

SUBSURFACE INJECTION OF LIQUID WASTE IN FLORIDA,
UNITED STATES OF AMERICA

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ABSTRACT

In 1979, liquid waste was injected into the subsurface of Florida by 10 injection systems at an aggregate average rate of 165,000 m³/d. All the systems inject into carbonate rocks that contain salty water. Extensive precautions are taken in the construction of the injection wells and in the monitoring of their operation to provide assurance that overlying and laterally contiguous freshwater resources do not become contaminated with either the injected waste or the saltwater displaced by the waste. Several concerns relating to the effectiveness of the confining bed above the injection zone for containing the injected wastes have arisen over the years. These concerns accentuate the value of a well-planned and implemented monitoring program from which one can evaluate the potential impact of waste injection on the subsurface environment.

INTRODUCTION

The practice of injecting liquid waste into the subsurface of the State of Florida began in 1959 and has been growing since. As of the end of 1979, ten systems were operational, eight of which are in the southern part of the State (Fig. 1). Five of the systems inject industrial liquid waste; the other five inject effluents from municipal sewage treatment plants. These systems inject a combined average of about 165,000 m³/d of which 21,000 m³/d is industrial liquid waste and 144,000 m³/d is municipal wastewater (table 1). Other systems currently being planned, constructed, or tested are expected to inject an additional 795,000 m³/d of treated sewage when fully operational. All of these new systems are or will be located in the southern part of the State, either along the densely populated southeastern coast or in Pinellas County along the west central coast of Florida west of Tampa.

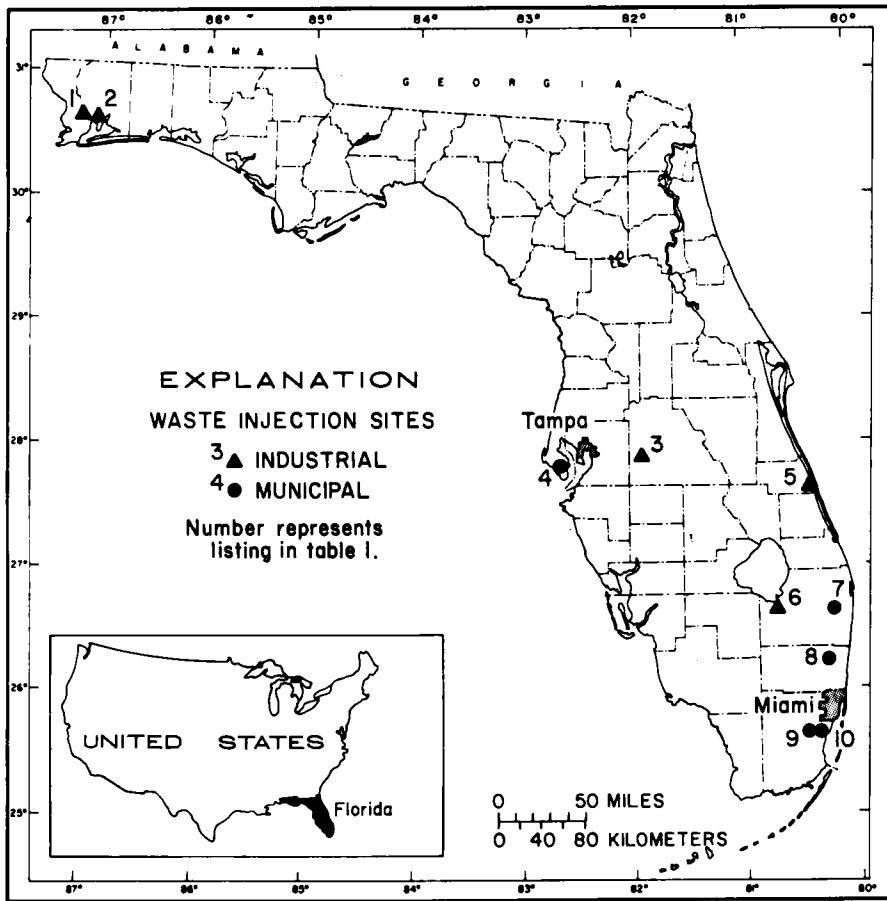


Fig. 1. Active waste injection sites in Florida, 1979.

TABLE 1
Active waste-injection systems, 1979

Number in Fig. 1	County	Number of active injection wells	Start of injection	Type of wastewater	Average injection rate m ³ /d
1	Escambia	2	1963	Industrial	11,730
2	Santa Rosa	1	1975	Industrial	3,030
3	Polk	1	1972	Industrial	1,140
4	Pinellas	1	1979	Municipal	15,100
5	Indian River	1	1979	Industrial	950
6	Palm Beach	1	1966	Industrial	3,890
7	Palm Beach	3	1979	Municipal	68,300
8	Broward	1	1975	Municipal	22,900
9	Dade	1	1973	Municipal	13,400
10	Dade	1	1971	Municipal	24,600
Total (rounded)					165,000

Oil-field brines also are injected at two locations--one in the extreme northwestern part of Florida and the other in the southern tip of the State. In addition, several thousand wells inject excess surface waters into underlying aquifers for drainage purposes. Virtually all of these drainage wells are in the peninsular part of the State. However, only passing mention of these other types of injection is made here as the focus of this paper is on injection of industrial and municipal wastewaters.

HYDROGEOLOGY

The Florida peninsula is the emerged part of the much wider Floridan Plateau, a prominent southeastern projection of the North American continent. The Floridan Plateau is underlain by a thick sequence of coastal plain sediments, ranging in age from Cretaceous to Holocene, that are predominantly limestones and dolomites with some evaporites and clastics. These sediments lie on middle Paleozoic and older sedimentary and crystalline rocks.

The carbonate beds of Eocene age particularly are generally porous and permeable and, collectively, these rocks comprise the major part of the Floridan aquifer--the principal source of fresh-water throughout most of Florida. However, in southern Florida the deeper part of the aquifer, and in some areas the entire thickness of the aquifer, contains moderately to very saline water. Saline water occurs also in the lower part of the Floridan aquifer in the westernmost part of the State and along much of the coastline. These saline parts of the Floridan aquifer, where other hydrogeologic conditions are suitable, are considered for the injection of industrial and municipal wastewaters.

Hydrogeologic factors considered in evaluating the potential of encountering subsurface zones in Florida suitable for injection of wastewater are (ref. 1): (1) permeability and porosity, including type of porosity, (2) salinity of formation water, (3) degree of vertical confinement, (4) geologic structure, and (5) potential for oil or mineral development. These factors have been used by Miller (ref. 1) in identifying the probability of encountering subsurface hydrogeologic conditions suitable for high-rate (more than 3,785 m³/d) injection throughout Florida. His map in abbreviated detail is shown as Fig. 2.

Injection at the two sites in northwesternmost Florida is into limestone of late Eocene age which constitutes the lower limestone of the Floridan aquifer. Transmissivity of the injection zone is

78 m²/d (ref. 2) at one site and 135 m²/d at the other (ref. 3). The top of the injection zone lies at depths exceeding 400 m. Dissolved solids concentration of the formation water is 12,000± mg/L at the injection sites, but 32 km to the northeast the water is fresh. The injection zone is overlain by a clay bed 60 m thick of extremely low vertical hydraulic conductivity--less than 1×10^{-6} m/day (ref. 4). The freshwater supply for the area is obtained from the surficial sand-and-gravel aquifer which extends to depths of 90 to 120 m below land surface.

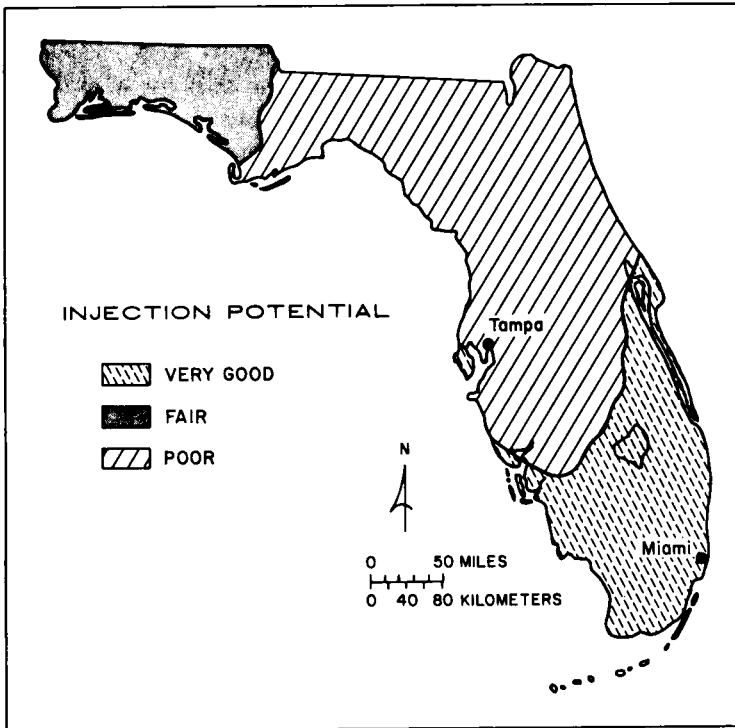


Fig. 2. Potential for subsurface injection of liquid waste in Florida considering hydrogeologic conditions. (Modified from ref. 1.)

In west central Florida on the Pinellas County peninsula just west of Tampa, injection is into dolomite of middle Eocene age which has a transmissivity of 93,000 m²/d (ref. 5). Dissolved solids concentration of the formation water is about that of seawater. The top of the injection zone is about 235 m below land surface. It is capped by limestone and dolomitic limestone that

has a vertical hydraulic conductivity of about 0.03 to 0.3 m/day. The principal water supply for the area is obtained from sites about 30 km or more to the north and northeast where the injection formation and the overlying limestone contain freshwater.

Florida's deepest injection well is in the central part of the peninsula, number 3 in Fig. 1. This well injects into limestone and dolomite of Paleocene and Late Cretaceous age at a depth interval of from 1,220 to 1,520 m below land surface (ref. 6). Transmissivity of this zone is less than $100 \text{ m}^2/\text{d}$ and may be as low as $37 \text{ m}^2/\text{d}$. These rocks contain brine having a dissolved solids concentration of 120,000 mg/L. The injection zone is overlain by 240 m of alternating beds of dolomite and anhydrite of Paleocene age that have low to very low permeability. The overlying Eocene carbonate rocks at this site are quite permeable but they contain water that is fresh in the upper part to moderately saline in the lower part. The freshwater-bearing part of the Eocene rocks is the principal source of water for the area; this aquifer extends to a depth of 472 m below land surface.

In southeastern Florida, a solution-riddled dolomite of early Eocene and late Paleocene age serves as the injection zone. These rocks are extremely permeable: their transmissivity is at least $300,000 \text{ m}^2/\text{d}$ (ref. 7). The top of this zone occurs at depths ranging from 800 to 1,000 m below land surface. The cavernous nature of these rocks causes difficulties in drilling through them and because of these difficulties the zone is known as the "Boulder zone." The zone contains water of basically seawater composition. Overlying the injection zone is almost 300 m of alternating limestone, chalk, and dolomite beds of overall low permeability. The freshwater supply for the area is obtained from the surficial Biscayne aquifer, which is predominantly a limestone of late Miocene through Pleistocene age that extends to a maximum depth of about 50 m.

MONITORING REQUIREMENTS

In Florida, extensive monitoring of the injection process and of the hydrogeologic system is required to assure that the freshwater resources are not being adversely affected by subsurface injection of wastes. Several factors contribute to this need. First, and most important, the hydrologic characteristics of the carbonate rocks underlying Florida are not easily conceptualized because of difficulties in predicting porosity and permeability distribution

owing to irregularly spaced fracture and solution openings. The larger openings also often cause difficulties in cement grouting of well casings which may result in doubt as to the effectiveness of the grout in sealing avenues for upward migration of the injected waste or of displaced formation water. Secondly, most of the existing or planned injection systems involve large volumes of waste--measured in thousands of cubic meters per day. Moreover, these large volumes are injected into saltwater-bearing parts of the same aquifer system that much of Florida depends on for its potable water supply. Lastly, at most of the injection sites, one or more freshwater aquifers overlie the injection zone.

The needed monitoring falls into two categories: "facilities monitoring" and "aquifer-system monitoring" (ref. 8). Facilities monitoring involves observations of the injection process for the purposes of evaluating well performance and for detecting failures in the integrity of the injection well. Some problems that can be detected through facilities monitoring include: (1) casing failure, (2) grout or packer deterioration, (3) clogging of aquifer pores adjacent to the well, and (4) severe dissolution of the receiving rock matrix. Parameters that are monitored include: (1) injection pressure, (2) rates and volumes of injection, (3) annulus pressure, where injection tubing is used, and (4) physical and chemical characteristics of the waste fluid.

Aquifer-system monitoring involves observations of the response of the subsurface environment to the stress of injection. These observations enable refinement of the conceptual and/or the predictive model of the hydrogeologic system and thus improve the degree of confidence associated with evaluations of the impact of subsurface waste disposal. Specific objectives of aquifer-system monitoring include: (1) determination of the pressure buildup distribution, (2) location of the waste and evaluation of the rate and manner in which it is moving, (3) assessment of changes in the characteristics of the waste, (4) detection of upward migration, and (5) displacement of saltwater-freshwater interfaces.

Aquifer-system monitoring is accomplished through observations of aquifer head and water quality from one or more observation wells. The degree of monitoring that is needed varies from site to site in accordance with hydrogeologic factors and the characteristics and quantity of the injected waste liquid. A thorough aquifer-system monitoring program that has been employed in Florida includes: (1) on-site wells located within 30 m of an injection well and open

to the next higher permeable stratum, (2) satellite wells located from some 30 to 3,000 m from an injection well and open to the receiving aquifer, and (3) regional wells located several or more kilometers from individual injection wells and open to the receiving aquifer (Fig. 3).

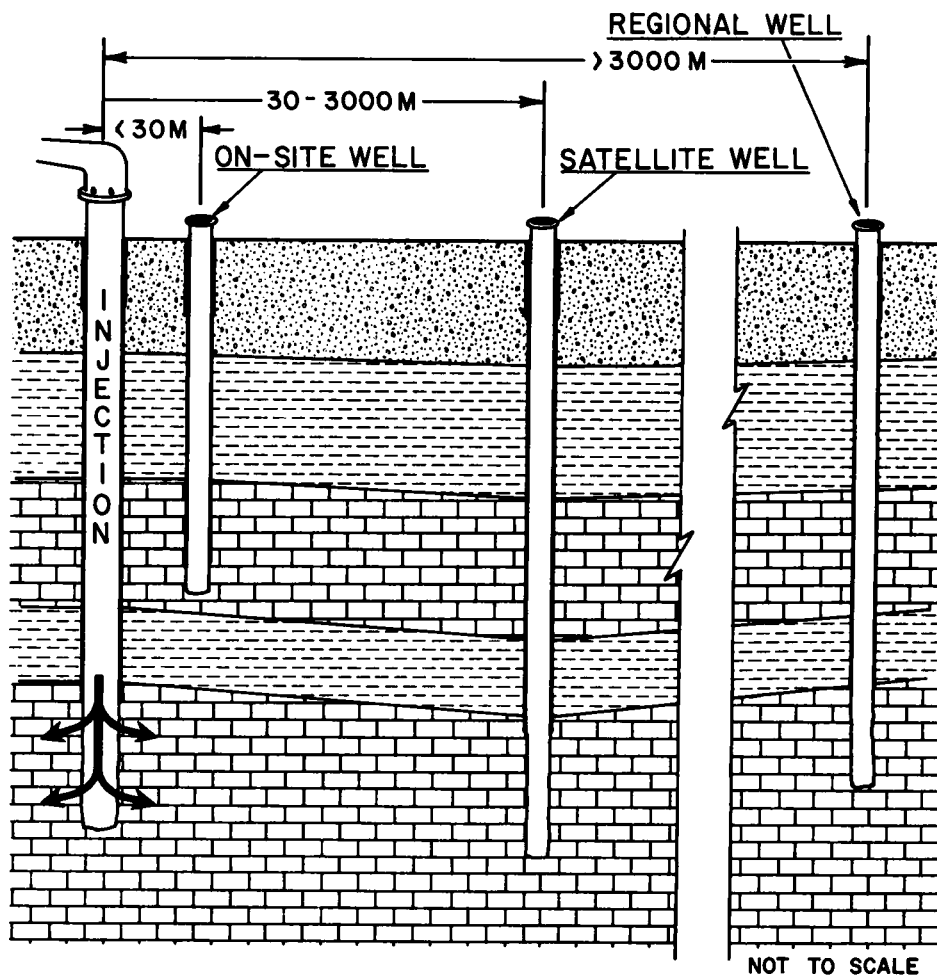


Fig. 3. Schematic diagram showing idealized spatial array of aquifer-system monitoring wells around an injection well.

On-site wells are used to monitor possible upward migration of the injected waste or displaced saltwater. Satellite wells are used to monitor the hydraulic effects of individual systems, movement of the waste, and alteration of the characteristics of the waste.

Regional wells are used to monitor the coalescing hydraulic effects of two or more systems and the potential for lateral displacement of a saltwater-freshwater interface. The information obtained from such a monitoring program is used to demonstrate that freshwater resources are not being adversely affected and to improve the understanding of how the hydrogeologic system responds to the stress imposed on it by waste injection--an area in which experience is quite limited.

MAJOR CONCERNS

The more significant concerns that have developed over the years relate primarily to the effectiveness of the confining bed overlying the injection zone for containing the injected waste and/or the saltwater displaced by the waste. During exploratory drilling and construction, much emphasis is placed on identifying the thickness, character, and hydrologic properties of the confining bed. Moreover, each injection site has as a minimum an on-site well or facsimile for monitoring conditions in the next permeable stratum above the confining bed. In some cases, this monitoring capability is provided within the injection well borehole by inserting a tube in the grout sheath that surrounds the injection casing throughout its depth except for the interval to be monitored.

The potential for upward migration results from several causes. The buildup in pressure within the injection zone can result in a large potential gradient across the confining bed. If the pressure becomes great enough, the confining bed may fracture, thus facilitating liquid movement through it. Thus far, major pressure buildup has occurred only in northwest Florida, particularly at site 1 in Fig. 1. The State regulatory agency has set a limit on the allowable pressure at the point of injection of about 60 kg/cm^2 in order to avoid fracturing the confining bed. Pressure buildup at that site in recent years has been about 54 kg/cm^2 (ref. 9).

Failure of the integrity of the confining bed through collapse and/or dissolution is a concern at sites where acidic industrial waste is being injected. At site 6 (Fig. 1), upward migration of the injected waste, which is hot ($\sim 75^\circ - 93^\circ\text{C}$) acidic ($\text{pH} \sim 2.6-4.5$), and less dense than the formation water, has been observed through sampling of a monitor well that penetrates to within 30 m of the injection zone top (ref. 10). At site 3 (Fig. 1), severe dissolution of the receiving strata by the injected acidic ($\text{pH} \sim 1$) industrial waste has occurred. A cavity 30.5 m high has developed around the

injection well bore to a maximum radius of at least 7 m. There is concern that continual growth of the cavity with accompanying spalling of the roof rock could destroy the integrity of the overlying confining bed.

Lastly, most of the wastewater that is or will be injected in Florida is treated sewage having a density of about 1 gm/cm^3 . This wastewater is injected into and displaces saline water having a density of about 1.025 gm/cm^3 . The resulting buoyant forces add to the hydraulic forces of injection, thus increasing the potential for upward migration of the injected wastewater or displaced saltwater.

SUMMARY

The practice of injecting liquid waste into the subsurface of the State of Florida began in 1959 and has been growing since. In 1979, the aggregate rate of injection of 10 operational systems averaged about $165,000 \text{ m}^3/\text{d}$. Of this total, secondarily treated sewage accounted for $144,000 \text{ m}^3/\text{d}$ and industrial effluents made up the remaining $21,000 \text{ m}^3/\text{d}$. Other systems currently being planned, constructed, or tested are expected to inject an additional $795,000 \text{ m}^3/\text{d}$ of treated sewage when fully operational.

All the operational systems inject into carbonate strata of mainly Eocene age, except for one that injects into carbonate strata of Paleocene and Late Cretaceous age. The receiving Eocene beds are saltwater-bearing parts of the Floridan aquifer, the principal source of freshwater throughout most of Florida. Extensive precautions are taken in the construction of the injection wells and in the monitoring of their operation to provide assurance that overlying and laterally contiguous freshwater resources do not become contaminated with either the injected waste or saltwater the waste displaces.

The more significant concerns that have developed over the years relate primarily to the effectiveness of the confining bed overlying the injection zone for containing the injected waste. For example, at one installation, the dissolution of overlying carbonate strata by the injected hot, acidic industrial waste has resulted in upward migration of the waste. At another, severe dissolution of the receiving strata by acidic industrial waste has resulted in the formation of a cavity 30.5 m high around the original injection well bore to a maximum radius of at least 7 m. At still another site, the pressure buildup approaches what the State regulatory

agency considers to be the safe limit to prevent hydraulic fracturing of the overlying confining bed. These occurrences underscore the concern and support the need for a well-planned and implemented monitoring program from which one can evaluate the potential impact of waste injection on the subsurface environment.

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