Industrial-Waste Disposal Wells in Ohio

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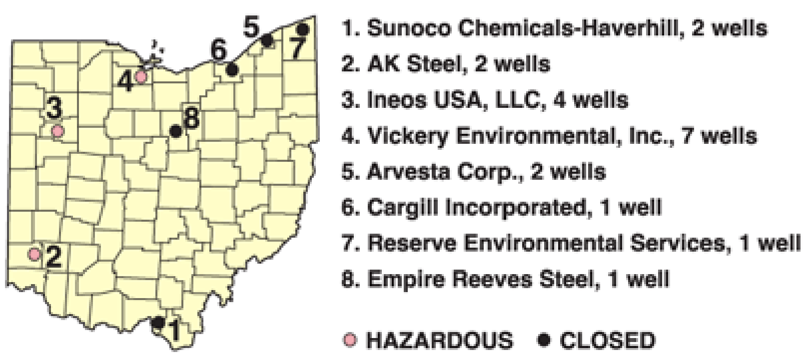
Depending upon your age, you may remember the common, pre-1970s images of industrial waste openly being dumped in American waterways. In Ohio such practices led to the near ruination of Lake Erie, the burning of the Cuyahoga River, and a proliferation of "No Swimming" signs. Fortunately, discharge of wastes into our surface waters is strictly regulated today, and many of our lakes and streams are well on their way to recovery; but this fact doesn't mean those wastes are no longer generated. The disposal of a significant volume of today's liquid industrial-waste products is through deep, subsurface injection wells. Nationwide, deep injection wells dispose of more than eight billion gallons of industrial wastes annually. Such huge volumes of liquid waste, permanently stored beneath our feet, have more and more citizens asking: "Where is it all going?"

Ohio currently has ten industrial-waste disposal wells in operation at three facilities. Eleven additional wells have been plugged during the life of this program. Approximately 260 million gallons of waste are injected annually into the deep subsurface strata of our state through the ten permitted wells. The wastes originate from a variety of industrial processes, including steel processing, fertilizer and fungicide production, and plastics production. Some of the newer components of this waste stream are products of other waste-disposal and clean-up methods, such as incinerator scrubber water, liquids recovered from industrial spill remediation, and leachate from solid-waste disposal sites.



Location of Class Injection wells.

A quick look at a list of waste generators illustrates how hard it would be for our society to do without the products from these industries. How different our lives would be without steel and metal alloys or the multitude of plastic products! And without modern fertilizers and fungicides, which dramatically increase the yield of our farmlands, the balance of American society as well as international relations would be altered. Add to this list the thousands of jobs and the millions of dollars these industries annually pump into our economy and one can quickly see that we are dependent upon these industries and thus must deal with the wastes they generate. Furthermore, we must always remember that how we deal with these wastes now will affect the well-being of generations to come.

Background

The U.S. Environmental Protection Agency's (USEPA) Underground Injection Control (UIC) program recognizes five classes of injection wells, which are are defined, in part, by each well's relationship to an Underground Source of Drinking Water (USDW). The Safe Drinking Water Act (SDWA) of 1974 designated as a USDW any aquifer whose water contains a concentration of less than 10,000 mg/L of total dissolved solids. The five injection well classes are:

- Class I wells—used for injection of industrial or municipal waste fluids beneath the lowermost formation containing a USDW.
- Class II wells—used for injection of brines produced by oil and gas production or fluids used for enhanced recovery of oil or natural gas.
- Class III wells—used for injection of fluids for the extraction of soluble minerals, such as salt solution mining in northeastern Ohio.
- Class IV wells—used for injection of hazardous or radioactive wastes into or above a USDW. As of May 11, 1984, all Class IV wells have been banned in the United States.
- Class V wells—wells not covered by Classes I through IV. These wells generally are used for the disposal of nonhazardous fluids and include storm water drainage wells, industrial-drainage wells, heat pump and air-conditioning return wells, cesspools, septic systems, floor drains, and sumps.

Under this system of classification, Ohio's deep industrial-waste disposal wells are all in the Class I category. The USEPA further subdivides this category on the basis of whether the injectate is classified as hazardous or nonhazardous waste. Three of Ohio's Class I facilities inject hazardous waste.

Deep injection of industrial wastes has been practiced since the 1950s. However, no federal regulations governed these wells until passage of the 1974 SDWA. Prior to 1974 individual states self-regulated the drilling and operation of Class I wells. In Ohio the Department of Natural Resources (ODNR) has maintained key involvement in the Class I program. The former Division of Oil and Gas originally had the responsibility of regulating this program. And the Division of Geological Survey has had the longest continuous involvement of any state agency with this program, having worked on it in various capacities since 1968.

In 1980 the USEPA promulgated most of the current UIC regulations. Under these rules, a state may develop a UIC program and apply for primary responsibility ("primacy") for that program. A state must use federal regulations as a baseline and may develop more stringent regulations. After passage of federal regulations, the Ohio Environmental Protection Agency (Ohio EPA) began taking a more pronounced role in the Class I program and in 1985 received primacy from the USEPA. Under current Ohio law, the Ohio EPA is required to review and provide technical assistance on all Class I permit applications from the ODNR divisions of Geological Survey; Soil and Water Resources; and, if the proposed well is in a coal-bearing area, Mineral Resources Management. Review by these divisions provides the Director of the Ohio EPA with information that relates a Class I well permit decision to protection of mineral and oil and gas resources, as well as ground-water availability. Comments generated by ODNR are considered by the Director of the Ohio EPA in establishing permit conditions, if it is decided that a permit to drill or a permit to operate should be issued.

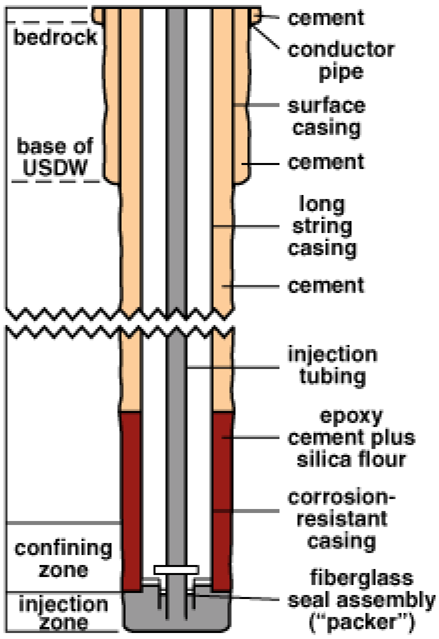
Under Ohio law, all Class I well permits are issued for five years. An operator must update each permit application and submit it for review prior to the expiration date. Permits for the three Class I facilities in Ohio are staggered so they do not all come up for review at the same time. Review of permit renewals, as well as permit modification requests, new well requests, appeals, or other Class I well issues requires the Division of Geological Survey's Energy Resources Group to spend a considerable amount of time on the geology of Class I sites.

In 1984 the U.S. Congress passed the Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act. Under this legislation, which has had a large impact on the regulation of some Class I wells, land disposal of all untreated hazardous waste is prohibited after specified dates unless the USEPA has determined that such disposal practices are protective of human health and the environment. These regulations are commonly known as the "Landban Program." Class I well operators have had to submit lengthy documents demonstrating that their sites and practices are safe and that human safety and welfare are protected. Under Landban, a petitioner must demonstrate that, to a reasonable degree of certainty, there will be no migration of hazardous constituents from an injection zone as long as the waste remains hazardous.

In 1987 the USEPA, through the Ohio EPA, contracted with the Division of Geological Survey to assist in the review of the Landban petitions for the hazardous-waste injection sites then operating in Ohio. The federal Landban regulations have strengthened the Ohio program and have allowed detailed analyses of the geology, construction, and operation of these injection wells.

The main design goal for all Class I wells is to deliver the waste to the permitted injection zone and keep it isolated without contaminating any USDW. Most problems with deep-well injection in the United States are attributable to poor well design, construction, and/or operation standards or requirements.

The general construction of a typical Class I injection well is illustrated in the accompanying diagram. The casing seals off formations above the injection zone and provides pressure control for the well operation. In some areas where bedrock is covered by thick unconsolidated deposits, a large-diameter conductor pipe is driven through these deposits into bedrock.



Schematic diagram showing typical
Class I well construction.

A large-diameter hole is then drilled to a depth below the base of the deepest USDW. Steel surface casing (approximately 2 inches narrower than the hole diameter) is run to the bottom of the hole, centered, and cemented in place. The cement job is tested for bonding throughout the length of the borehole.

The borehole is then extended to a predetermined total depth, and open-hole geophysical logs are run. These logs are necessary for determining the properties of the rocks encountered in the well and the condition of the borehole. In most instances, continuous, whole-rock core of the injection zone has been obtained for detailed analyses from at least one well from each class I site. The logs and most core from all Class I sites in the state are on file with the Division of Geological Survey. The "long string" casing is lowered through the surface casing to the prescribed depth in the hole, centered, cemented from the bottom to the surface, and tested. Depending on the material to be injected, special cements may be required. Typically, the lower portion of the long string casing is constructed of fiberglass, fibercast, or corrosion-resistant steel.

The injection tubing is placed inside the long string and sealed from the casing above by a packer at the top of the injection zone. The space between the injection tubing and the inner wall of the long string casing is called the annulus. The annulus is filled with an inert fluid (such as water and sodium chloride) and pressurized. The operator is required to constantly monitor the annulus pressure and report it to the Ohio EPA. Leakage from the tubing to the casing or from the casing to the surrounding rocks will cause either a pressure increase or decrease. The actual injection pressure also is monitored constantly. A fluctuation in either of these monitored pressures will automatically set off alarms and trigger shutdown devices to stop the injection pumps. The well operators are required to file monthly reports of their injection activities listing monitored pressures, injectate volumes, and injection rates.

A maximum allowable injection pressure, based primarily on the depth of the well, is set for each well. This limit must be below the fracture pressure for the well. This limit ensures that the operation of the injection well will not artificially initiate and propagate fractures in the injection-zone rock or the confining strata that protect the USDW's. Wells at three Class I sites in Ohio have had fracture treatment as part of their well-completion programs. Although well stimulation is not prohibited by state or federal law, the Division of Geological Survey believes that artificial fracturing in Class I injection wells is undesirable for several reasons. Most studies indicate that induced fractures at depth will be vertical. Once fractures are initiated they may be propagated further by operating the well at pressures close to the fracture limit. The integrity of injection sites is heavily dependent on modeling the flow of injectate away from the well bore and predicting the buildup of pressure as a result of continued injection. If the injectate is flowing along fractures it is not possible to reliably model the waste front or pressure front generated.

Proper well-treatment design and implementation are crucial to ensure that the rock units that make up the injection zone and confining strata will not be fractured in a way that will allow waste migration outside of permitted intervals. The Ohio EPA reviews plans for any well treatment to ensure that the integrity of the rock units will not be violated by the proposed treatment process.

Many geologic factors must be considered in choosing a suitable subsurface location for liquid-waste injection. Some of the major factors are: (1) the capacity of the geologic units to accept and confine the waste, (2) structural geology of the setting, and (3) presence or absence of valuable economic mineral resources within the potential area of influence.

Injection reservoir capacity

The three main parameters affecting the storage capacity of a geologic unit are its porosity (percentage of open pore space in the rock), permeability (degree of connectivity of pore spaces), and thickness. Another factor that must be considered is the lateral extent and consistency of a geologic unit. A thick, laterally continuous geologic unit with high porosity (storativity) through which liquids may pass easily (transmissivity) is most desirable.

The Division of Geological Survey has determined that the Cambrian-age Mt. Simon Sandstone is, throughout most of the state, the most suitable unit for emplacement of waste through Class I wells. Statewide, the Mt. Simon is the lowest Paleozoic sedimentary reservoir rock known; depth to the Mt. Simon ranges from 2,500 to over 13,000 feet below the surface. In western and central Ohio, the Mt. Simon is a fine- to coarse-grained, feldspathic to arkosic quartzose sandstone containing minor amounts of interbedded dolomite and shale. Its porosity averages about 13 percent and overall permeability is about 40 millidarcys, which are very high compared to most of Ohio's oil and gas reservoir rocks. For comparison, a "good" producing "Clinton" sandstone well (the "Clinton" is Ohio's leading oil and gas producing unit) averages approximately 8 percent porosity and 5 millidarcys permeability.

In eastern Ohio, the Mt. Simon is a dolomitic sandstone and is less suited for use as an injection unit; porosity is about 8 percent and permeability is about 10 millidarcys. The boundaries or characteristics of this west-to-east facies change in the Mt. Simon have not been mapped in detail.

In general, the thickness of the Mt. Simon Sandstone is fairly consistent throughout any particular area considered for injection purposes. Statewide, the thickness of the Mt. Simon ranges from about 44 feet to more than 300 feet, although there are areas where the Mt. Simon is absent because of depositional or structural irregularities.

Characteristics of the confining strata

In order to keep the waste from moving vertically toward a USDW or potentially valuable mineral resources, the reservoir rock for the waste should be underlain and overlain by strata with opposite flow characteristics, that is, a thick, continuous rock unit with very low porosity and permeability which will impede the flow of the injectate. Such rock units are called aquitards.

The Mt. Simon Sandstone is underlain by Precambrian crystalline rocks (billion-year-old granites, gneisses, gabbros, and metasedimentary rocks) of the Grenville Province in central and eastern Ohio and by Precambrian Granite-Rhyolite Province and East Continent Rift Basin (ECRB) assemblages in western Ohio. The Grenville Province rocks are all mostly impermeable. The ECRB has been found to contain thick sequences of sandstone and siltstone (Middle Run Formation) interlayered with extrusive igneous (mostly basalt) strata. Initial analyses of cores from two wells (Warren and Allen Counties) show that the Middle Run Formation has very low porosity and permeability but may locally contain a high degree of fracturing. The Granite-Rhyolite Province rocks are mostly igneous (andesite, basalt, granite) and metasedimentary. The ECRB, Granite-Rhyolite, and Grenville rocks should provide adequate seals to downward migration of wastes, although additional research is needed on Precambrian lithologies, contacts, and structures.

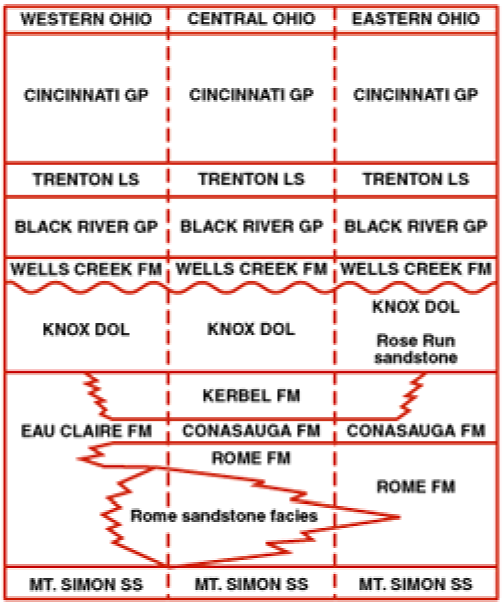
Overlying the Mt. Simon Sandstone in western Ohio are rocks of the Cambrian Eau Claire Formation. The Eau Claire is composed of interbedded shales, siltstones, fine-grained sandstones, and argillaceous dolomites. Overall, this unit normally has porosity of less than 4 percent and permeability of less than 1 millidarcy. However, some individual shale, siltstone, and dolomite layers within the unit act as very effective aquitards, having porosities of less than 1 percent and permeabilities of less than 0.1 millidarcy. Interbedded with these layers are siltstone and sandstone units of higher porosities and permeabilities. As a whole, the Eau Claire provides a very good confining layer for wastes disposed of in Class I wells; any fluids that might migrate through the less permeable units are "absorbed" by the higher permeability units.

In west-central Ohio the Eau Claire changes laterally eastward to the Rome Formation and the overlying Conasauga Formation. The Conasauga is very similar to the Eau Claire. In central Ohio the Rome is composed of a lower dolomite and an upper dolomite separated by a sandstone interval. Farther east, the sandstone disappears and the Rome is composed almost wholly of dolomite. The Rome dolomite is fairly impermeable, but the Rome sandstone has relatively high permeabilities. As with the Eau Claire Formation, the overall character of the Rome creates a good system of aquitards and buffers.

Overlying the Eau Claire/Conasauga in much of the state is the Kerbel Formation. The Kerbel is a medium- to coarse-grained sandstone and sandy dolomite that, for the most part, has excellent porosity and permeability. Where present, the Kerbel should provide another good buffer zone, storing injectate rather than transmitting it vertically.

The Knox Dolomite overlies the Kerbel Formation in its area of occurrence and the Eau Claire or

Conasauga throughout the rest of the state. The Knox also contains zones of low porosity/permeability interlayered with thick, vugular zones of high porosity/permeability.



Diagrammatic stratigraphic chart of Precambrian through lower Ordovician strata in Ohio (modified from Janssens, 1973).

In eastern Ohio the Rose Run sandstone within the Knox Dolomite provides another set of porous beds. A thick, porous zone may be present at the top of the Knox as a result of a regional erosional unconformity. The Knox unconformity may, at least locally, provide another avenue for lateral fluid migration.

Above the Knox unconformity, in ascending order, are the Wells Creek Formation, the Black River Group, the Trenton Limestone, and the Cincinnati group. Although the Trenton and the Black River may contain locally porous zones, these Ordovician strata may be viewed as a thick (>1,500 feet), low porosity/permeability succession which will impede the vertical flow of effluent upward toward any USDW. Some limestones in the upper portion of the Cincinnati group are, in some areas of southwestern Ohio, the stratigraphically lowest USDW in the state. Above the Cincinnati group lie the Silurian carbonates, which are the primary aquifers for much of western Ohio. Therefore, the Ordovician carbonates and shales may be viewed as the last inhibitor of upward migration of wastes into any sources of fresh water in western Ohio.

As can be seen in the accompanying table, the total thickness of confining strata, from the top of the active injection interval to the base of the lowest USDW, at Class I facilities in Ohio (excluding Cargill Incorporated) ranges from a minimum of 1,900 feet to 5,130 feet. Using the Mt. Simon as the primary receptor of Class I wastes insures the maximum protective thickness of strata below the lowest USDW.

Structural setting

In terms of structural geology, three areas of concern stand out when investigating the suitability of a Class I injection site: (1) the elevation of the injection interval relative to the surrounding structural setting, (2) the presence or absence of faults and/or fracture systems, and (3) the potential for injection-induced earthquakes.

In the subsurface environment, the natural flow of fluids, in general, follows the most direct path from areas of higher pressures to areas of lower pressures. Because the amount of overlying rock is the primary pressure-loading factor, this concept translates into flow from deeper environments to shallower environments along the path of least resistance. These normal flow rates are low, on the order of several inches per year at the depth of the Mt. Simon.

The injection rate and pressure will yield an approximate hypothetical radial flow of the injectate laterally away from the well into the injection formation. Continued injection creates an area around the well where pressures are higher within the injection formation. The longer the injection continues the larger the radius of this pressure front becomes. Thus, ideally, the fluid seeks to escape this higher-pressure area in a radial pattern. Once away from the area of pressure influence caused by injection, the fluid resumes its natural flow pattern. This flow pattern is dependent upon the relationship of the site to the local structural setting and hydrodynamic characteristics of the reservoir and confining layers.

If the site is located at the lowest portion of a downwarp or synclinal depression, the flow should continue to approximate a radial flow pattern, seeking lower pressure areas on the surrounding highs. If it is on the flank of a rise, the natural flow should be asymmetric toward the higher elevation. If the site is located at the top of an arch or anticlinal feature, lateral flow away from the injection site would be impeded by the natural flow (toward the injection well) of native formation fluids. This latter situation is undesirable because the injectate will then be inclined to migrate vertically should vertical routes exist.

Flow away from the injection site should follow the general principles given above unless:

- The integrity of the well construction fails.
- A permeability barrier is encountered, such as a nontransmissive fault or fracture, a sedimentary facies change in the reservoir rock, or the thinning of the injection unit against a unit of lower permeability.
- An avenue of higher permeability is encountered, such as a transmissive fault or fracture, artificial fractures induced in the rock, intersection with an unplugged well bore, or a facies change in the reservoir rock that results in a higher flow rate.

Aside from failure of a well's construction and the possibility of encountering an unplugged well bore, the potential for upward migration along a naturally occurring fault plane is probably the most serious threat to loss of integrity of waste confinement at a Class I site. Although fluid movement along a fault plane that is transmissive may proceed faster than through the confining strata, it may still proceed very slowly, from a human perspective. Injectate moving along a naturally occurring fault may take tens, hundreds, or thousands of years to reach a USDW, but it could still have undesirable effects when it does arrive. Because of this potential threat, the Division of Geological Survey investigates every site as thoroughly as possible for any indication of the presence of faults.

Earthquakes induced by injection of fluids are a well-known phenomenon. Probably the most widely publicized and documented instance was the series of earthquakes triggered by military waste injection at the Rocky Mountain Arsenal near Denver, Colorado. Several earthquakes in northeastern Ohio caused public concern that they too may have been triggered by deep injection wells.

When discussing the possibility of induced seismic events it is important to understand that injection activities do not cause earthquakes; rather, injection may trigger earthquakes.

Earthquakes are caused by the accumulation of crustal elastic-strain energy in a rock body that raises the stress level of the body to critical levels near rupture. An earthquake occurs due to the sudden release of energy as stress is released, generally along pre-existing faults. Therefore, injection of fluids into the subsurface cannot, by itself, establish the conditions necessary to cause an earthquake. But the injection of fluids into the subsurface can increase the pore pressure along a pre-existing fault, which may already be at, or near, a critical level of stress, to trigger a local release of seismic energy.

To reduce the risk that an injection well may trigger a seismic event, the U.S. Geological Survey has recommended that a review of the site should include: (1) a survey of recent and historic seismicity in the area, (2) measurement of stress in the reservoir rock, (3) assessment of the presence or absence of faults, and (4) determination that the intended injection zone has adequate porosity and permeability to store and transmit the waste at pressures well below the failure pressure of the rock. If the area appears to have any risk of seismic activity, a seismic monitoring program should be established.

To insure the integrity of the waste reservoir and to protect our mineral resources, the environment, and human well-being, the Division of Geological Survey began requesting seismic-reflection profiling and seismic-activity monitoring on Class I sites in the mid-1980's. Ohio legislation now includes authorization for the Director of the Ohio EPA to require such data collection on all Class I sites. Seismic profiling is the least expensive and best available technology to reveal geologic structures and details of stratigraphy over the area of potential influence. The use of seismic profiling is not foolproof; at best its resolution is normally about 30 feet (in terms of vertical offset or bedding thickness) at the depths under consideration. However, it is much better than having data from only one or a few wells to evaluate an area of pressure buildup that may reach 50 square miles or more. These data are proving to be a valuable tool in Class I site evaluations. Approximately 250 line miles of 2D seismic reflection profiles related to the Class I wells have been submitted to the Ohio EPA. Copies of these data are on file at the Division of Geological Survey.

Mineral resources

With time and the continued growth of our industrialized society, more and more natural resources are thought of not just as routine commodities, but as essential commodities. When oil was first found in salt wells in 1812 it was viewed as a nuisance; now our culture is heavily dependent upon its availability and price. Furthermore, mineral resources are not renewable; some may eventually become so scarce that worldwide shortages and socioeconomic disruptions could result. A conservative approach seems wise when protecting mineral resources from contamination by wastes. To protect mineral resources, the Division of Geological Survey believes that the Mt. Simon Sandstone is the most appropriate formation for Class I waste injection where it is present as a porous, permeable, unfractured reservoir.

For more information about Ohio's Underground Injection Control Program, visit the Ohio EPA Web site.

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