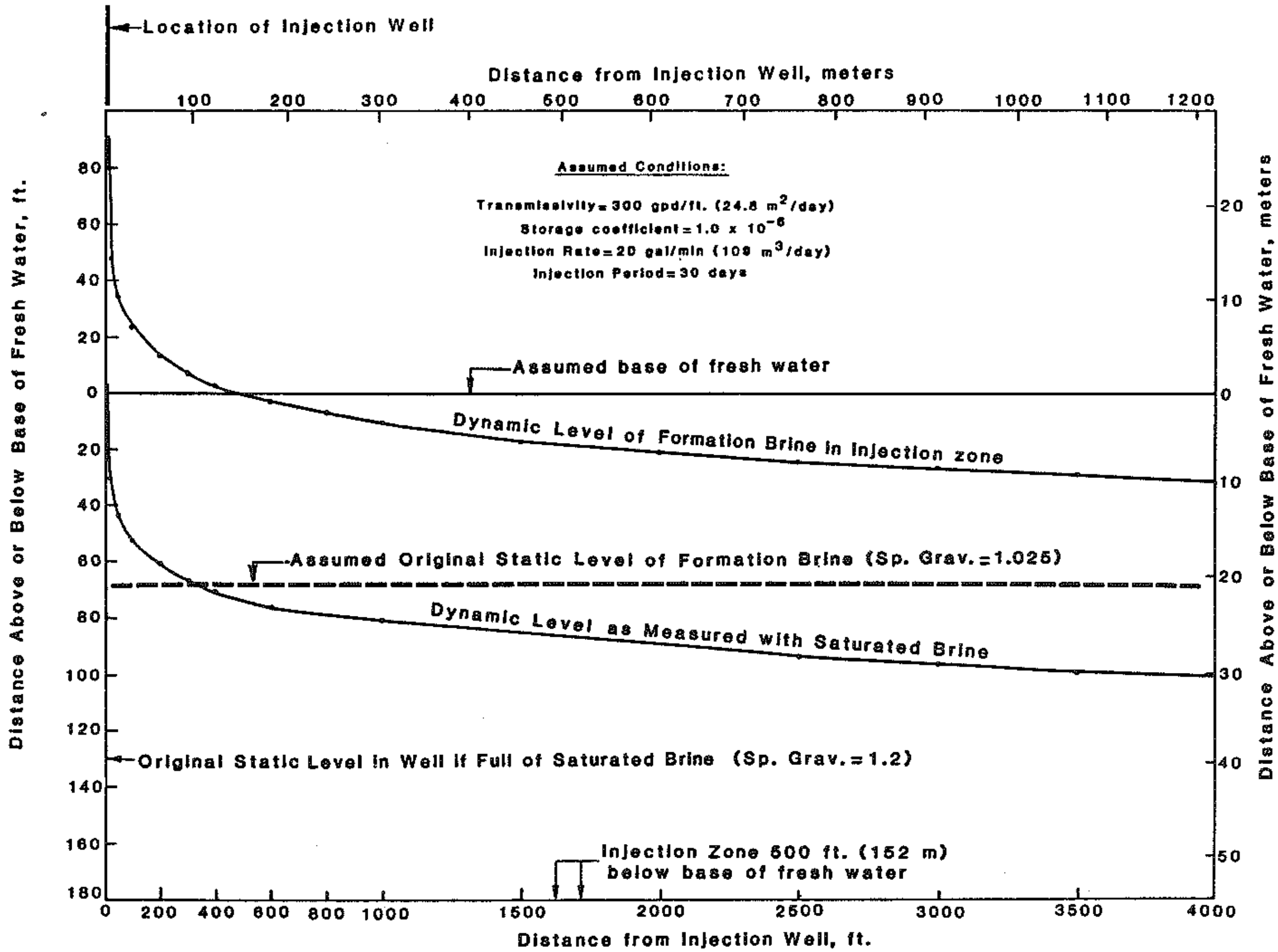


Figure 6. Hypothetical Water-Level Profile for the Detroit River Group (Homogeneous Media)

Conclusions

The available data suggest that continued injection of brines into the Detroit River Group can be accomplished relatively safely under operating rules different than most of North America. In most injection wells, shallow freshwater resources are protected from the elevated fluid pressures in the reservoir near the well by intervening low-permeability confining beds. This technique cannot be relied upon in southwestern Ontario due to the large number of undocumented abandoned boreholes. The use of the Detroit River Group for brine disposal should be restricted to gravity drive, thus those areas where high permeability allows high rates of injection would be the most desirable sites for injection wells.

The suggested regulatory procedure would require more detailed information to be gathered by the applicant than was previously necessary. This would be unnecessary if the applicant agrees to operate at a very low pressure or fluid level that was based on expectation of worst-case conditions. If the applicant desires to operate at the maximum prudent level, he would accept the responsibility for determination of the properties of the disposal zone necessary to properly evaluate the area of endangering influence of his well. An analyst would calculate the radial distribution of several assumed bottom-hole injection pressures and then convert these pressures to fluid levels using the density of the native formation brines, which would be the fluids most likely to reside in or invade undocumented boreholes. The profiles of fluid levels would be compared to profiles of freshwater heads to determine the size of the "critical area" or "area of endangering influence" that would occur at different operating bottom-hole pressures at different times, initially assuming a reservoir of infinite size. The Ministry could then choose a maximum operating bottom-hole pressure based on the area of endangering influence that appeared to present an acceptable level of risk. It is expected that due to the presence of undocumented boreholes in unknown locations, the area chosen should probably be restricted to a size which could be effectively monitored using wells installed in the freshwater aquifer.

Operators of disposal wells could monitor either operating fluid levels or operating bottom-hole pressure, but it would be to their advantage to monitor the latter. Since the hydraulic analysis would be based on bottom-hole pressures, the pressure stipulated by MOE would have to be converted to a water level using worst-case fluid density (salt-saturated brine, specific gravity = 1.2) in order to prevent exceeding the allowable pressure when using water-level criteria when this type of brine was injected. The operator would not be able to inject at the maximum allowable bottom-hole pressure if low density fluid were injected at an operating level based on saturated brine.

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Biographical Sketches

Robert T. Kent, a Principal and Vice President of Underground Resource Management, Inc. (URM), is responsible for directing a majority of the company's technical projects. Bob graduated from the University of Texas at Austin with a Bachelor of Science degree in Geology. Bob is a Professional Geological Scientist, as certified by the American Institute of Professional Geologists. He has over 12 years experience in the area of waste isolation and waste management. His major areas of expertise are subsurface injection systems and ground water contamination studies and his clients include industrial, municipal, state, and federal concerns. He has developed and presented seminars on both industrial waste injection systems and ground water contamination study techniques.

Daniel R. Brown is employed in the Technical Support Section of the Ontario Ministry of the Environment, Southwestern Region. Dan holds a Bachelor of Science degree in Geology from McGill University and a Master of Science degree in Geology from the New Mexico Institute of Mining and Technology. In his current position, he is responsible for the review of potential ground water impacts from pipelines, waste disposal operations, and other types of development.

Michael E. Bentley is a Senior Hydrogeologist with Underground Resource Management, Inc. Mike holds a Bachelor of Science in Geology from Kansas State University and a Master of Arts in Geology from the University of Texas at Austin. Mike has experience in several areas of hydrogeology including injection wells, ground water contamination studies, and water resources studies. His primary areas of interest include well hydraulics, regional hydrogeology, and contaminant site investigations.