A CLASS I INJECTION WELL SURVEY

Phase I Report: Survey of Selected Sites

Prepared for

UIPC

UNDERGROUND INJECTION PRACTICES COUNCIL

Oklahoma City Oklahoma

Prepared by CH2M HILL

April 1986

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EXECUTIVE SUMMARY

In August 1985, the Underground Injection Practices Council (UIPC) funded a study to conduct a national survey of Class I injection wells. The study was conducted by an independent, nationally recognized consulting engineering company. The two-phase study provides a comprehensive data base and an objective summary of the performance and operation of Class I injection wells.

Phase I of the study consisted of a survey of the operational history of 45 Class I well sites representing 106 individual wells. The selection of these 45 sites was based upon published reports and input from Underground Injection Control (UIC) program directors that identified injection well facilities with some history of alleged operational problems.

Phase II of the study consisted of a survey of approximately 250 Class I injection well sites (representing approximately 500 individual wells). Phase II included development of a comprehensive data base for each of these sites and an assessment of the performance characteristics of Class I injection wells. For both phases, the primary data source was the files of either the state or federal agency responsible for regulating Class I injection wells.

This report, which addresses only Phase I, provides a factual summary of the events surrounding alleged operational problems at 45 Class I injection well facilities. Case histories for each of these sites were prepared based on information in the appropriate agency files. Each owner and respective agency director was afforded the opportunity to review the draft case histories.

Approximately 45 percent of the owners and respective agency directors responded with comments. In those cases where additional factual and documented information was provided, the case histories were revised to incorporate this information. Other comments received that could not be documented, such as opinions regarding interpretation of data or information, were not included in the revised case histories.

The 45 sites selected for the Phase I survey reportedly had histories of operational problems. Many of these facilities were alleged examples of "failures" of this waste disposal technology. The results of the study, however, did not support these allegations. In fact, the results of this study showed the following:

- No factual documentation for health-related problems attributed to injection was found at any of the 45 sites.

- Only five sites had confirmed instances of leakage into an aquifer classified as an underground source of drinking water (USDW).

Many of the alleged injection well problems were either unrelated to the injection well operation itself or erroneously associated with well maintenance operations. In some cases, incidents involving waste handling, storage, and/or operations at surface facilities located at the same site as the Class I well were the actual cause of the problem. In other cases, routine well maintenance activities were equated with the problems.

Operational problems that can actually be characterized as well malfunctions include those events that allowed or may have allowed injected waste to escape confinement and migrate to the surface or underground or resulted in the well becoming permanently (and involuntarily) inoperative. Actual well-related malfunctions were identified at less than half of the injection wells at these 45 facilities.

In addition to the five sites where confirmed leakage into a USDW was identified, some type of malfunction related to the injection well(s) was identified at 21 other sites. The malfunction categories included contamination at the surface; leakage into an unpermitted zone, but not a USDW; and other. For most of these cases, the problems attributed to the injection well itself were related to design, construction, and/or operation standards or requirements which would <u>not</u> be allowed under current UIC regulations. In other instances, operator error, rather than inadequate or poor design or construction, resulted in the operational problem.

In virtually every case, including those sites where leakage into a USDW occurred, the problems have been or are being corrected. Corrective action typically includes plugging or reworking the well, drilling new wells, or developing alternative disposal methods. At several sites where groundwater and/or surface contamination had actually occurred, cleanup activities have been implemented.

The 45 sites examined in Phase I represent approximately 20 percent of the operational or previously operational Class I wells in the United States. This phase specifically focused on injection wells with alleged histories of operational problems. Only five of the 45 sites had confirmed leakage into a USDW. Furthermore, no factual documentation of health-related problems attributed to the injection wells was found at any of the 45 sites.

This report includes a summary of the results and the case histories, as well as discussions on the purpose and objectives of the study and the procedures used to collect data. Additional data and information regarding these Class I well facilities are contained in the Phase II Report, the Class I Well Data Base Report, and the Case History Review Appendix, all of which are available from the UIPC.

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FIGURES (Continued)

ACKNOWLEDGEMENTS

The following agencies provided valuable cooperation, support, and assistance in compiling the information presented in this document:

- o Alabama Department of Environmental Management
- o Arkansas Department of Pollution Control and Ecology
- o Florida Department of Environmental Regulation
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- o Kansas Department of Health and Environment
- o Louisiana Department of Natural Resources
- o Mississippi Department of Natural Resources
- o Natural Resources Defense Council
- o North Carolina Department of Natural Resources and Community Development
- o North Dakota State Department of Health
- o Oklahoma State Department of Health
- o Ohio Environmental Protection Agency
- o Commonwealth of Pennsylvania Department of Environmental Resources
- o Texas Water Commission
- o U.S. Environmental Protection Agency
  - Office of Drinking Water
  - Region II
  - Region III
  - Region IV
  - Region V
  - Region VIII
  - Region IX
  - Region X

These agencies supplied the project team with access to correspondence and report files, inventories, and data

bases; work space accommodations; and explanations of individual programs and file organization. UIC Program Directors and their staffs also provided timely review of the draft case histories.

Dr. Don L. Warner, of the University of Missouri-Rolla, critiqued drafts of the data collection worksheets. He also provided initial technical review of the case histories.

Section 1
INTRODUCTION

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PURPOSE

In the 1984 Hazardous and Solid Waste amendments to the Resource Conservation and Recovery Act (RCRA), Congress mandated that EPA investigate the underground injection of certain RCRA hazardous wastes. The EPA Administrator must promulgate final rules that may prohibit the injection of certain hazardous wastes, if he determines that injection as a disposal method may not protect human health and the environment for as long as the waste remains hazardous. This potential ban has generated widespread interest in underground injection.

The Underground Injection Practices Council (UIPC) is an incorporated, non-profit national organization composed of state UIC directors, representatives from other state and federal agencies, industries, well owners, consultants, and other individuals interested in underground injection. UIPC serves as a national forum for organizing discussions and consolidating technical information on issues related to groundwater resource protection and injection wells.

UIPC's first research priority was to undertake a study that would provide a comprehensive data base on the operation and performance characteristics of Class I injection wells. This study was designed to provide an objective assessment of the reliability of injection wells as a means of waste disposal.

OBJECTIVES

The objectives of the study include the following:

- o Provide timely and factual information on Class I injection well operations.

- Summarize the events surrounding alleged operational problems at selected injection well sites (Phase I).

- Collect and evaluate data on the performance of operational or previously operational Class I injection wells (Phase II).

The study was conducted in two phases, with the results published in two separate reports. The first phase of the study, presented in this report, summarizes the events surrounding the reported problems at 45 operational or previously operational injection well sites in the nation. The Phase II report will include a compilation of data on approximately 500 Class I wells in the nation, and summarize their overall performance.

UIC PROGRAM DEVELOPMENT

The Underground Injection Control (UIC) program is based on the federal Safe Drinking Water Act (SDWA). In 1974, Congress became concerned about the increasing use of injection wells for waste disposal and the potential problems this practice may pose to the nation's underground sources of drinking water (USDW's). EPA has designated any groundwater that currently supplies drinking water for human consumption or which contains a total dissolved solids (TDS) concentration of less than 10,000 mg/L as a USDW. Such waters receive protection under the UIC program.

Under Part C of the SDWA (Public Law 93-523, as amended by Public Law 96-502; 42 USC 300f et seq.), Congress directed EPA to develop a nationwide UIC program that would regulate injection systems and protect USDW's. EPA was charged with developing minimum federal requirements which every state had to meet; however, states had the option of developing regulations that were more stringent than the federal regulations.

EPA promulgated the current UIC regulations in 1980. The Congressional intent was for the individual states to administer the UIC program. States could receive EPA grant money to develop a UIC program and apply to EPA for primary responsibility ("primacy") for that program. In states without UIC primacy, EPA administers the program directly (known as a "direct-implementation" state).

The UIC program establishes five classes of injection wells. The classes of injection wells are defined, in part, by the well's physical relationship to a USDW. Class I wells, which are the subject of this report, are wells that inject fluids beneath the lowermost formation containing a USDW. Class II wells are used to inject brines produced by oil and gas activities, or to inject fluids for enhanced recovery of oil or natural gas. Class III wells are those that inject fluids for the extraction of minerals, such as in solution mining operations. Class IV wells inject hazardous or radioactive wastes into or above a USDW. Class IV wells injecting directly into a USDW were banned nationwide on May 19, 1980 (40 CFR Part 122.36), and all other Class IV wells were banned on May 11, 1984 (40 CFR Part 144.13). Class V wells are injection wells not covered by Class I through IV, and generally include wells injecting non-hazardous fluids into or above a USDW.

Individual states have the option of applying for primacy for all or only a portion of the classes. For example, in California, EPA administers the UIC program for Class I, III, IV, and V wells, while the state runs the program for

Class II wells. As of July 1985, of the 57 states or jurisdications, 33 have full primacy for all types of injection wells, while EPA is running the entire UIC program in 19, and 5 have shared primacy.

New regulatory requirements, along with advances in technology, have significantly improved the design and operation of injection well disposal systems. The primary performance standard for a well is whether the injected fluid is contained in the injection zone and is prevented from migrating into overlying non-permitted formations. Federal UIC regulations provide the minimum standards for the design and operation of the injection wells. State requirements may exceed federal regulations to provide an even greater degree of protection to local natural resources.

Section 2
SUMMARY

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SUMMARY

Class I injection wells were in use, or had been used, for wastewater disposal at only 43 sites of the 45 sites selected for evaluation. The operating and monitoring records of these 43 facilities were compared with the operational problems attributed to the facilities. Because one of the two remaining sites was a Class V well site, and the well at the other site was never constructed, operating data were not evaluated in these two cases. The status and operational history of injection wells at each of the 45 sites is summarized in Table 2-1 at the end of this section.

At 17 of the facilities studied, no environmental problems related to well malfunctions were noted. These survey results were in direct contrast to the expectations that such problems would be found at virtually every facility. Nevertheless, some kind of well-related malfunction was identified at 26 sites. In developing the case histories, it was noted that virtually all such incidents occurred before the development of the current minimum UIC standards. For example, two incidents of leakage into a USDW were related to a well design prohibited in the current regulations. Therefore, these events are unlikely to occur under today's standards.

CATEGORIES OF MALFUNCTIONS

Malfunctions associated with the injection operation at the 26 facilities fall into the following four general categories: leakage into a USDW, contamination at the surface, leakage into an unpermitted zone not containing a

USDW, and other. At four facilities, operational events fell into more than one category. Sites in each of the categories discussed below are referenced to the well numbers shown in Table 2-1.

Leakage into a USDW. Leakage into a USDW is reasonably documented to have occurred at five of the sites evaluated (No. 8, 9, 12, 23, and 44). These incidents were most commonly the result of a leak in the injection well casing, and were detected by either annular monitoring or via a separate monitoring well. In one case, the leak was detected when the injected fluid appeared at land surface around the wellhead. The affected area in this case appeared to be limited to the immediate vicinity of the well, based on data from monitoring wells.

At one of these five sites (No. 12), injection was actually permitted into a zone that was later reclassified as a USDW. Leakage into a USDW also occurred at this site. Individual states have, in the past, permitted injection into aquifers with TDS concentrations greater than approximately 3,000 mg/L, rather than the current standard of greater than 10,000 mg/L. No Class I system still discharging into groundwater with less than 10,000 mg/L was found during this study.

Leakage is suspected to have occurred at three other sites (Nos. 2, 11, and 17). At these sites, the leakage was not actually confirmed, but was presumed to have occurred because conditions existed which could have permitted leakage.

Some type of corrective action was completed in response to each of the leakage events. Wells were permanently plugged and removed from service at four sites. At two sites, the wells were taken out of service, and will either be plugged or converted to regional monitor wells. The wells were repaired at the remaining two sites, with one well placed back in service and the other in the process of being placed back in service.

Aquifer restoration and cleanup efforts were begun at three sites. An extensive groundwater contamination investigation was conducted at one site, which included drilling numerous monitor wells and installing a groundwater recovery system. Over 5.2 million gallons of contaminated water had been recovered by December 1984. At another site, a recovery system was installed and pumped until the contamination reached a level acceptable to the regulatory agency. At the third site, the open annulus in which wastewater had been detected was pumped (and the recovered water reinjected) until remedial cementing of the annulus was completed.

Contamination at the Surface. Contamination at the surface is reported to have occurred as a result of well operations at only four of the facilities evaluated (No. 11, 23, 31, 43). At two of these sites, operational problems falling into other categories also occurred. Contamination at the surface includes the spillage or leakage of formation, annular, or injection fluids on the land surface. These incidents occurred as a result of excessive injection pressure causing a blowout at the well head or surface piping, flow from improperly abandoned wells within the area of potentiometric effect of the injection system, hydraulic surges, or casing leaks.

Remedial efforts included improving the well design, installing a groundwater recovery system, and excavating contaminated soil. At three sites, the wells were permanently plugged.

Incidents of surface contamination resulting from the operation of holding lagoons, treatment system components, or surface piping were not considered to be related to injection well operations. For example, if effluent contaminated soil beneath piping to the wellhead, this incident was not attributed to the well operation.

Leakage into an Unpermitted Zone not Containing a USDW. This was the most common malfunction found, with 17 incidents reported (No. 2, 10, 13, 14, 15, 18, 19, 22, 23, 25, 26, 27, 28, 30, 38, 43, and 44), including one incident in which leakage also appeared at the surface. Not all reported leakage could be confirmed, for reasons such as mechanical problems or physical barriers that prevented performance of appropriate tests to demonstrate mechanical integrity. In those cases where an actual leak could not be demonstrated, the regulatory agency implemented remedial action as if the unconfirmed leak occurred.

The typical cause reported for this kind of malfunction was leaking packer assemblies, which allowed wastewater to come into contact with the protective well casing, causing corrosion that eventually resulted in a leakage. In a few cases, the leakage resulted from use of an injection tubing that was not resistant to corrosion by the wastewater. In either case, the well casing soon developed leakage, and repair or plugging of the well was required. Repair efforts generally consisted of resetting the packer or installing a corrosion-resistant liner or tubing in the well. For relatively old wells that were constructed before current standards were developed, repairs were not always feasible. Therefore, these wells were usually plugged with cement and replaced with new wells.

Another potential cause of injection into an unpermitted zone is inadequacy of the confining zone. This was reported as a possible cause in two incidents, but was not actually confirmed. However, the injection operations were stopped at the facilities involved.

Other. At three sites studied (No. 1, 4, and 6) events that did not fall into the other categories occurred. At one site (No. 6), injection activities appear to be linked to increased frequency in earth tremors in the area, and were subsequently halted. At another site (No. 4), operators were permitted to fracture the injection zone prior to UIC primacy assumption, but were not allowed to continue operating after primacy assumption. Crimping of the injection casing at the third site (No. 1) prevented future demonstrations of mechanical integrity. Consequently, the regulatory agency required that the well be plugged and removed from service.

PERMANENTLY NON-OPERATIONAL WELLS

At 17 of the sites evaluated, one or more injection wells were taken out of service and permanently plugged. Of the 106 wells included at these sites, only 27 were actually permanently removed from service and plugged. Most of these wells were constructed from the 1960's to mid-1970's, prior to current minimum federal UIC regulations. In almost every case, some type of operational problem was linked to the wells as described in the foregoing paragraphs.

Most of the wells were permanently plugged by filling the casing with cement grout. When not plugged, the wells were retained as monitoring wells, either as part of continuing injection operations at the facility, or to monitor the degradation of the wastewater already in place.

INCIDENCE OF MALFUNCTIONS

Actual well-related malfunctions were identified at 43 of the 106 wells at these facilities. The facilities studied represent all or most of those well sites with known or suspected problems based on the UIC program directors' responses to the questionnaire shown in Appendix A. Therefore, the incidence of well malfunctions among Class I facilities is apparently very low. The review of agency files for all of the approximately 500 reported Class I wells at approximately 250 facilities indicates that most significant Class I well malfunctions are included in the case histories in this report. This suggests a malfunction rate of approximately 9 percent for all types of malfunctions. Only 2 percent of the malfunctions are related to contamination at the surface or leakage into a USDW.

Based on information found in the various agency files, the malfunctions listed above are least likely to occur in systems where the operator is quick to take a well out of service for inspection and mechanical integrity tests at the first indication of an abnormality in operating data. The inspection or mechanical integrity testing typically identified the need for repair. These operations are considered well workovers, and are frequently and mistakenly equated with well malfunctions rather than maintenance operations. An example of the situation is Agrico Chemical's Verdigris facility. Three workovers were performed on the injection well between April 1980 and March 1983. These operations were conducted to inspect and replace the packer and during one of the workovers the original steel injection tubing was replaced with fiberglass. The workover operations themselves are not necessarily indications of well malfunctions. Rather, they are routine preventive maintenance operations intended to prevent malfunctions.

POSITIVE EFFECTS OF UIC PROGRAM DEVELOPMENT

This study provided an opportunity to survey state and federal Class I well programs in the nation. Although the programs were in various stages of development and varied widely in complexity, a positive trend was observed in recordkeeping, permitting, and enforcement since UIC program implementation.

Data gathered on both operational and previously operational Class I wells were compared to determine the difference in the quality of records maintained before and after UIC program implementation. In many instances, the records on "pre-primacy" wells were incomplete, or reflected less emphasis on inspection and enforcement. Little consistency from state to state existed as observed from older records. Large differences in the permitting, compliance inspection, monitoring, and enforcement activities were common prior to the implementation of the federal UIC program.

Variations between states that had assumed primacy were still evident; however, differences were noted with respect to the development and the length of time the state UIC program been in effect. One example of the improvements resulting from UIC program implementation is the repermit application. That document, in many of the states visited, represented an updated, consistent compilation of data pertaining to a well's operational history. Since states were granted primacy over an extended period, and since existing facilities have up to five years from the date of primacy to apply for a UIC permit, another three or four years will probably be needed to achieve the full effect of UIC program implementation. At that time, all existing facilities will have been repermitted and brought up to the minimum requirements established.

Table 2-1
SUMMARY OF SURVEY RESULTS

No	Facility and Location	Page No.	No. of Wells*	First Year of Injection	Comments
1	Stauffer Chemical Company, Cold Creek Plant, Bucks, Alabama	3-2	2/1	1969	Well No. 1: Casing fatigue above perforated interval discovered in 1980 and plugged in 1984. No environmental problems. Well No. 2 and 3: no environmental problems.
2	U.S. Steel Corporation, Fairfield, Alabama	3-7	0/1	1974	First indication of well leaking into an unpermitted zone in 1977. No confirmed impact on a USDW. Well plugged in 1981.
3	ARCO Alaska Inc., Prudhoe Bay, Alaska	3-13	2/0	1976	No environmental problems
4	Ethyl Corporation, Magnolia, Arkansas	3-19	2/0	1971	WDW-6 used for sludge injection. Not repermitted, no environmental problems WDW-1: no environmental problems
5	Rio Bravo Disposal Facility, Shafter, California	3-24	1/0	1983	No well related problems, pipelines at surface facilities were twice noted as leaking hazardous waste in 1984 and 1985.
6	Rocky Mountain Arsenal, Denver, Colorado	3-32	0/1	1962	Operation terminated due to a reported link between the injection of waste and the increase in the frequency of earth tremors in the Denver area from 1962-1965. Well was shut down in 1966.
7	Kaiser Aluminum and Chemical Corporation, Mulberry, Florida	3-37	1/0	1972	No environmental problems.
8	Kendale Lakes WWTP, Miami, Florida	3-44	1/0	1972	Leakage into a USDW detected in 1982 and taken out of service.
9	City of Margate WWTP, Margate Florida	3-49	2/0	1974	Leakage into a USDW detected in 1983. Well was repaired by cementing annulus.
10	McKay Creek Pollution Control Facility, Largo, Florida	3-54	2/0	1984	Upward migration of effluent into non-USDW unpermitted zone in 1984.
11	Monsanto Chemical Corporation Cantonment, Florida	3-60	3/0	1963	Well C temporarily shut down due to suspected leak to USDW discovered in 1984. Regulatory agencies evaluating mechanical integrity test results. Well B: no environmental problems. Well A: power surge broke packing that sealed liner causing diesel oil to spew from annulus in 1963.
12	QO Chemicals, Belle Glade, Florida	3-69	2/2	1966	Initial permitted zone (1965) is now classed as USDW. Original wells plugged (1976) and new wells drilled in 1977. No environmental problems associated with new wells.

*Active/Abandoned. Active includes standby.

Table 2-1
(Continued)

No	Facility and Location	Page No.	No. of Wells*	First Year of Injection	Comments
13	South Cross Bayou Pollution Control Facility, Pinellas County, Florida	3-79	4/0	1984	Detected vertical migration of effluent into a non-USDW unpermitted zone (1985). Test injection program to resume after verifying casing integrity of injection wells.
14	City of St. Petersburg, Northeast WWTP, Florida	3-86	3/0	1980	Possible vertical migration of effluent into a non-USDW unpermitted zone during test period in 1980. Monitor well was plugged in 1985.
15	City of St. Petersburg Southwest WWTP, Florida	3-94	3/0	1977	Possible injection into non-USDW unpermitted zone during test period in 1977.
16	City of Stuart WWTP, Florida	3-100	1/0	1977	No operating problems. No environmental problems.
17	Sunset Park WWTP, Miami, Florida	3-106	1/0	1969	Possible leakage into a USDW via leaking casing (1981 & 1982). Taken out of service in Company 1983.
18	Velsicol Chemical Company Marshall, Illinois	3-111	2/0	1965	Well 1: Owner unable to demonstrate mechanical integrity, probable leak of waste into a non-USDW unpermitted zone (1971). Well is permitted for emergency use only. No environmental problem associated with Well No. 2.
19	Vulcan Chemicals, Wichita, Kansas	3-118	5/3	1957	Corrosion discovered in Well No. 6 indicates possible leak into an unpermitted zone (1979). No environmental problems with the wells as they are currently operating.
20	Waste Management Inc., Furley, Kansas	3-133	0/0	N/A	Permit application only - well not drilled
21	CECOS International, Lake Charles, Louisiana	3-134	1/0	1976	Extensive monitoring determined no well-related environmental problems (1985).
22	Rollins Environmental Services, Iberville, Louisiana	3-142	1/0	1976	Leak into non-USDW through injection casing. Repaired hole in casing (1978).
23	Tenneco Oil Company, Chalmette, Louisiana	3-146	4/2	1960	Wells 1 and 2: Leakage into USDW and subsequently plugged in 1981 and 1984, respectively. Wells 3, 4, 5, 6: no environmental problems
24	Dow Chemical Company Midland, Michigan	3-156	0/0	NA	All wells classified as Class V-brine disposal wells
25	Hercofina, Wilmington, North Carolina	3-157	2/2	1968	Waste leaked into an unpermitted (non-USDW) zone. Waste incompatible with receiving aquifer. Taken out of service in 1972.

*Active/Abandoned. Active includes standby.

Table 2-1
(Continued)

No	Facility and Location	Page No.	No. of Wells*	First Year of Injection	Comments
26	Chemical Waste Management, Vickery, Ohio	3-167	6/1	1976	All wells experienced leakage of injection or annular fluids into unpermitted zones, but all zones were non-USDW's. All active wells have been upgraded.
27	Empire Reeves Steel, Mansfield, Ohio	3-181	0/1	1968	The well suffered severe corrosion of the tubing and casing. Possible leakage into an unpermitted zone through corroded casing. The well was plugged because of this corrosion in 1971.
28	American Airlines, Tulsa, Oklahoma	3-185	2/0	1960	Suspected, but unconfirmed leak into unpermitted zone, discovered in 1984. Owner cannot confirm mechanical integrity. Well No. 1 operating on temporary permit. Operation permit for Well No. 2 under consideration; Well completed in 1984.
29	Agrico Chemical Company, Rogers County, Oklahoma	3-192	1/0	1977	No environmental problems associated with injection well.
30	Chemical Resources Inc., Tulsa, Oklahoma	3-198	1/0	1974	Waste leaked into unpermitted zone in 1983 through corroded casing. No leakage into a USDW. leak repaired and well returned to service.
31	Hammermill Paper Company, Erie, Pennsylvania	3-205	0/3	1964	Well No. 1 backflowed effluent at surface. Well No. 2: injection casing collapsed. Well No. 3: no operating problems. Injection system is alleged to have caused upward migration of effluent through an improperly abandoned gas well; allegations never confirmed. All wells plugged and abandoned in 1972.
32	Jones & Laughlin Steel, Aliquippa, Pennsylvania	3-214	0/1	1961	Pressure buildup and casing damage. Well plugged in 1972.
33	American Magnesium Co., Snyder, Texas	3-218	0/1	1968	Well plugged in 1983 when company moved to Canada. No environmental problems established.
34	CECOS International, Odessa, Texas	3-226	1/0	1978	No well-related environmental problems.
35	Chemical Waste Management, Corpus Christi, Texas	3-234	1/0	1973	No well-related environmental problems.
36	Cities Service Fractionators, Mount Belvieu, Texas	3-239	1/0	1971	No well-related environmental problems. Well reclassified as Class II and transferred to Railroad Commission in 1985.

*Active/Abandoned. Active includes standby.

Table 2-1
(Continued)

No	Facility and Location	Page No.	No. of Wells*	First Year of Injection	Comments
37	DSI Transport, Deer Park, Texas	3-245	1/0	1981	No well-related environmental problems.
38	DuPont, Corpus Christi Plant Ingelside, Texas	3-249	2/1	1976	One well was found to be leaking into an unpermitted zone because of casing corrosion. The well was repaired in 1980. The zone receiving the leak is currently included as part of the permitted injection zone under the UIC guidelines.
39	DuPont, Sabine River, Orange, Texas	3-254	7/3	1965	The wells have experienced problems with decreased injectivity because of an unconsolidated sand injection zone "sanding in" the wells. No environmental problems associated with these wells.
40	Empak, Inc., Deer Park, Texas	3-273	1/0	1980	The permitted injection pressure was once exceeded and a fine was levied (1981). No environmental problems associated with this well.
41	Malone Services Company, Texas City, Texas	3-278	2/0	1970	No well-related environmental problems.
42	Potash Co. of America, Dumas, Texas	3-285	1/0	1962	No environmental problems associated with this well.
43	Sonics International, Dallas, Texas	3-288	0/2	1974	Leakage into an oil bearing zone and a nearby oil well. Surface contamination was caused by well blowouts and leaks. Both wells were abandoned in 1982.
44	Velsicol Chemical Corporation, Jefferson County, Texas	3-296	2/2	1965	Leakage into a USDW. Two monitoring wells were installed as part of the site cleanup in 1976.
45	Northwest Petrochemical Corp., Anacortes, Washington	3-301	2/0	1960	Second well never used. Use of first well discontinued when state permit expired in 1985.

*Active/Abandoned. Active includes standby.

Section 3
CASE HISTORIES

Section 3
CASE HISTORIES

The 45 case histories presented in this chapter are arranged in alphabetical order by state, and alphabetical order by owner name within each state. Four subheadings were used in the case histories: Background, Site Description, Well Construction Details, and Chronology of Operational Problems. The Background section includes the plant location, nature of the operation, a description of the disposal system operation, brief statement of operational problems attributed to the facility, and the present status of the facility. The Site Description section covers the local geography and topography, potable water source, and hydrogeologic setting. The original well construction and any recompletions are described in the Well Construction Details section. Selected well diagrams based on the information in the agency files are included in this section. The confining and injection zones and depth to the lowermost USDW are shown on the diagrams where that information was available. Information presented under Chronology of Operational Problems includes a discussion of the type of operational problems discovered, the effects on USDW's and the environment, the regulatory agency response, resolution of the problem, and present status of the well operation.

STAUFFER CHEMICAL COMPANY, COLD CREEK PLANT BUCKS, ALABAMA

Background. Stauffer Chemical Company disposes of aqueous wastes via Class I injection wells at their Cold Creek plant in Bucks, Mobile County, Alabama. The wells are located on the plant site, about 20 miles north of the City of Mobile.

Three Class I injection wells have been used at the Cold Creek plant to inject nonhazardous wastes generated onsite from the production of pesticides and herbicides. Wells 2 and 3 are currently operating in compliance with a State UIC permit. Well 1, the subject of this case history, is no longer in use. The same waste was injected into all three wells.

Various individual process waste streams were collected and combined in tanks for the partial removal of organic compounds by flotation and for pH adjustment. Wastes were next filtered for solids removal and piped to the well head. The injected waste consisted of solutions of ammonium and sodium chlorides which contained less than 2 percent dissolved organic compounds. Total dissolved solids in the injected waste stream normally ranged from approximately 130,000 to 140,000 mg/L and pH ranged from 8 to 12 standard units.

Injection Well 1 was drilled and completed in February 1969. Injection began in August 1969 and continued until March 1984. In 1983, the last full year of operation, 15,185,358 gallons of waste were injected into Well 1 with average injection rates of 50 to 70 gallons per minute (gpm) and average well head injection pressures of 175 to 200 pounds per square inch (psi). The well was permanently abandoned and plugged in April 1984.

Injection related surface facilities at the site consisted of collection piping, holding and treatment tanks, filtering devices and injection pumps. After Well 1 was plugged, these facilities remained in service, providing pretreatment for the waste to be injected into Wells 2 and 3.

Site Description. The Stauffer Chemical Company-Cold Creek Plant lies in the Gulf Coastal Plain physiographic province. The area is underlain by unconsolidated to poorly consolidated sedimentary deposits. These deposits are composed primarily of sand, clay, and gravel with lesser amounts of limestone. Sediments in the Gulf Coastal Plain dip southward at 30 to 50 feet per mile. However, this general pattern is disrupted by the Mobile Graben, a structural feature which extends from beneath Mobile Bay northward under the plant to a location about 20 miles north of the plant site. Geologic units within the graben are folded into broad domes and basins which may be several miles across and have several hundred feet of closure. Beneath the plant site, the strata are essentially horizontal. The west boundary fault lies about 2½ miles west of the site at the injection horizon, and the east boundary fault lies over 4 miles east of the site at the injection horizon. Above the injection horizon, displacement across the boundary faults decreases toward the surface and both faults disappear below the base of the Bucatunna Clay (Stauffer Chemical Co., 1981). The injection interval in Well 1 was from 3,410 to 3,490 feet into sands in the Nanafalia Formation of Eocene age. The Nanafalia Sands are confined by shale units of the Tuscahoma Formation which immediately overlie the sands.

The Bucatunna Clay, which lies at a depth of 1,260 feet and is 150 feet thick, provides protection of USDW's. The base of the USDW occurs near the base of the Bucatunna at a depth of 1,400 feet, as determined by geophysical well log analysis at the time of drilling (Stauffer Chemical Co., 1981). The first aquifer above the Bucatunna is within the Byram Formation and has a total dissolved solids content of 4,500 mg/L. Local water supply aquifers are sands and gravels in alluvial deposits at depths generally less than 200 feet.

Well Construction Details. The injection well was constructed as follows: 16-inch diameter steel conductor pipe cemented into a 20-inch borehole, set at 33 feet; 10-3/4-inch diameter surface casing cemented into a 15-inch borehole, set at 1,238 feet; 7-inch diameter injection casing cemented into a 9-7/8-inch borehole, set at 4,216 feet; and 4-1/2-inch diameter injection tubing set at 3,400 feet with a Baker packer. The well was completed by perforating the 7-inch casing from 3,410 to 3,460 feet and from 3,480 to 3,490 feet, into sands in the Nanafalia Formation.

The well head was designed and equipped for continuous monitoring of injection pressure, flow rate, and annulus pressure. Ports for sampling the waste immediately prior to injection were present at the well head. Seven onsite monitor wells installed in conjunction with the injection well operations monitored groundwater quality in the lowest USDW beneath the site and in the two aquifers used for water supply in the area.

Chronology of Operational Problems. Well 1 was drilled and completed in February 1969 and injection of wastes began in August 1969. During a regularly scheduled biannual inspection of Well 1 in March 1979, difficulties in raising and lowering tools in the hole indicated that the 7-inch casing had crimped. As a result, a more complete mechanical integrity testing program was performed in April 1980. During the 1980 testing, several facts came to light: the 7-inch casing had narrowed (crimped) at four places in the perforated section of casing; the casing above the packer and above the injection zone was undamaged; and the temperature survey log and the radioactive tracer survey log indicated no fluid was being lost around or behind the packer and that injected fluids were entering the injection zone (Stauffer Chemical Co., 1981).

The decision was reached to plug and abandon Well 1 as soon as a replacement injection well could be constructed for two reasons: 1) if the crimping worsened the placement of a cement plug through the injection zone would be difficult and proper plugging might become impossible, and 2) the crimping prohibited logging tools from reaching the bottom of the well and prohibited the company from being able to continue to demonstrate mechanical integrity below a depth of 3,400 feet. The well was plugged between April 2 and 11, 1984.

No contaminants were ever detected or suspected to be leaving the well at any zone other than the permitted injection interval and no threat or harm to human health or the environment occurred as a result of more than 14 years of satisfactory injection.

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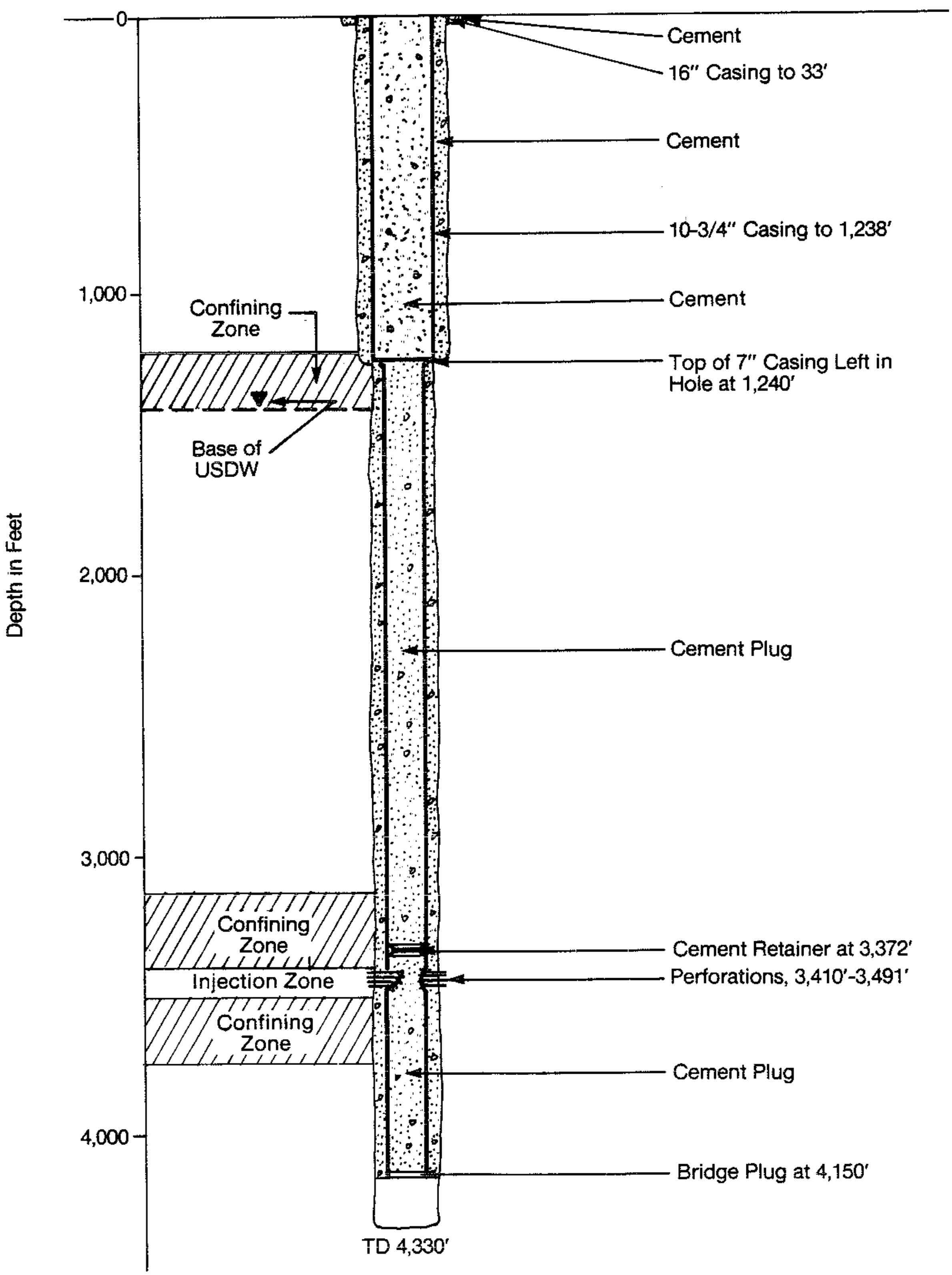


STAUFFER CHEMICAL COMPANY
Bucks, Alabama

INJECTION WELL NO. 1 (Plugged April 1984)

UIPC

U.S. STEEL CORPORATION
FAIRFIELD, ALABAMA

Background. United States Steel Corporation operated a Class I injection well in Jefferson County, Alabama. The well was located at the U.S. Steel Fairfield Plant.

The well was used to dispose of hazardous, low pH waste pickle liquor generated onsite during steel manufacturing operations. Wastes were collected, filtered for solids removal, and piped to the well head. The primary components of the waste stream were sulfuric acid and hydrochloric acid with high levels of dissolved metals, e.g., iron, manganese, chromium, cadmium, and zinc. The pH of the injected solution was generally less than 1.5 standard units.

Drilling for the injection well began in March 1970. Related surface equipment and monitoring systems were completed in September 1974. Waste injection began in September 1974 and continued until May 1977 when injection was stopped after a tubing and casing failure. The well was directionally drilled and recompleted, and injection began again in February 1978. The Alabama Water Improvement Commission ordered closure of the well on March 31, 1980. The well was permanently abandoned and plugged in February 1981.

While the well was in operation, surface equipment associated with the injection activity included holding tanks, surge protection systems, filtering devices and injection pumps. All of these structures were removed when the injection well was permanently abandoned.

The state regulatory agency required the use of two monitoring wells at the Fairfield site, which were referred to as the "shallow" and "deep" monitor wells. The deep well was completed at a depth of 4,416 to 4,466 feet, and the shallow well was completed at 719 to 765 feet. The deep monitor well was designed to monitor water quality and pressure in the injection zone within the Red Mountain Formation. In addition, the annulus of the deep monitor well was open to the Pottsville Formation from 1,020 to 2,970 feet, thus enabling monitoring of this zone. The shallow monitor well was designed to monitor water quality within the lowest usable freshwater zone within the Pottsville Formation.

Site Description. The U.S. Steel Fairfield Plant lies on the boundary between the physiographic provinces of the Appalachian Plateau (northwest of the Opossum Valley Fault) and the Appalachian Ridge and Valley (southeast of the fault). The boundary fault dips southeastward, away from the injection well site (Kidd and Shannon, 1978). The injection well was located in the plateau area, underlain by a thick sequence of flat-lying sedimentary rocks ranging in age from Pennsylvanian at the surface to Cambrian at the bottom of the injection interval. The well completion interval was from 4,415 to 6,072 feet but most waste disposal occurred within a zone between 4,400 and 4,700 feet in the Red Mountain Formation of Silurian age and in a zone between 5,400 and 6,000 feet within the Knox Formation of Cambro-Ordovician age. The intervening unit is an Ordovician limestone with low permeability and porosity, and no waste is believed to have entered this zone (Tucker and Kidd, 1973).

Most of the permeability in the two zones that received waste was attributed to fractures or secondary porosity. Confining units separating injected wastes from overlying underground sources of drinking water (USDW) consist of approximately 1,000 feet of Mississippian cherts, limestones, sandstones, and shales, as well as about 1,500 feet of sandstone, siltstone, and shale in the lower Pottsville Formation. The base of the USDW at the site is at 1,789 feet, as determined by borehole geophysical logging at the time of drilling (ADEM, 1981). This point is in the middle of the Pottsville Formation, and is about 2,600 feet above the top of the injection interval.

Well Construction Details. The original injection well was constructed as follows:

- o A 16-inch steel conductor pipe was grouted into a 20-inch hole and was set at 64 feet.
- o A 10-3/4-inch-diameter surface casing, cemented with pozmix and Class H cement, was set at 1,110 feet in a 13-3/4-inch borehole.
- o A 7-5/8-inch-diameter, intermediate casing, cemented in place, was set at 4,415 feet in a 9-5/8-inch borehole.
- o A 2-7/8-inch-diameter injection tubing was set to 4,434 feet with a Lynes external casing packer at 4,406 feet.
- o The well was completed as an open hole from 4,415 to 6,072 feet.

The offset injection well was completed as follows:

- o The original well was plugged back to 1,480 feet and a directionally drilled hole was completed to 5,775 feet.
- o A 5½-inch-diameter steel casing, cemented in place, was set at 4,150 feet.

- A 3½-inch diameter injection tubing was set at 4,150 feet.

- The well was completed as an open hole from 4,150 to 5,775 feet.

The wellhead was the same for both completed deep wells and was constructed so that injection pressure, flow rate, and annulus pressure were continuously monitored during injection activities. Access ports were also available at the well head for waste sampling immediately prior to injection.

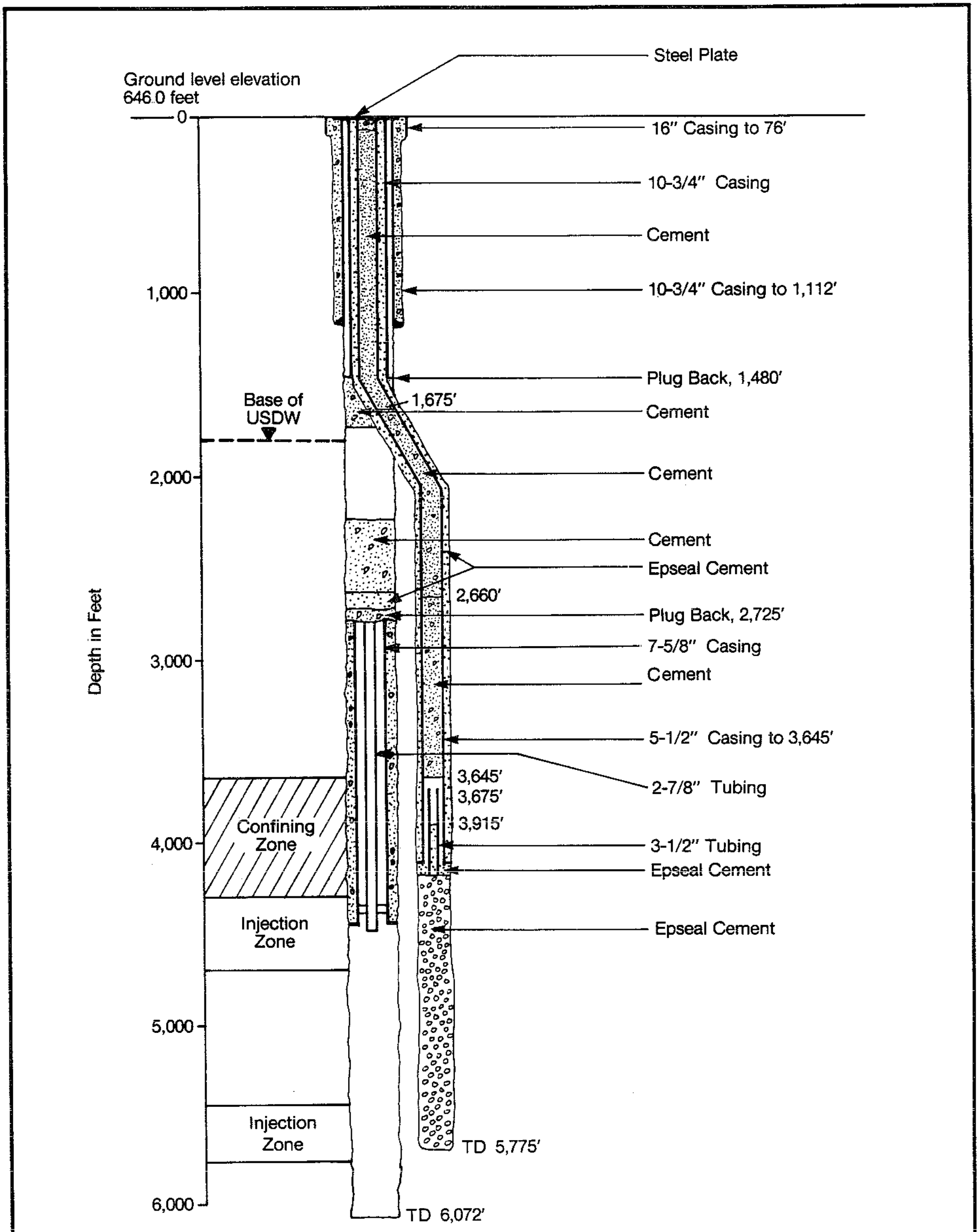
<u>Chronology of Operational Problems</u>. Injection began in September 1974 and continued, generally uninterrupted, until December 1976. During this time, higher injection pressures began to be required, apparently as the result of plugging. No changes were observed in the monitoring wells.

In December 1976, the wellhead pressure in the deep monitor well annulus which monitors the Pottsville Formation rapidly increased to approximately 850 pounds per square inch (psi), in response to a leak in the injection well tubing and casing below 1,400 feet. This indicates that the injection well allowed the release of wastes into the Pottsville Formation. Injection into the Pottsville continued for approximately five months. After the injection well was shut-in, directionally drilled, and recompleted, no further indications of injection into the Pottsville were seen. However, upon startup of injection activities in the "new" boring in February 1978, the trend toward increasing injection pressures continued (Moore and Hinkle, 1979).

In March 1978, the well was shut down for 3 months to remove partial plugs and debris from the lower parts of the well in an attempt to lower injection pressures. While the procedure was successful in that wastes could be injected into the lower injection zone following the work, the trend toward higher injection pressures resumed.

During the last year of operation, the well head injection pressure generally ranged from 1,400 to 1,800 psi with pressures commonly over 1,600 psi during periods of continuous injection. Injection pressure increases were felt to be the result of chemical incompatibility between the injection zone rocks and the waste stream. It appeared that as fractures in the Red Mountain and Knox formations became filled with solids and precipitates, additional pressure was required to open more fractures. The apparent problems with waste compatibility and increasing injection pressures led to plugging and abandoning the well. Waste injection ceased in February 1981.

The wastes injected into the lower part of the Pottsville Formation from December 1976 to May 1977 may or may not have affected a USDW. Since the deep monitor well annulus is open to the Pottsville from 1,020 to 2,970 feet and the depth of the casing leak in the injection well is reported in available data only as "below 1,400 feet," there is a chance that the lower part of the USDW was somewhat affected from the injection operation. However, the water level and water quality in the shallow monitor well, completed in the upper part of the Pottsville in the zone of fresh, usable water was not affected by the injection well. This indicates that no significant harm to human health or the environment occurred from this source.



UNITED STATES STEEL
Fairfield, Alabama

DISPOSAL WELL

ARCO ALASKA, INC.
PRUDHOE BAY, ALASKA

Background. ARCO Alaska, Inc., operated two hazardous waste injection wells in conjunction with oil and gas production from the Prudhoe Bay Unit at the North Slope operations. The facility is located in Prudhoe Bay, on the northern coast of Alaska.

The wells were converted for injection of oily wastes associated with oil field production. Two wells are maintained for backup disposal capacity because production from the Prudhoe Bay Unit would be adversely affected if the injection wells were out of service for more than one week (ARCO Alaska, 1984).

The injected waste stream consists of water-based and oil-based drilling muds; other fluids used in well completion; crude oil, fuels, lubricating oils, hydraulic fluids, solvents, spent acid, and caustic fluids; and antifreeze fluids, production chemicals, heat exchanger bundle cleaning sludge, and laboratory wastes. Collectively, the waste stream is called oily wastes, and contains the following identifiable hazardous waste streams (ARCO Alaska, 1984):

- Heat exchanger bundle cleaning sludge
- Barrel drainings
- Laboratory wastes
- Contaminated and off-specification fuel
- Unused and off-specification chemicals
- Product spills
- Lubrication oil

Certain hazardous wastes will not be injected, including dioxins, polychlorinated biphenyls, and "acute hazardous" wastes, excluding tetraethyl lead.

Originally, five wells were drilled in 1973, spaced approximately 50 feet apart, to study the effects of permafrost thaw on well casing. After 22 months of testing, the northeast and northwest wells were modified for oily waste injection in 1976 and 1978, respectively, by perforating and setting a tubing and packer.

The southeast and southwest injection wells were recompleted for saltwater injection in late 1984. The center well in the five-spot pattern was never recompleted and is not being used for injection.

The northwest and northeast wells have been used for hazardous waste injection. The northwest well is currently authorized by rule to inject hazardous wastes. ARCO has applied for an EPA Class I hazardous waste injection permit for the northwest, southeast, and southwest injection wells. The northeast well was damaged during a pressure test and has not been used since October 19, 1984.

Surface facilities include holding tanks for water, diesel and oily wastes, and filters for removal of large solids. Two positive displacement pumps are used for injection. The average injection rate is 80 gallons per minute, with a maximum of 160 gallons per minute per pump. The average daily injection volume is 21,000 gallons at an average injection pressure of 500-700 pounds per square inch (psi) (ARCO Alaska, 1984). Relief valves are in place to return the injection stream to the holding tanks in the event of operational upset.

The northwest well operated at injection pressures that exceeded the EPA calculated allowable injection pressure. For example, with a specific gravity of 0.8 for the injected fluid, the surface pressure would have been limited to

766 psi. Typical injection pressures were 700 psi, whereas the calculated allowable pressure (based on the specific gravity of the injection fluid and well depth) was approximately 500 psi. For the Class I well permit, ARCO has requested a waiver of the injection pressure limit, based on the provision in 40 CFR Part 144.16(a), which allows for less stringent requirements when injection is not into, through, or above a USDW. The southeast and southwest wells are authorized under emergency permits to inject at surface pressures to 1,400 psi for saltwater only. The Class I permit applications for the three wells are still under EPA review.

Site Description. The injection wells are located in the Prudhoe Bay Unit Eastern Operating Area on the North Slope of Alaska. The injection zone consists of heterogeneous sequences of thick sandstone and gravel intervals, at an approximate depth of 150 feet below the permafrost. Structurally, the Tertiary formations become more shallow to the west, intersect with the permafrost to the southwest, and pinch out stratigraphically updip.

There are no underground sources of drinking water at the site. Permafrost exists to a depth of 1,850 feet, and formation fluids sampled beneath the permafrost contain fluids with greater than 10,000 mg/L total dissolved solids (TDS). Estimated original TDS in the injection zone range from 10,000-45,000 mg/L.

The upper part of the Teritary Sagavanirktok Formation contains thick, primarily unconsolidated sandstones and gravel interbedded with shales, siltstones, and mudstones. These beds are used for injection in the interval 1,978-2,093 feet, and contain excellent porosity and permeability where they are not frozen in the permafrost.

Confinement is provided by several shale and siltstone beds above and below the injection zone. Confinement is also provided by intersection with the permafrost to the southwest and by the updip stratigraphic pinchout of the injection interval.

Well Construction Details. The northwest well was originally drilled to a total depth of 2,200 feet in June 1973. A 13-3/8-inch casing was set to 100 feet and cemented back to the surface. A 5-1/2-inch casing was set to 2,200 feet and cemented to the surface. After completion of the permafrost testing, the well was perforated in the intervals 1,980-2,005; 2,032-2,062; and 2,073-2,093 feet. A 2-3/8-inch steel tubing was hung from the surface and set with a packer at 1,960 feet. A 1-1/4-inch steel circulating string was set to 1,920 feet. The plugged back total depth of the well is 2,093 feet.

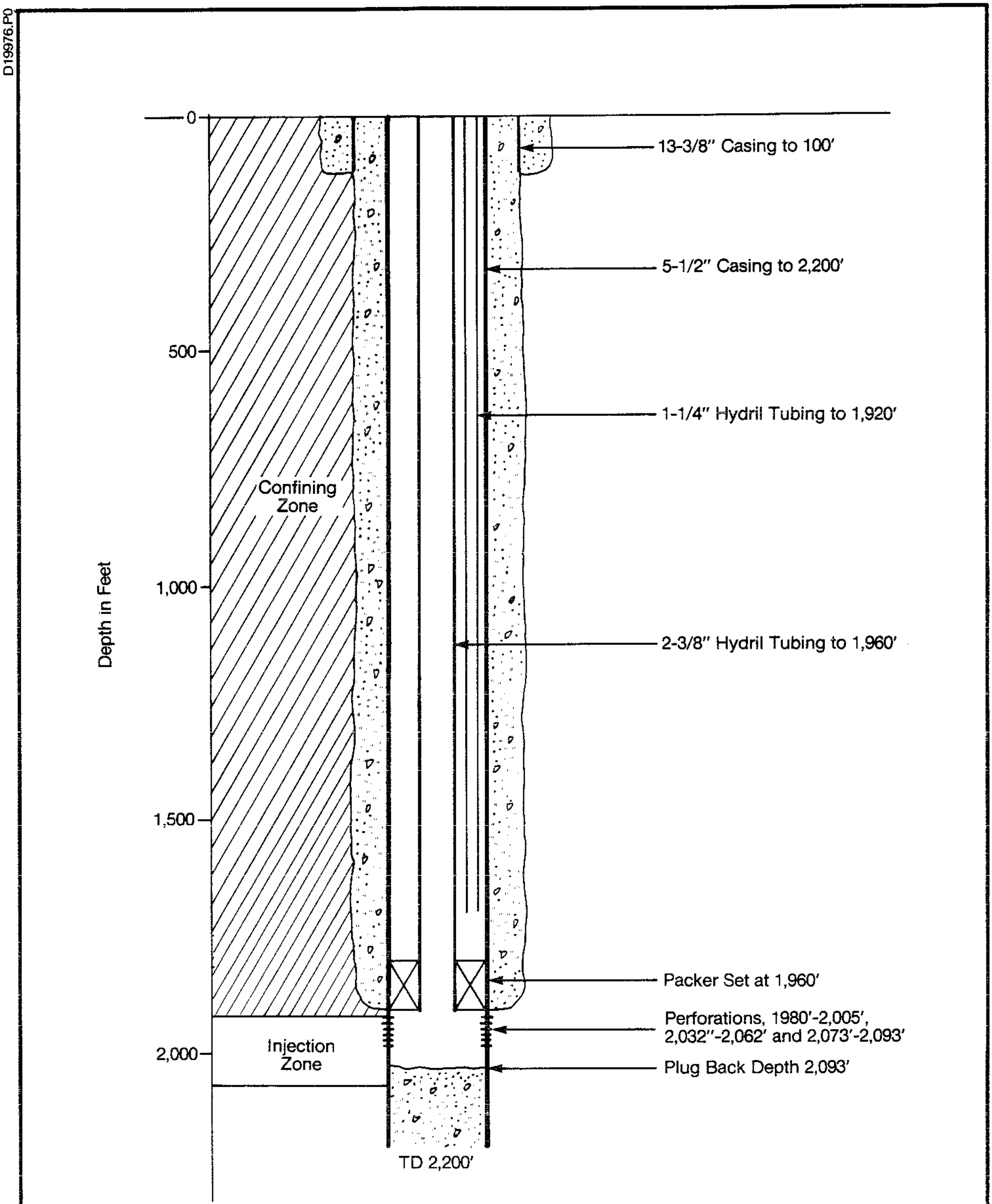
The southeast, southwest, and northeast wells, which were also originally drilled in 1973, were constructed similarly to the northwest well. The 13-3/8-inch surface casings were set to 100 feet. The 5-1/2-inch casings were set to approximately 2,200 feet and perforated in the 1,980- to 2,000-foot interval. The 2-3/8-inch tubings were set with packers at 1,960 feet and the 1-1/4-inch circulating strings were set at 1,920 feet. The glycol circulating strings were installed in all wells for continuous glycol circulation to prevent the well from freezing up since it was not used constantly. Each wellhead includes a surface safety valve. The 5-1/2 to 2-3/8 (glycol) annulus is continuously monitored, as are the injection pressure and rate.

Chronology of Operational Problems. The northwest well has injected oily wastes since August 1976. Downhole compatibility of the injected wastes with the formation fluids and injection strata has been demonstrated by the absence of compatibility problems during the well's operational life. A diesel buffer is injected between injected fluid batches, and surface compatibility procedures are also practiced.

No indication of operational problems was found in the public record. ARCO has indicated (J. Athans, 1985, personal communication) that some minor spills occurred during off-loading the vacuum trucks prior to injection. Snow contaminated with waste fluid would be cleaned up, stored in a holding tank, and injected when it melted in June.

The northeast well was used to inject hazardous wastes from 1976 to 1984. Improper preparations for a pressure test in October 1984 resulted in the 2-3/8-inch tubing collapsing about twenty feet below land surface. No fluid escaped outside the 5-inch casing as a result of this incident. The well was killed on October 19, 1984, and has not been used since (H. Scott, 1985, personal communication). The well was not repaired because, at that time, its capacity was not needed, and it would have been easier to use the southeast and southwest wells when additional capacity became necessary.

As of August 15, 1985, hazardous waste has not been injected at the site, but has been trucked to an incinerator in Chicago, Illinois. Since August 15, the northwest well has been used only for saltwater injection.



ARCO ALASKA, INC.
Prudhoe Bay, Alaska

NORTHWEST INJECTION WELL

UIPC

ETHYL CORPORATION
MAGNOLIA, ARKANSAS

Background. Ethyl Corporation operates two Class I waste disposal wells at its Magnolia, Arkansas, plant. A third well is permitted but not yet drilled. One well (WDW 1) has been operating under authorization by rule since July 6, 1982, when the Arkansas Department of Pollution Control and Ecology (ADPC&E) received primacy over the UIC program in Arkansas. WDW 1 is used for the disposal of aqueous waste from the diethylchlorothiophosphate [DECTP, $(C_2H_5O)_2P(S)Cl$] process. This waste is considered hazardous because of arsenic content and high pH. Another well (WDW 2), which has not yet been constructed, is also classified as a hazardous waste disposal well and will be used to dispose of contaminated process water and, if necessary, as a backup well for WDW 1. The third permitted well (WDW 13) has been operating as a Class V injection well which injects spent brine back into the Smackover Limestone, after the extraction of the bromine. WDW 13 is classified as a non-hazardous waste disposal well and will be used to dispose of contaminated process water (Golden Strata Services, 1983).

A fourth well (WDW 6) has been operating as a non-hazardous Class I waste disposal well under authorization by rule since July 6, 1982. This well has been used twice, once in April 1971, and once in October 1980, to dispose of neutralization pond solids. This well was used for several days when the pond was cleaned out; high pressure pumping equipment was rented and used to inject the sludge. Because it was necessary for Ethyl to fracture the formation to inject the sludge, which violates 40 CFR 146.13 (a)(1), WDW 6 was not permitted and must now be plugged and abandoned (David Thomas and Ray Quick, ADPC&E, 1985, personal communication).

The three permitted wells contain or will contain instrumentation to continuously monitor surface injection pressure, injection flow rate, injection volume, waste stream temperature, annulus pressure, and annular fluid pH (Golden Strata Services, 1983).

Site Description. Ethyl Corporation's Magnolia plant is located on Quarternary alluvial sediments in the Gulf Coastal Plain. The injection zone is in the Upper Cretaceous Tokio Formation, present at a depth of 3,100 feet. This formation is composed of gravel and sand with some inter-tongues of clay and lignite. The maximum thickness of this unit is about 350 feet. The upper confining strata consist of approximately 1,700 feet of dense marine clays, marls, chalks, and some sands (David Thomas and Ray Quick, ADPC&E, 1985, personal communication).

The base of the USDW occurs around 1,000 feet, near the base of the Sparta Formation. This formation occurs within the Eocene Clairborne Group. The Clairborne Group includes the Cockfield, Cook Mountain, Sparta, Cane River, and Carrizo formations, all of which are composed of sand and clay. Near the Ethyl site, the Sparta Sand is perhaps the deepest formation from which drinking water is obtained (David Thomas and Ray Quick, ADPC&E, 1985, personal communication).

Well Construction Details. The hazardous waste well (WDW 1) was completed to a depth of 3,165 feet into the Tokio Formation. A 13-3/8-inch carbon steel casing was set to 169 feet and cemented to the surface. An 8-5/8-inch carbon steel casing was set to 3,198 feet and cemented to the surface. The well was completed by plugging back to 3,165 feet during casing installation, and the 8-5/8-inch casing was perforated from 3,048 to 3,093 feet, and from 3,139 to 3,164 feet. A 5-1/2-inch carbon steel tubing was installed to 2,991 feet and secured using a Texas Ironworks (TIW) packer placed at the bottom of the tubing (Golden Strata Services, 1983).

The sludge injection well (WDW 6) was recompleted at a depth of 3,362 feet. The original well completion depth was 9,150 feet. A 13-3/8 carbon steel casing was set at 263 feet and cemented to the surface. A 9-5/8-inch carbon steel casing was set at 1,512 feet and cemented to the surface. A 7-inch carbon steel casing was set at 8,918 feet and cemented to the surface. This casing was plugged back to 3,362 feet with cement and perforated between 3,084 to 3,102 feet, 3,104 to 3,110 feet, and 3,112 to 3,152 feet. A 4-1/2-inch steel injection tubing with TK75 coating was installed to 3,065 feet and secured with a TIW packer set at the bottom of the tubing (Golden Strata Services, 1983).

WDW 6 had no continuous monitoring instrumentation since it was infrequently used. Monitoring instrumentation was in place shortly before, during, and after the use of the well (Golden Strata Services, 1983).

Chronology of Operational Problems. The ADPC&E reports that the Ethyl Corporation bromine extraction facility has had no problems associated with their injection wells. WDW 6 was injecting sludge from a neutralization pond. This event took place every few years, and operation of the well was only for a short period of time. However, since high pressure pumps had to be used to induce the fracturing of the formation, the well was not repermitted by the ADPC&E.

The apparent success of the wells currently operated and the need for additional disposal capacity resulted in Ethyl Corporation's plans to add another Class I well (WDW 2) and convert the existing Class V well (WDW 13) into a Class I disposal well.

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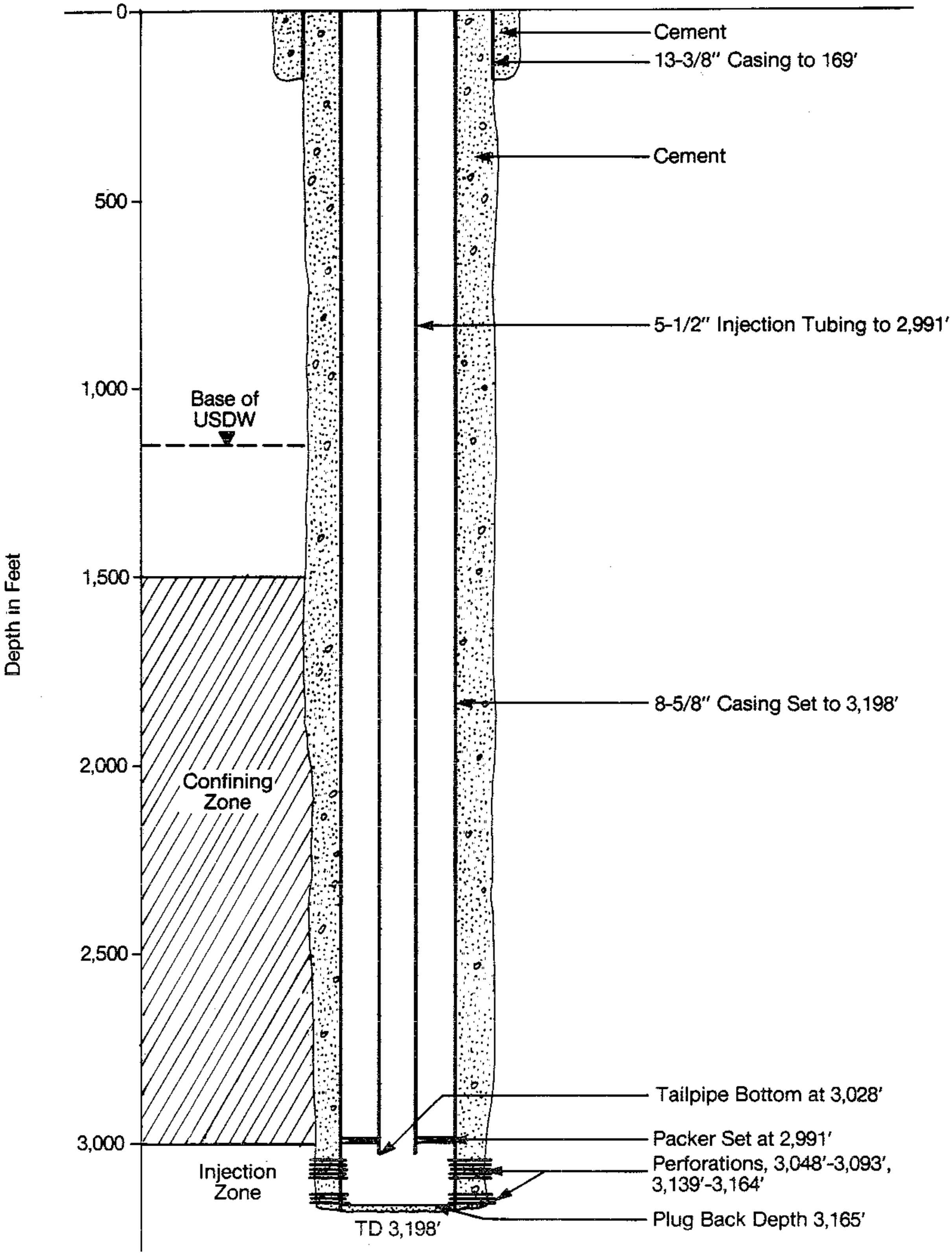
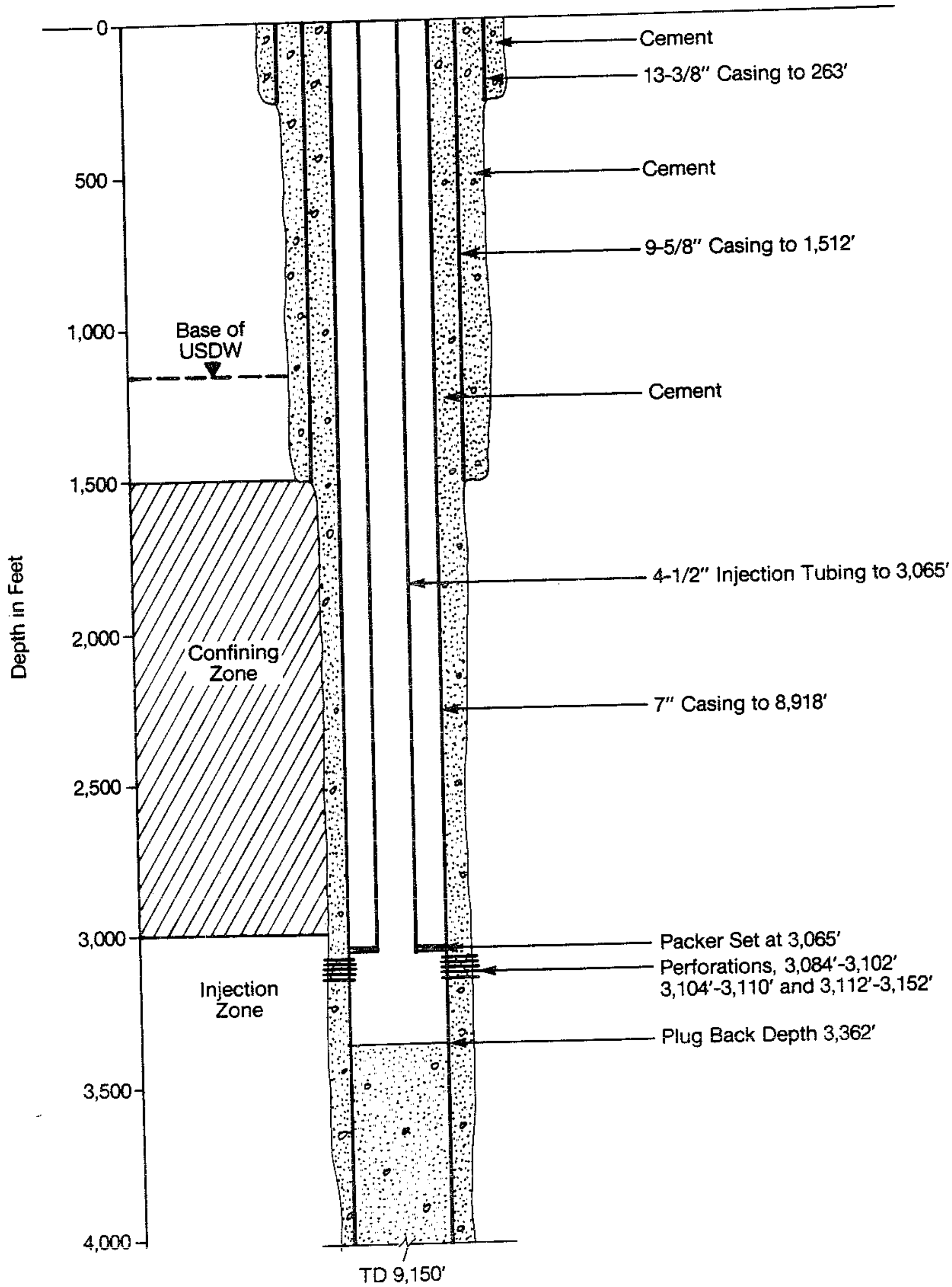


ETHYL CORPORATION
Magnolia, Arkansas

DISPOSAL WELL WDW 1



ETHYL CORPORATION
Magnolia, Arkansas

DISPOSAL WELL WDW 6

RIO BRAVO DISPOSAL FACILITY
SHAFTER, CALIFORNIA

Background. The Rio Bravo Disposal Facility, located in the Rio Bravo field, southern central San Joaquin Valley, near Shafter, Kern County California, was a commercial, offsite hazardous and nonhazardous waste disposal facility. Wastes generated offsite were trucked to the site. Approximately 20 truckloads of wastes per day were handled at the site when it was operational. The facility has not injected waste since January 1985.

Hazardous wastes received at the site were stored in two 1,000-barrel capacity carbon steel tanks enclosed in a secondary containment structure, and passed through cartridge filters prior to injection. These wastes included solvents and pesticides, miscellaneous ignitable and corrosive wastes, and numerous toxic wastes (Tetra Oil Company, 1984).

Nonhazardous wastes received at the site were handled separately from the hazardous wastes. Nonhazardous wastes included oil field brines, scrubber wastes, produced water, and water softener brines (U.S. EPA, 1985e). The facility received only nonhazardous wastes from September 1983 until May 1984 when it began receiving its first shipments of RCRA-manifested hazardous wastes (Tetra Oil Company, 1984).

The injection well, Mary Anderson #1, is a converted abandoned oil well that was used for injection, with a disposal capacity of 336,000 gallons per day (gpd). A maximum injection pressure of 3,500 pounds per square inch (psi) was proposed in the permit application, but EPA had prepared a draft permit in July with a maximum of 2,000-psi surface injection pressure. Operating pressures ranged from 1,700 to 2,700 psi prior to draft permit preparation and well closure (R. Mechem, 1985, personal communication).

The original permit application included proposals for three other new wells, which would involve conversion of abandoned, shut-in, or producing wells to injection wells. EPA denied the permit application for the Mary Anderson #1 well on September 30, 1985, and the owners have recently contacted EPA about plugging and abandonment or possible conversion to a monitor well. EPA is currently reviewing applications for the proposed well conversions (R. Mechem, 1985, personal communication).

Site Description. The facility is located in the Great Valley of California, a synclinal trough that is bounded by the Sierra Nevadas, Coast Ranges, and San Emigdio Mountains. The site is nearly flat, surrounded by low hills, and is on the edge of an oil and gas field. Primary land uses are oil field production and irrigated agriculture (Regional Water Quality Control Board (RWQCB), 1983).

The site is underlain by alluvial sands, clays, and gravels to a depth of approximately 600 feet. Potable groundwater occurs within this formation at a depth of 185 feet. The base of freshwater (defined in this case as water having less than 3,000-μmhos/cm specific electrical conductance) occurs at an approximate depth of 2,500 feet. Depth to the USDW has not been determined, but the total dissolved solids in the injection zone exceed 35,000 mg/L.

The injection zone occurs at a depth of approximately 11,400 feet, and consists of the Rio Bravo and Vedder Sands of 45- and 300-foot thicknesses, respectively. Both formations are Micoene age, areally extensive marine sands. Oil has not been produced from the Rio Bravo Sand in this area since 1966 (RWQCB, 1983). The confining zone immediately overlying the injection zone, the Freeman-Jewett Silt, is 850 feet of impermeable marine siltstones and hard, brown shales. Approximately eight thousand feet of interbedded marine sands, clays, siltstones and shales separate the injection zone from the base of fresh water (Tetra Oil Company, 1984).

Well Construction Details. The Mary Anderson #1 was originally drilled as an oil producing well in 1938 to a total depth of 11,420 feet. The well was redrilled and recompleted in 1983 for use as an injection well. Current configuration is a 13-3/8-inch surface casing set to 2,566 feet and cemented back to the surface. A 7-5/8-inch casing was set in an 11-inch hole at 11,385 feet, and cemented back to 6,491 feet and in the interval from 2,566 to 145 feet. The 5-inch casing was plugged back to 11,420 feet and perforated in the 11,377- to 11,416-foot interval. A 2-7/8-inch tubing is hung from the surface and set with a packer at 9,787 feet. The casing/tubing annulus is filled with brine.

Chronology of Operational Problems. The facility has had a complicated permitting history and operational history since injection began in September 1983. The EPA, California RWQCB, the State Department of Health Services (DOHS), and the County Health Department all have permitting jurisdiction. The original permit issued to the Rio Bravo Refining Company permitted the owner to recomplete the abandoned oil well as an injection well for disposal of gas plant blowdown, pump drains, crude oil dehydration wastewater, and oil field produced brine water. Maximum permitted daily discharge was 210,000 gpd. The RWQCB, Central Valley Region, issued waste discharge requirements for this activity on June 24, 1983. Injection of nonhazardous wastes began in September 1983.

Permitting jurisdictional problems developed when EPA assumed primacy for the UIC Program in June 1984. At approximately the same time the owners notified the RWQCB that there would be a "material change in the character, location, or volume of the discharge," EPA assumed primacy for underground injection, but the RWQCB maintained discretion to issue waste discharge requirements. The RWQCB did not change the Rio Bravo's discharge permit when the facility announced in April 1984 that it would begin accepting hazardous wastes.

EPA considered Rio Bravo an existing facility when it assumed primacy (June 25, 1984), which allowed the facility a 6-month grace period (under authorization by rule) in which to submit the EPA permit application for hazardous waste disposal. Meanwhile, the DOHS, which shares permitting responsibility for above-ground hazardous waste storage and pipeline systems, issued an interim status document in August 1983, allowing the facility to continue operating while EPA processed its two-part application for a hazardous waste facility. Rio Bravo began accepting hazardous wastes in May 1984.

On October 30, 1984, Rio Bravo submitted its permit application to EPA for injection of hazardous wastes. On November 9, 1984, a leak of approximately 200 gallons of hazardous wastes occurred. The leak was from a hairline crack in the pipeline to the wellhead. The waste sprayed from the wellhead over a 3,500-square-foot area. The spilled waste was compound of 99.0 percent water, 0.5 percent oil, 0.5 percent grease, 1.0 ppm chromium, and 0.002 ppm vinyl chloride (EPA, 1985e). Cleanup involved excavation and removal of 270 cubic yards of soil. Subsequent soil sampling indicated the soil was non-EP-toxic. Corrective actions as a result of this incident include designing spill containment at the well area, upgrading the piping system, upgrading the corrosion monitoring system, and designing an emergency monitoring system (Rio Bravo Disposal Facility, 1985). The facility was shut down before any corrective actions were implemented.

As a result of this incident, the Kern County Public Works Department, Building Inspection, issued a Cease and Desist Order to the facility for operating without approval from the County Planning Department (California Public Works Department, 1984). The facility was ordered to correct the problem or apply for a county conditional use permit within 20 days. The facility was allowed to continue operating while the county permit was being processed. In December, EPA notified the facility that they had violated federal regulations for failure to properly notify EPA of the incident (EPA, 1985).

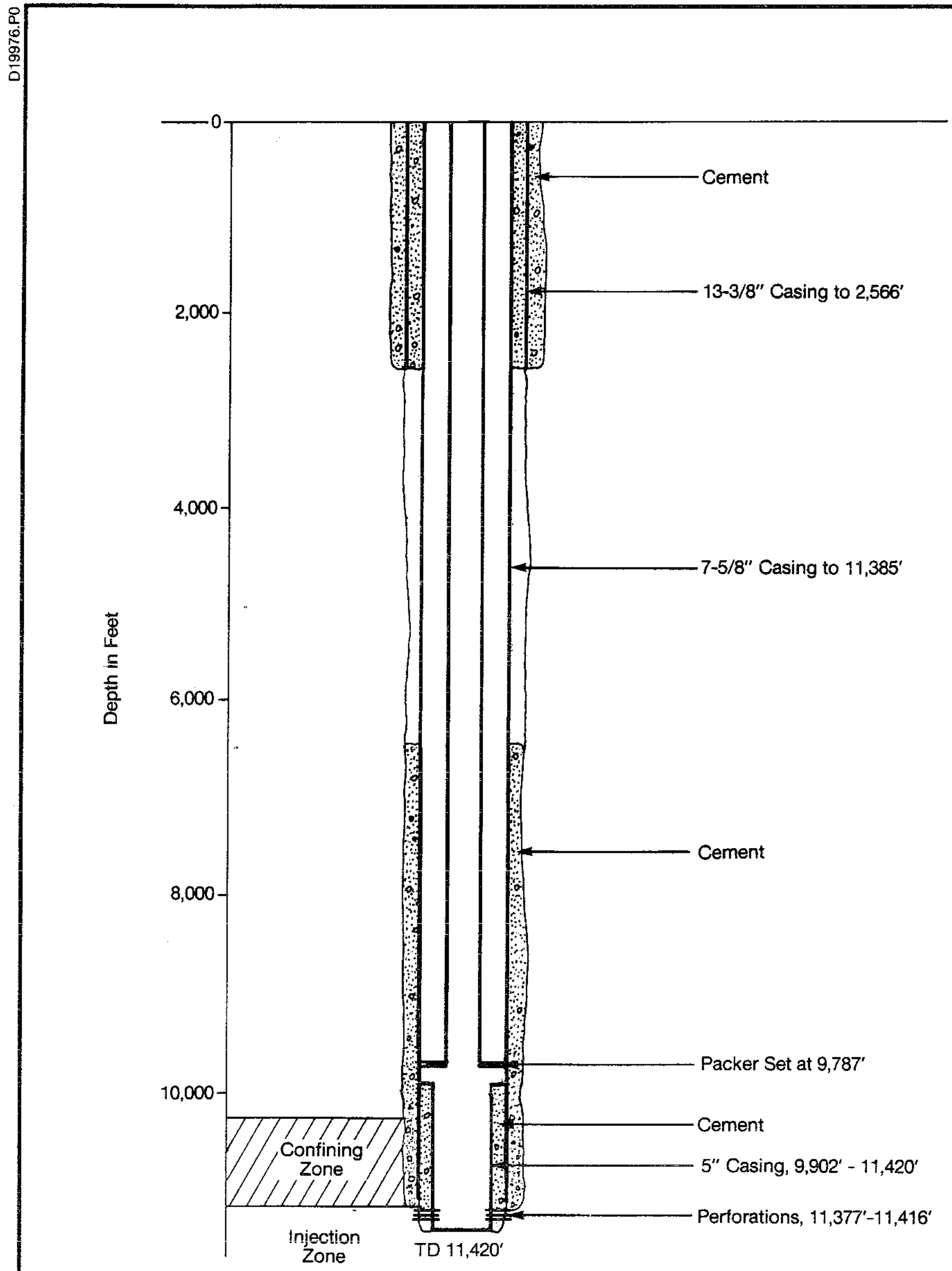
The owners submitted a complete UIC permit application by December 24, 1984, and were preparing a county conditional use permit application when a second spill occurred January 9, 1985. A small, continuous 0.5-mm leak occurred from the pipeline which transports the waste fluid from the facility to the injection well. The pipeline is above ground except where it passes under Highway 43. The spill occurred adjacent to the highway, and covered an area approximately 10 feet by 30 feet by 6 inches deep. The owners indicated the affected area was 2 feet by 7 feet, for a total loss of 15-20 gallons of fluid. The spilled waste reportedly contained toluene, xylene, ethyl benzene, 1,1,1, TCA, and tetrachloroethylene, with a pH of 13 (EPA, 1985). Ten cubic yards of contaminated soil were hauled to a landfill followed by soil sampling to verify complete removal.

This second spill resulted in Kern County and the State Department of Health Services issuing a Determination of Imminent and Substantial Endangerment and Remedial Action Order, which concluded that "there may be an imminent or substantial endangerment to public health or welfare or to the environment, because of releases and threatened releases of hazardous substances from Rio Bravo." Rio Bravo was ordered to cease accepting hazardous wastes immediately, to dispose of all hazardous wastes currently stored onsite immediately, to fence the well and pipeline, and to develop a soil sampling plan to assess the surface contamination from pipeline failures (DOHS, 1985). The DOHS revoked the Interim Status Document and denied the permit application for a hazardous waste facility. The DOHS also stopped all work on review of the previously submitted application. The Rio Bravo facility could not resume operation until a new hazardous waste permit was applied for and approved. Rio Bravo owners appealed (and won) to the Kern County Superior Court on their right to have an administrative hearing on the revocation of the Interim Status Document and denial of the hazardous waste facility permit application. As of June 1985, the hearing was still pending.

The County District Attorney and DOHS have filed suit against Rio Bravo for noncompliance with the fencing requirement in the remedial action order. In addition, Rio Bravo submitted a conditional use permit to the county, which was denied on the basis of incomplete and insufficient information (EPA, 1985e). In July 1985, Rio Bravo owners filed for Chapter 11 reorganization under federal bankruptcy law.

As part of EPA permit review in January, and partly as a result of the two spills, EPA requested that the owners stop injecting until the well's mechanical integrity could be demonstrated. In June 1985, a temperature survey, spinner survey, radioactive tracer survey, corrosion log, and pressure fall-off test were performed. All test results were favorable, indicating that the well itself had mechanical integrity (Ken E. Davis Associates, 1985). EPA continued their permit review, prepared a draft permit, held a public workshop on July 31, 1985, and a public hearing on August 15, 1985. EPA denied the permit application on September 30, 1985, on the grounds that the numerous oil wells within the area of review represented potential pathways of fluid migration (R. Mechem, 1985, personal communication).

The injection well at the Rio Bravo facility was operated for nine months in 1984, and has been shut down since January 1985. The only problems at that site on the public record were spills related to leaks in the above ground piping leading to the wellhead. Information concerning the well itself indicates no operational problems. Overlapping permit authorities, transfer of authorities at the time Rio Bravo began injecting hazardous wastes, Rio Bravo owners' omission in not obtaining all required local, state and federal permits, considerable concern over the large number of existing oil wells within the area of review, and public outcry over the spills all contributed to the facility closure.



RIO BRAVO DISPOSAL FACILITY
Shafter, California

MARY ANDERSON NO. 1

Background. The disposal well is located on the Rocky Mountain Arsenal grounds, northeast of the City of Denver, Colorado. The arsenal grounds adjoin the north extent of the Denver, Stapleton Airport.

The arsenal was originally constructed in 1943 and was operated at full capacity during World War II, producing various defense products. In 1952, Shell Chemical Company began production of insecticides on the arsenal grounds. Industrial wastes produced at the arsenal were stored in a number of clay bottom evaporation lakes. In 1955, these waste lakes were found to be contaminating shallow wells in the area (U.S. Army Environmental Hygiene Agency, 1965). The Rocky Mountain Arsenal disposal well was constructed in 1961 as an alternative to lake storage of waste, and was in operation from March 1962 to February 1966. The surface facilities have been idle since 1966 and information obtained during this study (September 1985) indicate that the arsenal plans to close the facilities in the near future.

All liquid waste produced at the arsenal flowed into a diked section of Lake F, a 96-acre waste lake. Waste to be discharged down the well flowed through a clarifier to a wet well, was pumped through pressure filters to a storage tank, and then was pumped down the wells (Dildine, 1984).

Waste was injected down the well at varying rates and pressures during its life. Initially, the injection pressure was approximately 550 pounds per square inch (psi) with an injection rate of 200 gallons per minute (gpm). Gravity flow was used for approximately seven months with an approximate injection rate of 60 gpm. Near the end of the well's use, an injection pressure of 1,050 psi resulted in an injection rate of 300 gpm (Evans, 1966). While the well was in operation (March 1962 to February 1966), approximately 164 million gallons of liquid waste was injected. Operation of the well was stopped after a reported link between the injection of waste and the increase in the frequency of earth tremors in the Denver area.

Site Description. The Rocky Mountain Arsenal is located in a north-south trending asymmetrical syncline known as the Denver Basin. The basin extends northward into Wyoming and is flanked on the west by the southern Rocky Mountains and on the east by the high plains.

In the area of the arsenal, the Denver Basin is underlain by approximately 12,000 feet of consolidated sedimentary rocks ranging in age from Cambrian to Recent. The injection zone chosen for the Rocky Mountain Arsenal well is in fractured Precambrian rocks at a depth of 11,975 feet to 12,045 feet (Trautmann, 1982). The base of fresh water is reported at 1,250 feet.

Well Construction Details. The Rocky Mountain Arsenal well was constructed by setting a 20-inch casing to 139 feet. A 13-3/8-inch casing was set to a depth of 2,020 feet and cemented to the surface. An 8-5/8-inch casing was then set to 11,171 feet and cemented to the surface. A 5-1/2-inch liner was cemented from 11,007 feet to 11,975 feet (E.A. Polumbus, Jr., and Associates, Inc., 1961). A 6-3/4-inch open hole exists from 11,975 feet to 12,045 feet.

Approximately 9,000 feet of 5-1/2-inch injection tubing with a 5-foot, 2-5/16-inch, stinger section was installed in the well. A Baker Model "D" permanent packer was set at a depth of 8,998 feet.

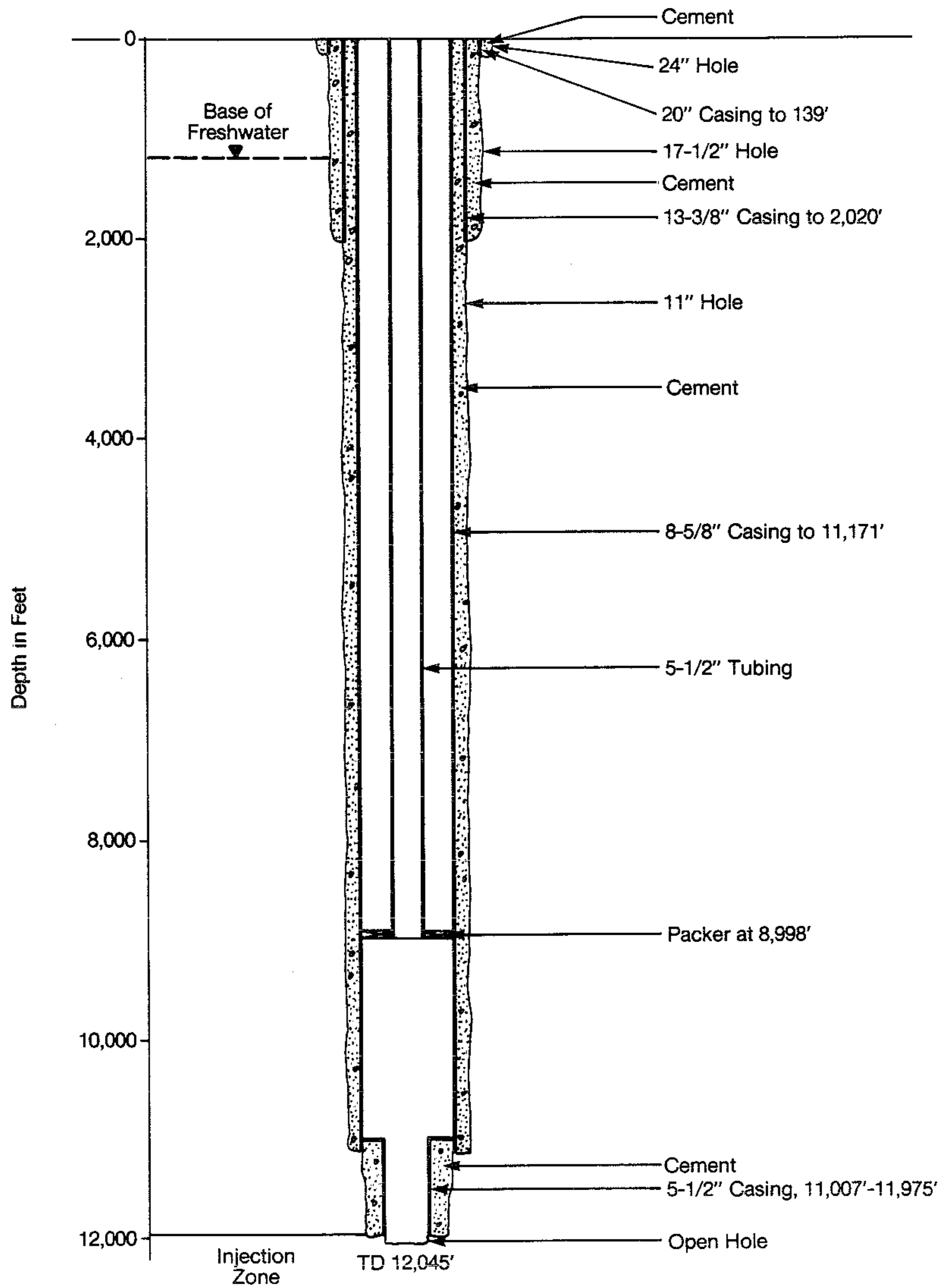
Currently, the well is in its original configuration with the exception of a 2-1/4-inch instrument package stuck in the tubing at the 9,000-foot level. Attempts at retrieving the package resulted in blockage of the tubing below 4,018 feet.

Chronology of Operational Problems. In March 1962, the Rocky Mountain Arsenal well began injecting wastewater. From March 1962 through September 1963 the injection pressure was approximately 550 psi and the injection rate was about 200 gpm. At the end of September 1963 the injection well was shut down until September 1964. From September 1964 until the end of March 1965 the well was operated by gravity flow only. The average injection rate during this time was about 60 gpm. Beginning in April 1965, higher injection pressures were used. Pressures as high as 1,050 psi at an injection rate of 300 gpm are reported. On January 20, 1966, the well was shut down. Gravity flow injection was again used from February 14 to 19, 1966. The well was permanently shut down in February 1966 (U.S. Army, 1962-1966).

In April 1962, an earthquake of magnitude 3.1 with its epicenter in the Denver area was recorded. This was the first earthquake in that area since November 1882. Between April 1962 and September 1965, 710 earthquakes, with epicenters in the vicinity of the arsenal were recorded. The magnitude of these earthquakes varied from 0.7 to 4.3 on the Richter scale. The earthquakes frequently seemed to correlate with the volume injected at the arsenal wells.

Operation of the arsenal well was terminated after a reported link between injection of waste and earthquakes in the Denver area.

A research program was initiated in an attempt to assess the link between the Denver earthquakes and the operation of the well. During the summer and fall of 1968, pumping tests were conducted. In February 1969, an instrument package became lodged in the well near the 9,000-foot level. The results of this study are apparently inconclusive.



ROCKY MOUNTAIN ARSENAL
Denver, Colorado

INJECTION DISPOSAL WELL

KAISER ALUMINUM AND CHEMICAL CORPORATION MULBERRY, FLORIDA

Background. A Kaiser Aluminum and Chemical Corporation plant is located in Mulberry, Polk County, Florida, about 30 miles east of Tampa. This plant uses fluosilicic acid, a byproduct of local phosphoric acid manufacturing plants, to produce sodium fluosilicate (Na_2SiF_6). The low pH, high-chloride waste stream is considered hazardous because it is reactive and corrosive. A typical analysis of constituents in the injected fluids includes 2.5 percent Cl^-, 1.5 percent HCl, 0.2 percent F, and 0.6 percent Na. The plant has used one injection well since October 1972 to inject onsite hazardous wastes.

The well was originally drilled for waste disposal, and as of December 1976, had injected a cumulative volume of 346 million gallons of waste (Vecchioli, 1979). Only 33 million gallons were injected in 1984, and the well currently operates on a 5-day/week schedule. Approximately two of the days the well injects the corrosive waste stream and the remainder of the week it injects groundwater and stormwater from past waste management areas at the site. After injection, the acidic waste reacts with the calcium carbonate injection formation and is neutralized. The acid level and injection rate are low enough that carbon dioxide produced from this reaction will remain in solution in both the injected and formation waters.

Prior to well construction, the waste stream was neutralized with lime and discharged into a coarse sediment basin, and then to a 30-acre lake. This lake would occasionally overflow into adjacent streams. Eventually, the lake became a problem because of elevated levels of chlorides and fluorides. Groundwater in the area was likewise impacted.

Kaiser constructed the well to replace this unsuitable disposal method. Wastewater is now pumped to a rubber-lined 40,000-gallon head tank and then to the injection well. Injection is either by gravity flow or pump pressure. Pump capacity sets the operating maximums for the well.

Kaiser had applied for and received a construction permit for a second well, renewed it, and then let it expire in March 1985 (FDER Correspondence files). The 1983 Florida Legislature banned all future Class I wells injecting hazardous wastes, so Kaiser no longer has the opportunity to construct a second well.

Acidic injection into the calcium carbonate strata results in a controlled reaction which dissolves a cavity in the dolomite formation. Kaiser has maintained a protective layer of #5 oil against the roof of the cavity. Radioactive tracers are introduced into the oil and used to monitor the oil's position. Leakage through the underlying confining beds has also been suggested in the literature.

Site Description. The Kaiser well is the deepest Class I well in the state, with a total depth of 4,984 feet. The well penetrates over 4,000 feet of primarily limestone and dolomite, passing through four USDW's, before reaching the top of the injection zone at 4,322 feet.

The lowermost USDW at the site is found in the Oldsmar Limestone and upper Cedar Keys Limestone, at depths ranging from about 2,000 feet to approximately 3,320 feet. The Floridan aquifer is 1,300 feet thick at the site, to a depth of 1,545 feet below land surface, and consists of limestone and dolomite. The total dissolved solids (TDS) content is approximately 3,000 mg/L. The Tampa and Hawthorn formations serve as confining units to the Floridan. A secondary artesian aquifer exists in the Hawthorn. An unconfined aquifer in the surficial sands comprises the fourth USDW at the site.

The injection zone is in the lower Cedar Keys Limestone Formation, the underlying Lawson Limestone, and beds of Taylor age. The open hole portion of the well occurs through these formations at depths of approximately 4,000 feet to 4,984 feet. The injection zone consists of vuggy dolomites and chalky limestones, with the formation fluids containing 115,000 mg/L TDS (FDER Correspondence files, 1985). In April 1976, during a geophysical logging operation, it was discovered that the open hole contained sediment below the depth of 4,450 feet. The sediment is believed to be an insoluble residue from dissolution of overlying formations.

The injection zone is underlain and overlain by confining beds. The lower confining bed ranges from 500 to 2,000 feet thick, and is more permeable than the overlying confining bed. The upper confining beds consist of alternating anhydrite and dolomite beds of the middle Cedar Keys Limestone, with a total thickness of 780 feet. Top of these confining beds occurs at approximately 3,320 feet (Hickey and Wilson, 1982).

Well Construction Details. The well was originally constructed with an open hole completion between 4,040 to 4,984 feet below land surface (Vecchioli et al., 1979). A 30-inch steel casing was set to 106 feet, a 24-inch steel casing was set to 202 feet, and the 10-3/4-inch steel casing was set to 2,931 feet. Annular monitoring tubes were set in the annulus between the 24- and 10-3/4-inch casings at depths of 1,254 to 1,264 feet and 2,775 to 2,788 feet, to monitor the upper and lower Floridan aquifer.

The total length of the 7-5/8-inch injection string was 3,992 feet, with the bottom 33 feet being a corrosion resistant Hastelloy casing. A 4-1/2-inch fiberglass injection tubing, with slotting in the lower 30 feet, extended 411 feet beyond the 7-5/8-inch casing into the open hole. A non-corrodible packer assembly was set between the tubing and casing (Wilson et al., 1973).

In 1974, a satellite monitor well was drilled 2,291 feet from the injection well and completed into the injection zone (Wilson et al., 1979).

<u>Chronology of Operational Problems</u>. Two major workover events occurred during the operation of the Kaiser well. Leaking annular fluid was first detected in April 1976. The tubing was successfully tested, but casing testing revealed a leak where the corrosion resistant casing was threaded to the last string of steel casing at a depth of 3,959. During an attempt to perform a remedial squeeze cement job, the Hastelloy casing, the packer bore receptacle, and a fibercast collar broke off and fell down the hole (Vecchioli et al., 1979; Florida Department of Environmental Regulation (FDER) Correspondence files).

The situation was corrected by remedial cementing, replacing the tubing and setting a new packer. The well configuration after the successful workover was as follows:

- An open hole beginning at 3,992 feet
- Remedial cementing of the 7-5/8-inch casing above 3,992 feet
- A new packer installed at 3,828 feet, and
- The new 4-1/2-inch fiberglass tubing set to 4,333 feet with slotting on the bottom 27 feet

The annulus below the packer and the upper part of the open hole were filled with #5 oil to protect the lower tubular goods from the effluent (Vecchioli et al., 1979).

Two explanations are offered for the lower casing separation. An initial inadequate cement job, resulting from a cavity adjacent to the well bore, contributed to the heavy Hastelloy casing breaking away from the steel casing. Another explanation is that the acidic effluent dissolved the supporting formation away from the casing (EPA, 1985).

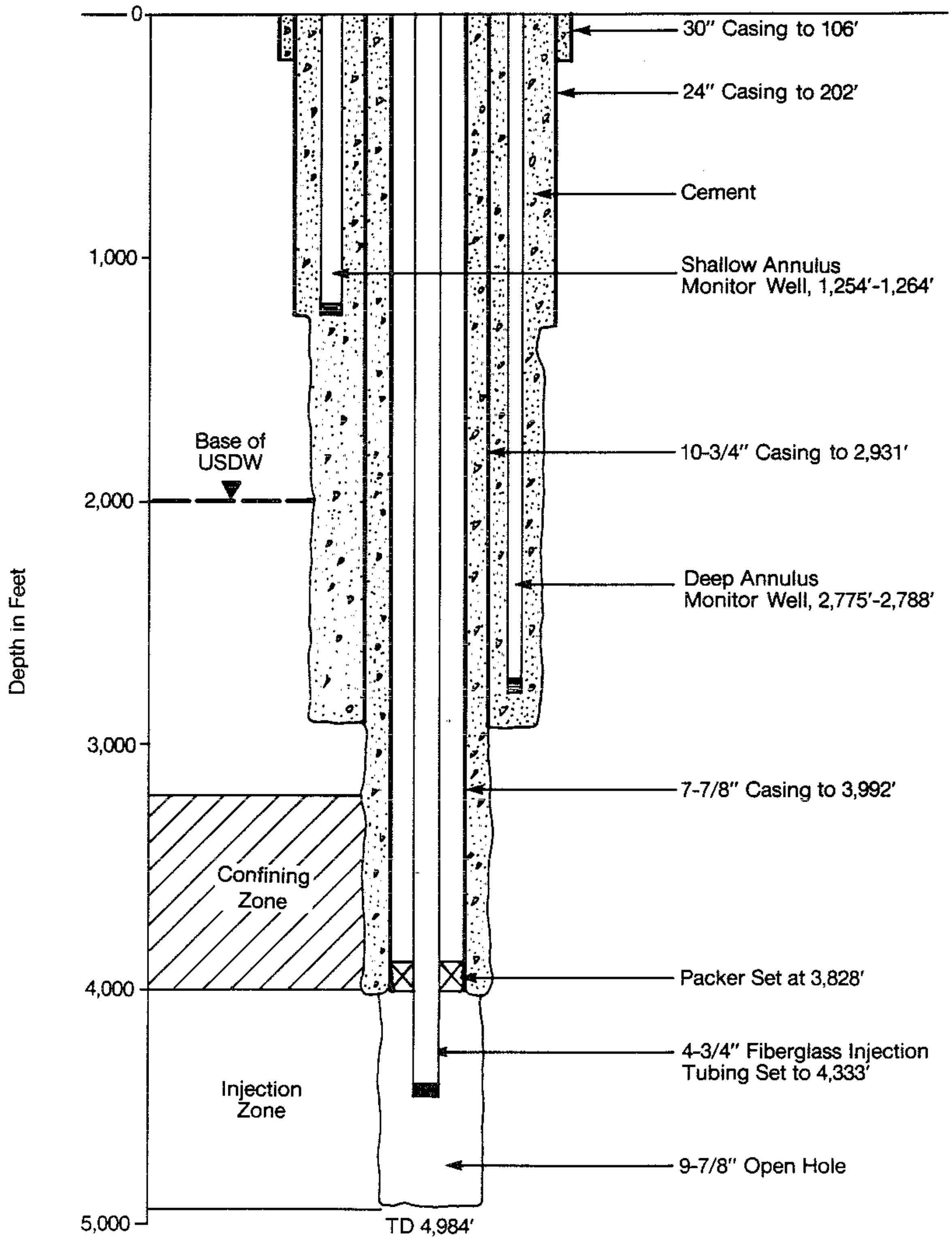
The second incident occurred in January 1981, when leaking annular fluid was detected. A tubing leak at 2,492 feet allowed effluent to migrate into the annulus. Some corrosion damage occurred to the 7-5/8-inch casing in the intervals 2,466 to 2,638 feet and 3,530 to 3,878 feet as a result. The casing was pressure tested and determined to still have mechanical integrity, although the collapse strength was somewhat reduced (EPA, 1985c).

The tubing and packer were replaced, and no annular fluid has been lost since the replacement. Kaiser improved its monitoring system as a result of this incident.

Kaiser has been performing sonar and mechanical caliper logs in the injection well since 1976. The 1976 logs indicated the development of a cavity in the open hole in the interval between 4,050 and 4,500 feet. The cavity was about 100 feet high with a maximum diameter of 23 feet. Cavity development results from the acidic effluent dissolving the calcium carbonate in the injection zone, which neutralizes the waste. The cavity growth rate is related to injection rate, and has been an estimated 10,000 ft^3/year since 1978. The cavity is monitored as part of the operating permit, and as of November 1982, had a maximum diameter of 42 feet at

4,390 feet. Growth rate since 1982 declined to an estimated 4,200 ft^3/year because of reduced injection rate (FDER Correspondence files, 1985b).

Hickey and Wilson (1982) performed injection tests at the site in 1975 and 1976. The authors' interpretation of the data from these tests is that the neutralized waste may be leaking into the underlying confining beds. The overlying confining beds are "probably relatively impermeable and significantly retard the vertical movement of neutralized waste effluent" (Hickey and Wilson, 1982).



Constructed: 1972

KAISER ALUMINUM
Polk County, Florida

INJECTION WELL NO. 1

UIPC

KENDALE LAKES WASTEWATER TREATMENT PLANT MIAMI, FLORIDA

Background. The Kendale Lakes Wastewater Treatment Plant (WWTP) operated one municipal injection well for disposal of secondary treated wastewater associated with the plant's activated sludge treatment process. The facility, located in southwest Miami, handled an average daily flow rate of 2.25 million gallons per day (mgd) of sanitary wastewater from the residents in that area.

The injection well was constructed in 1972 for General Waterworks Corporation. Ownership was transferred to the Miami-Dade Water and Sewer Authority (MDWSA) some time after the facility was operational.

The injection well functioned without incident until May 1982, when during a period of relatively high flow to the well produced by heavy seasonal rains, the monitoring annulus pressure increased to greater than background levels. Chlorine residual in the annulus confirmed the presence of a leak in the injection casing. The facility was taken out of service and plant influent was diverted to another WWTP located at Virginia Key. The facility was eventually abandoned when the larger capacity South District WWTP, which uses nine deep wells for effluent disposal, was placed into service in 1983.

Site Description. The Kendale Lakes WWTP is located in southwest Miami approximately 3-1/2 miles west of the Sunset Park WWTP which was also operated by MDWSA. The Kendale Lakes facility originally operated by disposing of secondary treated municipal effluent to a county-owned canal, which connects with the canal network of the Central and Southern Florida Flood Control District. The injection system, which includes the injection well, deep monitoring annulus, surge control system, and monitoring and control instrumentation, allowed the discharge of effluent to Florida's surface waters to be discontinued.

The City of Miami's Southwest Water Well Field is located 1.1 miles east of the Kendale Lakes injection well. The City's Alexander Orr Water Well Field is less than one mile northeast of the Sunset Park injection well. These two well fields produce water from the shallow Biscayne aquifer. The wells in service are less than 100 feet in depth. The Biscayne aquifer underlies all of Dade and Broward counties and parts of Palm Beach and Monroe counties. Lithologically, the aquifer is a highly permeable limestone in south and west Dade County, becoming increasingly sandy and less permeable to the Atlantic coast and northward.

The sands and limestones of the Biscayne aquifer are separated from the highly mineralized Floridan aquifer system by the Hawthorn and Tampa formations. These units are composed of highly plastic phosphatic clay and soft limestones which serve as an aquiclude. Total thickness is nearly 800 feet within the area of the disposal well.

The Floridan aquifer, composed of the Tampa, Suwannee, Avon Park, Lake City, and Oldsmar formations, underlies all of Florida, southern Georgia, and parts of Alabama and South Carolina. This aquifer is composed of nearly 3,500 feet of carbonate rocks. The upper Floridan aquifer is used only as a supply of water for irrigation purposes in southern Florida. Formation water containing total dissolved solids (TDS) of 10,000 mg/L occurs at approximately 1,800 feet, becomes more saline with depth, and eventually approaches seawater-like concentrations in the Oldsmar Formation. The Oldsmar is the target zone of injection throughout southern Florida.

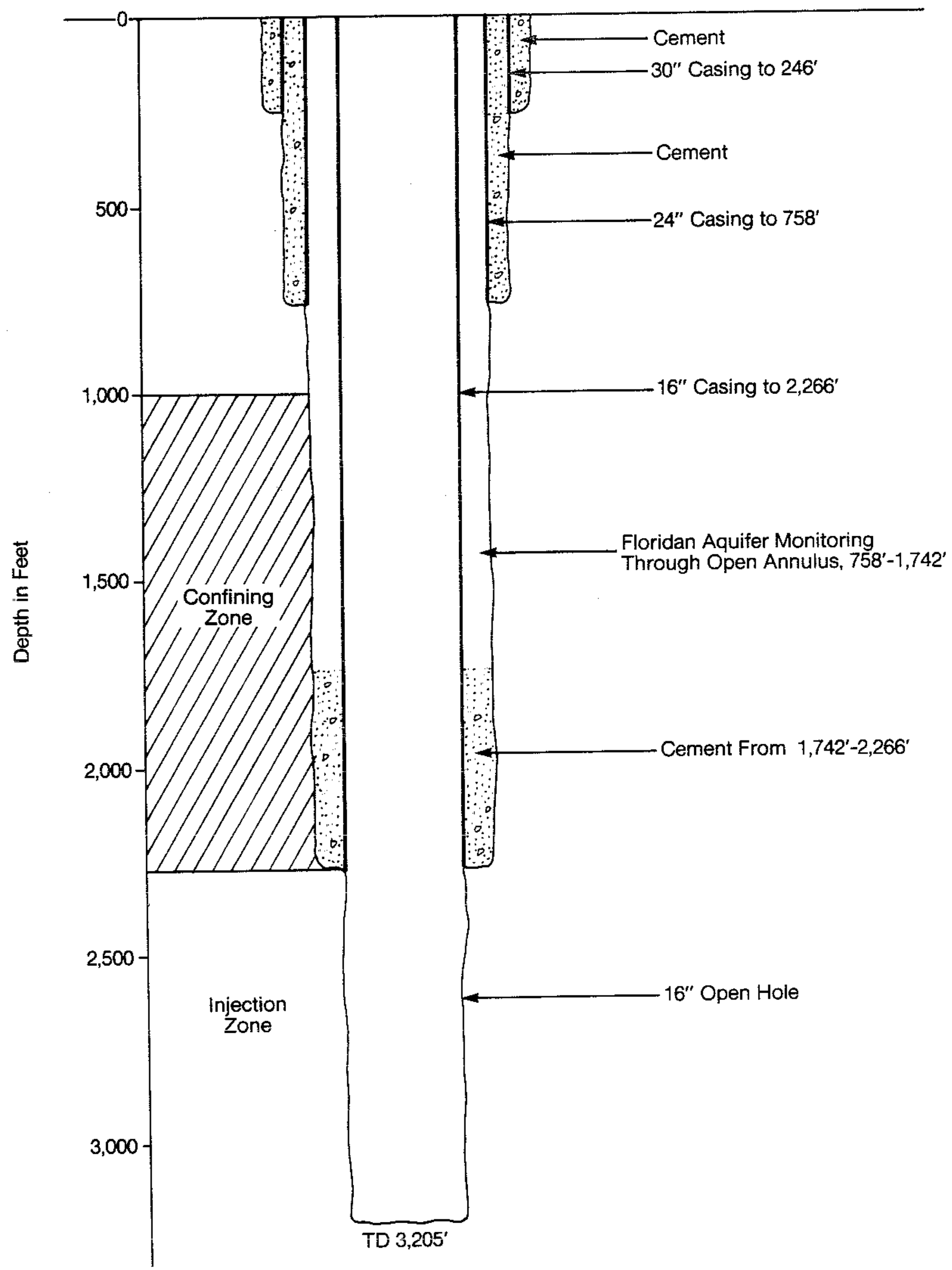
Within the Oldsmar, cavernous zones (Boulder Zone) composed of dense dolomite allows injection of wastewater at rates exceeding 10,000 gpm with surface injection pressures of approximately 70 pounds per square inch gauge (psig). The chalks and dense dolomitic limestones and dolomites above the injection zone serve as confining strata isolating the injected fluids.

Well Construction Details. The Kendale Lakes disposal well is constructed with three steel casings which were used to isolate and conduct the treated wastewater into the injection zone. A 30-inch casing was set at 246 feet and cemented to the surface, isolating the Biscayne aquifer and the clays of the Hawthorn Formation. A 24-inch casing was set at 758 feet and cemented to the surface. The 24-inch casing completely isolates the aquiclude separating the Biscayne aquifer from the mineralized waters of the Floridan aquifer system. A 16-inch injection casing is set at 2,266 feet and cemented back to 1,742 feet, forming an open annular monitoring interval between the 1,742-foot depth and the bottom of the 24-inch casing at 758 feet. The injection casing penetrates the impermeable chalks and dense dolomites of the Lake City Formation which serve as the upper confining layer of the injection zone. The well was completed open hole to a depth of 3,170 feet into the Oldsmar Formation. The Boulder Zone, the principal receiving interval, occurs between 2,950 and 3,000 feet.

Chronology of Operational Problems. The system operated satisfactorily from 1972 to 1982. On May 30, 1982, during high influent flows produced by heavy rains in south Florida, the monitoring annulus pressure rose above background. Fluctuations in annulus pressure were observed until June 8, 1982, when chlorine residual was detected in the annulus fluid, confirming the presence of a leak. The well was taken out of service and the annulus pressure dropped and remained steady.

A downhole TV survey was performed. The survey revealed a 4-foot vertical split in the casing between 1,254 and 1,258 feet. After review of the May 30 to June 9 annulus water levels, injection pressure and flow records, the UIC Technical Advisory Committee took the position that the casing split resulted from water hammer caused by a power failure while injecting at exceedingly high rates. Apparently the water hammer prevention system was out of service.

Rather than repairing the well, the MDWSA requested that the well be abandoned since a new and larger facility (South District WWTP) would be placed into service in early 1983. Influent to the Kendale Lakes WWTP was diverted to the WWTP located on Virginia Key and the injection well system was taken out of service.



KENDALE LAKES
MIAMI-DADE WATER AND SEWER AUTHORITY
Dade County, Florida

CITY OF MARGATE WASTEWATER TREATMENT PLANT
MARGATE, FLORIDA

Background. The City of Margate Wastewater Treatment Plant Injection Well No. 1 (IW-1) is located in Broward County, Florida, approximately 10 miles inland from the southeast coast. IW-1 was constructed in 1973 and put into operation in February 1974. The well is designed to dispose of secondary treated municipal wastewater at a maximum injection rate of 15 million gallons per day (mgd). The present average flow to the well is 8 mgd. The well is equipped with continuous flow, injection pressure, and annulus pressure monitoring instrumentation. A monitor well completed between the depths of 2,110 to 2,120 feet is equipped with continuous water level recording instrumentation. In addition, both the monitoring annulus and monitoring well are sampled for water quality on a monthly basis.

Margate's wastewater treatment plant is designed and operated for secondary treatment of municipal wastewater. The facility originally discharged the chlorinated treated wastewater to an adjacent canal. As the Broward County environmental regulations became more stringent, deep well disposal became the only viable method to eliminate discharge to surface waters.

In January 1983, a minor leak in the casing or grout seal was confirmed by the gradual freshening of the annular monitoring fluids in the injection well. The onsite monitoring well located 550 feet southeast of the injection well showed no changes in groundwater quality above the injection zone. However, small volumes of treated water were being withdrawn from the monitoring annulus of the injection well which was also open to a USDW.

Site Description. IW-1 is located on the southeastern coast of Florida. The well penetrates through Eocene and younger carbonate deposits. The principal injection zone is the Eocene Oldsmar Formation present below the depth of 2,500 feet. The injection zone is very transmissive, permitting injection at rates of 10,500 gallons per minute (gpm) with wellhead injection pressures of less than 70 pounds per square inch gauge (psig). The reported wellhead pressures result almost entirely from friction losses in the casing and the buoyancy of the lower density wastewater on the native formation fluids (CH2M HILL, December 1984).

The Biscayne aquifer is the major source of potable groundwater in southeast Florida, and extends to depths of 150 to 200 feet. This unit is underlain by nearly 650 feet of impermeable clay and soft limestone (Hawthorn and Tampa formations) that extends to nearly 1,000 feet in depth. The base of the USDW occurs in the Floridan aquifer within the Eocene Lake City Formation at an approximate depth of 1,800 feet. The USDW's are separated from the injection zone by low permeability chalk, dolomitic limestone, and dolomite. These strata overlay the injection zone and have a cumulative thickness of nearly 800 feet.

Well Construction Details. IW-1 is constructed with three concentric steel casings which conduct the treated wastewater to the injection zone. A 36-inch carbon steel casing is set from a depth of 312 feet and cemented to the surface. A 30-inch carbon steel casing is set and cemented to surface from a depth of 1,102 feet. The 24-inch carbon steel injection casing is set at 2,457 feet and was cemented up to 2,309 feet, leaving an open annulus for monitoring. The well was completed as an open hole to 3,200 feet (Black, Crow & Eidsness, March 1974).

Chronology of Operational Problems. When wastewater was detected in the annulus of IW-1 in 1983, the Florida Department of Environmental Regulation (FDER) required that the City develop another disposal method prior to repairing the well. After an investigation of the alternatives, a second injection well (IW-2) was permitted for construction (CH2M HILL, June 1985).

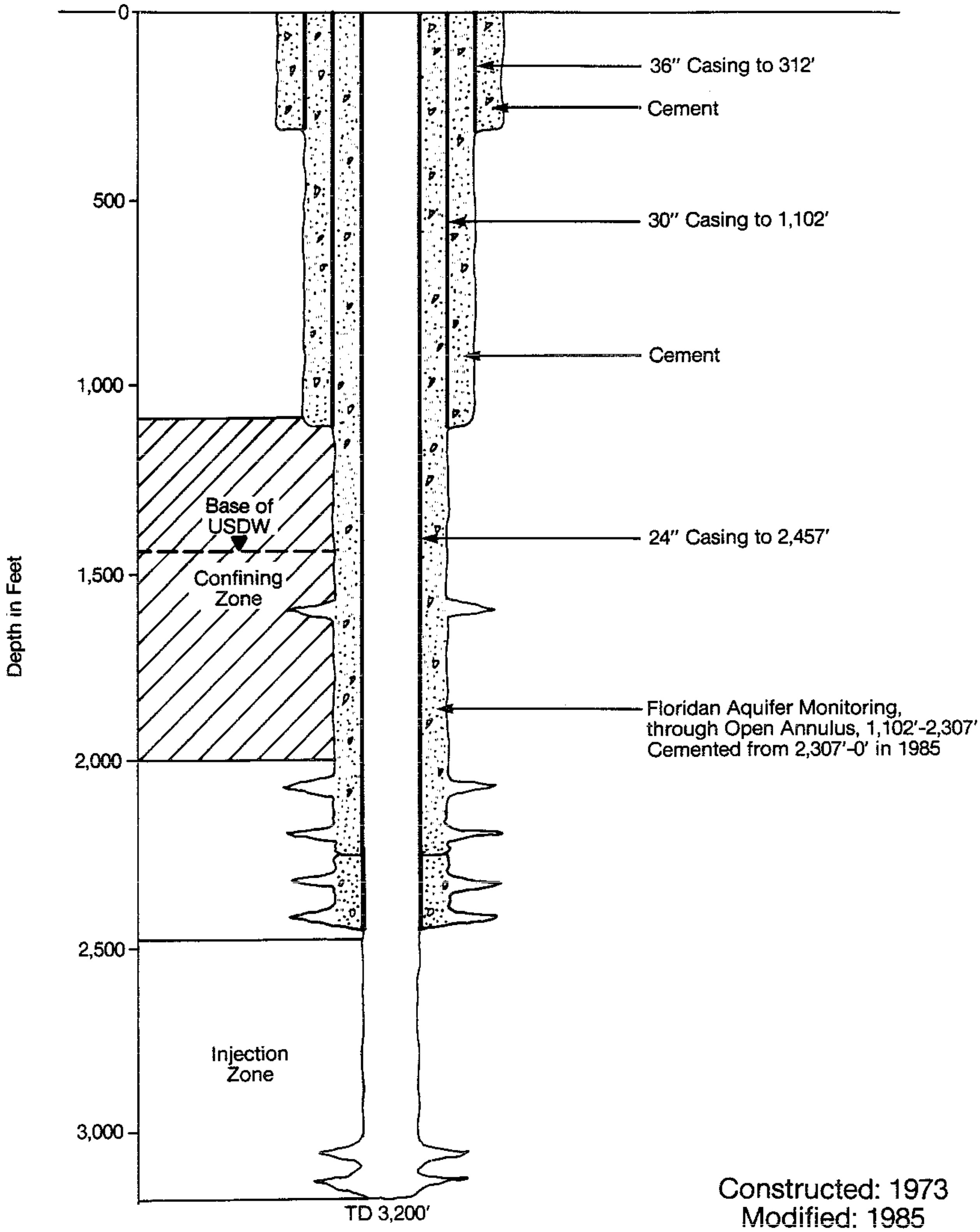
The FDER required the completion of IW-2 prior to any repair work to IW-1. This permitted the effluent to be disposed of in the same injection zone when IW-1 was out of service during the repair effort. Unlike an industrial disposal well, the Margate facility serves the residents of that area, and shutting down the facility was not feasible, unless treated effluent could be discharged to adjacent canals.

Prior to the repair of IW-1, the annulus was continuously pumped to prevent the wastewater from entering the unpermitted strata of the open annulus. The recovered water was reinjected into the well. The FDER approved this activity since the quality of the treated wastewater posed no threat to usable drinking water of Southeast Florida.

IW-1 was repaired in April 1985. The repair was successfully made by placing ultra-light cement (Spherelite®) in the open annulus. The cement was placed from land surface to the bottom of the annulus in one complete pumping stage. Radioactive tracer surveys were used to verify the depth to which the cement was placed. The injection casing was sealed, thus preventing any potential further discharge of fluid into a USDW. By cementing the annulus, the well was brought into compliance with present day regulations.

A new multi-zoned monitor well was installed during the construction of IW-2, which was sited 175 feet from IW-1. With both monitor wells in service, no effluent was detected.

The presence of treated wastewater in the annulus of IW-1 indicates that some leakage did occur, allowing the contact of treated wastewater with formations containing USDW's. However, the monitoring annulus was pumped out and this fluid re-injected as a means of preventing the contamination of the USDW in the area. The results obtained from both monitoring wells never showed contamination. The well was repaired and returned to service with no detection of contamination radially away from the well.



Constructed: 1973
Modified: 1985

CITY OF MARGATE
Broward County, Florida

INJECTION WELL NO. 1

MCKAY CREEK POLLUTION CONTROL FACILITY LARGO, FLORIDA

Background. The Pinellas County Sewer System operates the regional McKay Creek Pollution Control Facility at Largo, Florida, which is located on the west central coast of the peninsular county. The facility is located about 100 feet inland from Clearwater Harbor. The McKay Creek plant is a 6.0-mgd activated sludge sewage treatment plant. Chlorinated effluent is discharged to Boca Ciega Bay and through deep well injection.

The disposal well system consists of one injection well (F-1), one standby injection well (F-2), one onsite injection zone monitor well (Well A, formerly Well A-3), and one offsite injection zone monitor well (OS-I). Three wells monitor the first permeable zone above the confining zone: D-1 and D-2, which are onsite, and the offsite OS-II. Well D-0 monitors the 3,000- to 10,000-mg/L total dissolved solids (TDS) zone onsite, and Well OS-III monitors that zone offsite. The offsite monitoring complex is located approximately 7,500 feet to the northeast of the injection well site (Seaburn and Robertson, Inc., 1983).

The McKay Creek plant is a typical activated sludge plant with a design flow of 6.0 mgd that can be expanded to 9.0 mgd. Pretreatment is provided in chlorine contact chambers. Average daily flow is 2.70 mgd with a peak flow of 6.04 mgd (Florida Department of Environmental Regulation (FDER), 1985a). Commercial sources contribute 13 percent of the flow. Injection pressures range from 10 to 36 pounds per square inch (psi). When injection pressures reach 40 psi, the injection pumps shut down and the effluent is discharged to a surface water outfall (FDER, 1985d).

The Southwest Florida Water Management District (SWFWMD) developed and approved an elaborate monitoring plan that includes physical, biological, and inorganic parameters typical of sewage effluent monitoring. Sampling frequency varies from continuous to daily, weekly, or monthly for the onsite wells and quarterly for the offsite wells (FDER, 1985d).

In November 1984, the owner reported that upward migration of injected waste into a non-USDW permeable zone above the confining zone had occurred. The waste fluid was detected at Monitor Well D-1 (FDER, 1985e). Since injection began in F-1, well head pressures have gradually increased. Mechanical integrity for the two injection wells also had not been verified under the new UIC regulations. In January 1985, the owners agreed to shut in Well F-1 until corrective action could be established and mechanical integrity verified (1985e). In May 1985, the FDER approved a compliance schedule to complete these activities. No USDW's have been affected by the upward leakage detected in D-1 (FDER, 1985f).

Site Description. The McKay Creek site is situated on the western coast of the densely populated Pinellas peninsula. Fresh groundwater supplies are limited on the peninsula, and municipal well fields tapping the Floridan aquifer are located in inland Pinellas County, and in Pasco and Hillsborough counties.

The only potable water at the site occurs in a surficial sand aquifer that is generally less than 20 feet thick. The underlying Hawthorn Formation, consisting of approximately 90 feet of calcareous sandy clay at the site, provides upper confinement for the Floridan aquifer. The upper part of the Floridan aquifer consists of approximately 200 feet of permeable limestone.

Confining beds within the Floridan aquifer underlie the upper permeable zone and are composed of approximately 470 feet of limestone, dolomitic limestone, and dolomite. The injection zone consists of dolomite and dolomitic limestone of the upper Avon Park Limestone. The top of the injection zone occurs at an approximate depth of 800 feet, and extends to an approximate depth of 1,028 feet (Hickey, 1982). Total dissolved solids in the injection zone were approximately 38,000 mg/L.

Well Construction Details. The current disposal well system consists of two injection wells and eight monitor wells. Only Well F-1 has been used for injection. A 40-inch casing was set to 350 feet and cemented to surface, followed by a 28-inch casing set and cemented to 750 feet. A 16-inch casing was set to 800 feet and cemented back to surface. A 14-3/4-inch open hole extends to a total depth of 1,025 feet. Injection Well F-2 is of identical casing sizes and setting depths. Wells D-0, D-1, and D-2 are onsite, single-zone monitoring wells completed to monitor the 240- to 260-foot, 445- to 600-foot, and 540- to 630-foot intervals. Well C-1 is a shallow onsite well monitoring the interval between 76 to 190 feet. The offsite monitor wells are single-zone completion in the intervals 770 to 901, 551 to 585, and 236 to 265 feet for OS-I, OS-II, and OS-III, respectively.

Chronology of Operational Problems. Original construction at the site consisted of Monitor Wells A-1 and A-2, the "B-series" Cluster Monitor Well (B1-B4), and the first test Injection Well, A-3. SWFWMD required a 60-day tracer dye injection test in 1977 in an effort to define the injection zone more accurately. Results of the dye injection test indicated that leaks in the 16-inch casing of A-3 caused injected fluid to migrate into a permeable zone above the test-injection zone (FDER, 1985b). Further testing in June 1977 confirmed that leaks existed in the A-3, B-1, and B-3 casings. Repair of A-3 was not possible; in December 1978, SWFWMD issued Order. No. 78-94 which required converting A-3 to an injection zone monitor well, abandoning "B-series," A-1, and A-2, and constructing and testing Injection Wells F-1 and F-2 and Monitor Wells D-0, D-1, and D-2. This work and construction of the offsite monitoring complex were also completed in 1981.

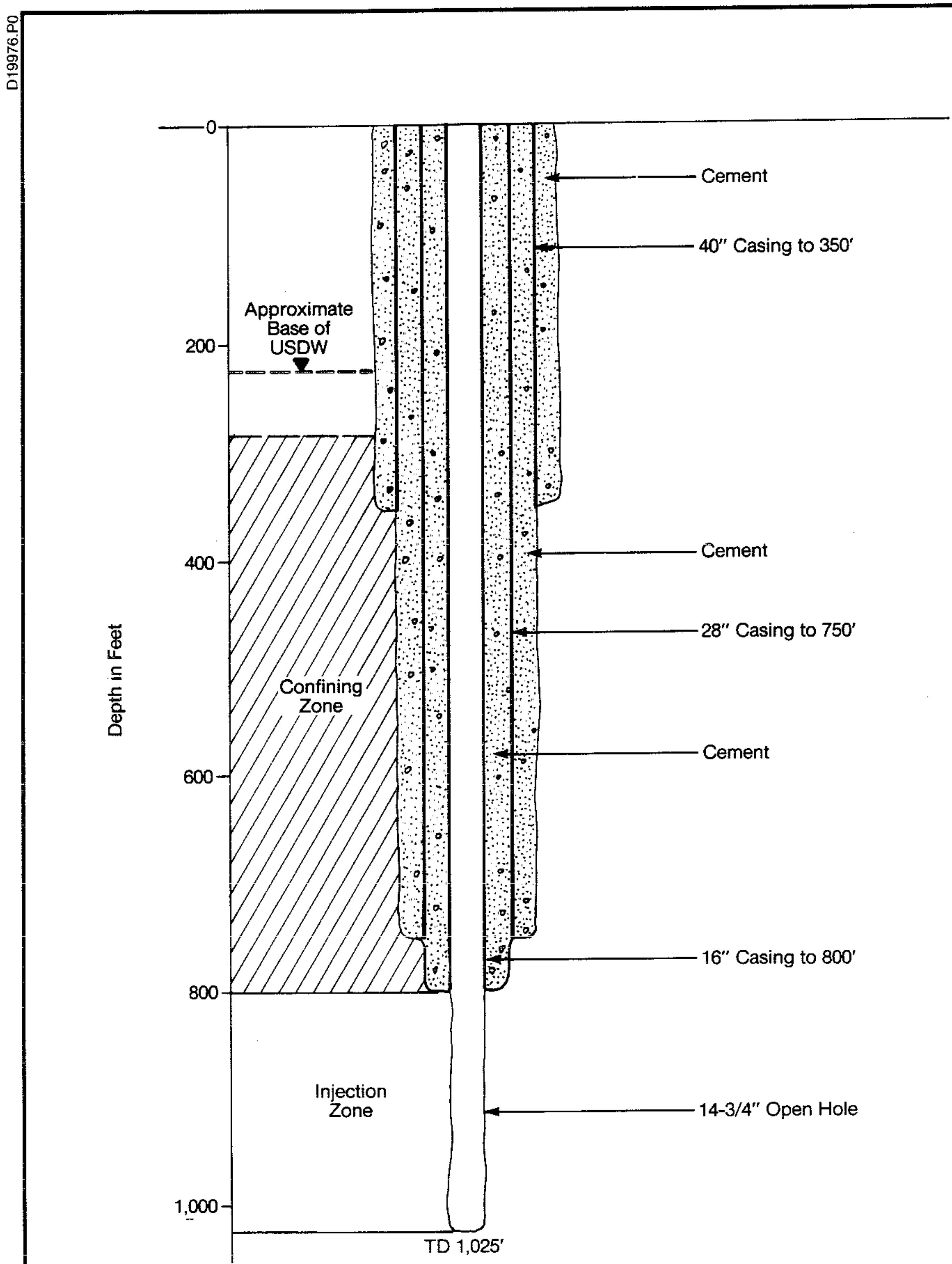
Order No. 78-94 also authorized a 30-month injection test. Background sampling for this test began in July 1983 and the 30-month injection test began on July 2, 1984. After 190 days of testing, the test was stopped because of increasing pressures and apparent upward leakage (FDER, 1985b). Effluent had been detected at Wells A and D-1. Effluent arrival at Well A was expected since it monitored the top of the injection zone and was only 75 feet from F-1. Effluent arrived at Well D-1, monitoring the zone 445 to 600 feet at a distance of 75 feet from the point of injection, within 31 to 66 days from start of injection testing. Wells D-2 and F-2, located 800 feet from the injection well, did not detect any injected fluid migration. Effluent was not expected to arrive at D-1 in such a short time, and was expected to arrive at F-2 during the 190-day test period. The County concluded that these unexpected results may indicate that anisotropic conditions exist in the injection zone, and that a longer injection testing time is needed to determine injection fluid movement (Pinellas County, 1985).

Possible explanations for the apparent upward movement of fluid are fractures, movement through the annulus around the well, or through the confining unit (FDER, 1985b). A program to investigate the possible causes was developed, and included verification of casing integrity on Wells F-1, F-2, and A, and radioactive tracer logging and noise logging. Results of this program were not available.

Pressure buildup was also observed at F-1. A downhole TV survey was run and large quantities of floating algae were observed in F-1. These may be contributing to the clogging conditions. A program to take sidewall cores from the open hole of F-1 was conducted in May 1985. Eleven samples were recovered, which were composed of fine-grained carbonate material with a reddish color. No bacteria were found in the cored material, but fungus was identified on a recovered limestone fragment (Seaburn and Robertson, Inc., 1985). A plastic coffee stirrer was also recovered from a sampling tool.

Results of this study could not conclusively attribute the well clogging problem to either filtration of suspended solids by the rock material or bacterial clogging. Large pieces of suspended materials injected during the test injection periods were identified as contributing factors. The study recommended that the well be cleaned out prior to resuming the test injection programs.

As of November 1985, plans were being made to pressure test Wells F-1 and F-2 and clean out F-1.



McKAY CREEK
Pinellas County, Florida

INJECTION WELL F-1

MONSANTO CHEMICAL CORPORATION
CANTONMENT, FLORIDA

Background. The Monsanto Corporation operates a large nylon manufacturing plant in Cantonment, Escambia County, in the western panhandle of Florida, about 13 miles north of Pensacola. Monsanto injects a non-hazardous composite waste stream containing monobasic and dibasic acids, alcohols, amines, ketones, mineral acids, esters, and inorganic salts. Only wastes produced onsite are injected. Cumulative volume injected through 1978 was 14.7×10^9 gallons (Merritt, 1984). Prior to 1985, the pH of the untreated waste stream periodically dipped below 2, rendering the waste RCRA-hazardous due to its corrosivity. In mid-1985, a neutralization system was installed which is designed to maintain the pH above 2 at all times, eliminating the hazardous classification.

Prior to 1963, the acidic industrial-process waste was discharged into the Escambia River after treatment. Increases in production were eventually limited by the dissolved oxygen standard established for the river, which could not always be met (Barraclough, 1966, and Dean, 1964). Consequently, Monsanto constructed a test injection well (Well A) in 1963, and has been using it and two other wells (Wells B and C) constructed in 1965 and 1982. Monsanto is permitted to operate any two injection wells simultaneously, with the third well on standby. Production levels during the last several years usually require the operation of only one well at a time.

From initial injection in July 1963 until April 1968, the waste was pretreated with aqueous ammonia to raise the pH to 5.5 (Goolsby, 1971). Pretreatment was discontinued when a precipitate formed, but injection of waste with a pH ranging from 2.3-3.0 was resumed in May 1968. The low pH waste tended to dissolve the calcium carbonate in the formation surrounding the borehole, and provided for further injection without undue pressure buildup. This was expected in that the aquifer rock is composed of greater than 90 percent calcium carbonate (Goolsby, 1971). Prior to 1975, well head injection pressure had not varied linearly with the injection rate, but dropped with increased injection rates (Faulkner and Pascale, 1975).

The waste is stored in a holding pond prior to injection (Merritt, 1984). Permitted injection rate for any two injection wells is 2,400 gallons per minute (gpm) with a maximum of 1,200 gpm for a single well, with a maximum injection pressure of 200 pounds per square inch (psi).

Currently, only Injection Wells A and B are in use. Injection Well C has been shut down since December 1984, because of a suspected lack of mechanical integrity.

Site Description. The hydrogeology at the site is well known. The sand-and-gravel aquifer is the principal USDW in the region, with excellent water quality. It exists at the site to a depth of 448 feet in the undifferentiated Pleistocene terrace deposits and the Citronelle Formation. A thick, areally extensive clay aquiclude known as the Pensacola Clay underlies the sand-and-gravel. The Pensacola Clay ranges in thickness from 150 to 980 feet with an interbedded sand layer, the Escambia Sand member, from 20 to 160 feet thick. At the site, the Pensacola Clay is 460 feet in thickness, with the sand layer only 25 feet thick (Goolsby, 1972).

The undifferentiated Chickasawhay and Tampa limestones comprise the upper Floridan aquifer which is also a USDW, but the quality of the sand-and-gravel aquifer is so superior that the Floridan is seldom used. The upper

Floridan is 218 feet thick at the site, and contains slightly brackish water with total dissolved solids (TDS) concentration of 1,100 mg/L. An extensive clay confining bed, the Bucatunna Clay, underlies the upper Floridan, and extends from southern Alabama and Mississippi to the Gulf of Mexico. The Bucatunna Clay member of the Byram Formation averages 125 feet thick, but is the thickest (220 feet) at the Monsanto site (Goolsby, 1972). According to geochemical data presented in Barraclough, 1966 and Goolsby, 1972, the transition to formation waters with TDS exceeding 10,000 mg/L occurs within the Bucatunna Clay.

Beneath the Bucatunna Clay is 359 feet of the lower Floridan aquifer in the Ocala Limestone. The lower limestone has a TDS value exceeding 12,000 mg/L, and serves as the injection zone. A shale and clay aquiclude of undetermined thickness underlies the injection zone (Merritt, 1984).

Well Construction Details. Injection Well A was initially constructed as a test well. A 24-inch surface casing was installed to 85 feet, followed by an 18-inch steel casing set into the upper limestone at 982 feet, and cemented back to the surface. A 12-inch steel casing, with the bottom 20 feet stainless steel, was set into the lower limestone at 1,390 feet and cemented in place with neat cement (Goolsby, 1971). Total depth drilled was 1,808 feet. The original construction was designed to accommodate an 8-inch stainless steel liner, sealed with a packer and using a fluid filled annulus. However, the packer failed to seat, and rather than pulling the liner, a diesel-filled annulus was emplaced (Dean, 1964).

Injection Well B was constructed in 1965 about 1,300 feet southwest of Well A. A 16-inch steel casing was set to 110 feet. A 10-inch steel casing, with the bottom 20 feet stainless steel, was set to 1,415 feet and cemented to the surface with neat cement. A 6-inch diameter stainless steel liner was set at 1,417 feet, and seated with a packer. The open hole extended to a total depth of 1,654 feet (Faulkner and Pascale, 1975).

Construction of Injection Well C was completed in early 1982, with injection commencing in December. A 30-inch surface casing set to 106 feet was followed by an 18-inch steel casing set to 1,190 feet and cemented to the surface. A 10-3/4-inch steel casing was set to 1,386 feet, and cemented back to 1,110 feet with Epseal grout. The remaining portion of the casing was then cemented back to the surface with Portland cement. The annulus between the 6-5/8-inch stainless steel injection string, set to 1,391, and the 10-3/4-inch casing was sealed with a packer set at 1,356. The open hole extended to 1,664 feet (Florida Department of Environmental Regulation (FDER), 1985b).

Monitoring. Monsanto Corporation initially constructed two monitor wells. A shallow monitor well located 100 feet from Injection Well A was completed into the upper Floridan aquifer, which is the first permeable zone above the confining zone. Wellhead pressure is continuously monitored and water quality is sampled quarterly. A deep monitor well, located 1,300 feet south of Injection Well A, was designed to monitor pressure and water quality changes in the injection zone. The dilute waste front first reached the deep monitor well in mid-1964 and, by January 1969, undiluted waste with a pH of about 2.3-3.0 had reached that monitoring point (Merritt, 1984, Faulkner and Pascale, 1975). In February 1969, the well was plugged with neat cement from bottom to land surface to prevent any possible pathway for upward waste migration.

In 1970, two injection zone monitor wells were constructed. One was located 1.9 miles north of the injection well site, and the other was located 1.5 miles south of the injection site. Water levels are measured continuously and water quality is sampled periodically. Water quality changes in samples from the south deep monitor well indicate that the highly diluted waste front arrived at that point in mid-1973 (Faulkner and Pascale, 1975). Waste has not been detected at the north deep monitor well.

A regional monitoring system was also established for this site. Regional monitoring wells are located 22 miles east, 17 miles northeast, and 33 miles northeast of the injection well site. Background water quality measurements, continuous water-level measurements, and periodic water quality data are collected (Faulkner and Pascale, 1975).

In 1982, a second shallow monitor well was completed in the upper Floridan aquifer near Well C.

An analysis of the monitoring data in 1974 indicated that pressures in the injection zone had increased significantly, and were calculated to extend more than 40 miles from the site (Faulkner and Pascale, 1975). Neither pressure changes nor water quality changes in the upper Floridan aquifer have been detected (Faulkner and Pascale, 1975). This pressure differential attests to the integrity of the Bucatunna Clay.

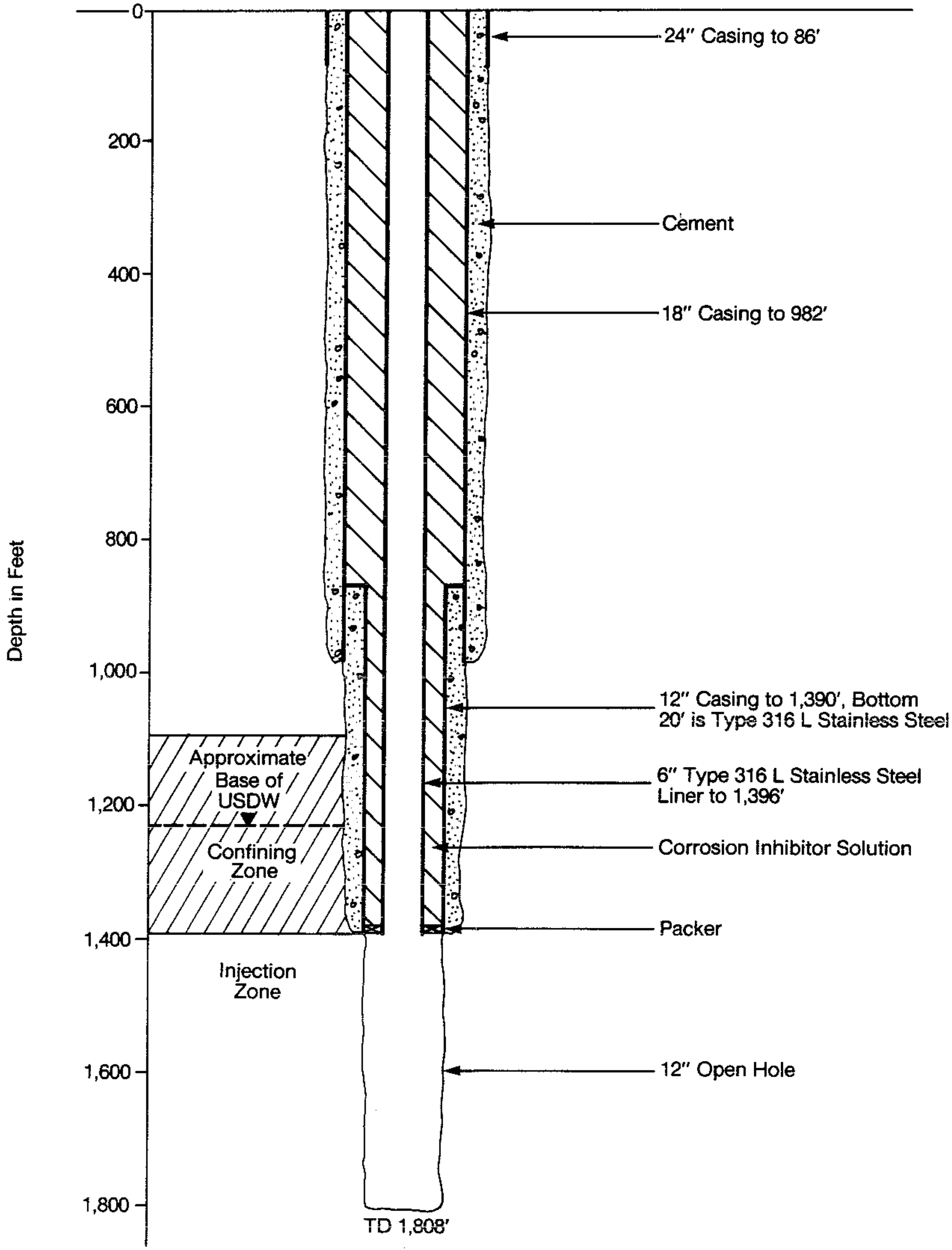
Chronology of Operational Problems. A power surge soon after initial operation of Well A broke the packing that sealed the liner, causing diesel oil to spew from the annulus (Dean, 1964). It was later discovered that the power failure resulted in the collapse of the upper 700 feet of liner. A new, thicker wall, 6-inch diameter stainless steel liner was installed to a depth of 1,396 feet, along with a recirculation system using a chromate corrosion-inhibitor solution in the annulus (Dean, 1964). This initial problem with Injection Well A was repaired, and there have been no reported incidents since the well was repaired.

Injection well C operated without incident for two years beginning in December 1982. On December 8, 1984, a Monsanto employee noticed methane gas bubbles coming up through rain water puddles around the wellhead. The state agency was notified on December 10, 1984, and the well was immediately shut down. The remaining wells were allowed to operate (FDER, 1985e). It was determined that the gas bubbles contained methane, and were coming from the cemented annular space between the 18-inch and 10-3/4-inch casings. The methane may have been naturally occurring, a byproduct of the waste fluid, or a combination of the two.

The agency took the position that the presence of the gas bubbles indicated the lack of a cement bond between the casings. Since the state agency suspected the well no longer had mechanical integrity, it could not be placed back in service until mechanical integrity was demonstrated. The state agency suspected that a microannulus may have existed and provided the pathway for the upward gas migration. A radioactive (R/A) tracer survey was planned to determine the presence of a microannulus. The 18-inch x 10-3/4-inch annulus was sealed at the top and a radioactive tracer fluid was pumped down the annulus in an attempt to determine the migration path. However, test results were inconclusive, and consequently, the methane gas source and the extent of the microannulus were never definitely established.

In May 1985, an Injectrol P grout was pumped down the annulus to seal the methane leak. The grout was emplaced from 0-180 feet below land surface (Mike Kennedy, 1985, personal communication) at which time the state agency and Monsanto agreed to terminate the grouting operation.

As of December 1985, Monsanto has completed testing all three wells for mechanical integrity using both temperature logs and R/A tracer logs. The state agency and its Technical Advisory Committee are currently reviewing the logs. A favorable review of the integrity testing will allow Monsanto to return Well C to service. However, the State may still require additional monitoring in the lower sand-and-gravel and the upper Floridan aquifer.



MONSANTO CORPORATION
Escambia County, Florida

INJECTION WELL A

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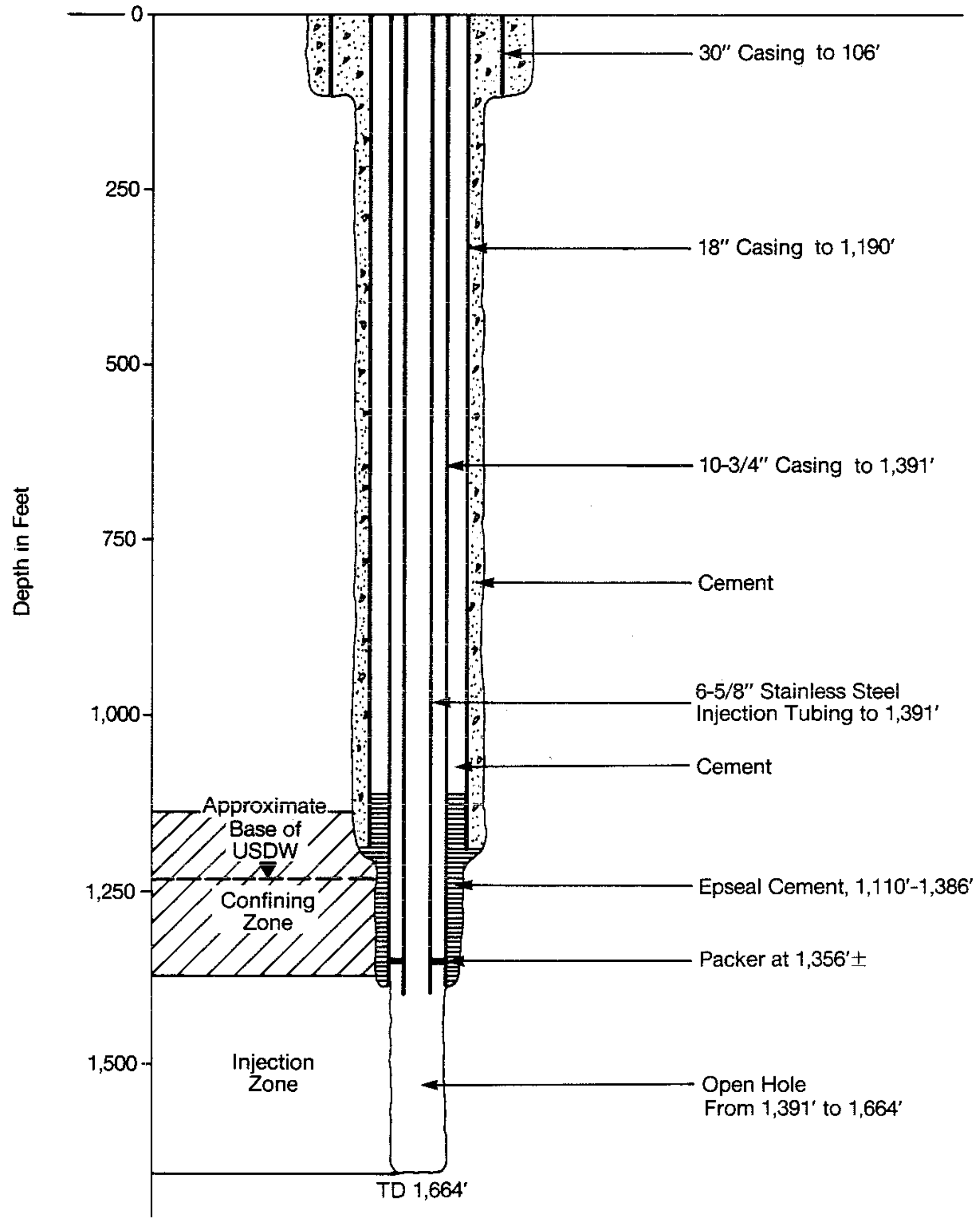


MONSANTO CORPORATION
Escambia County, Florida

INJECTION WELL C

UIPC

QO CHEMICALS, INC.
BELLE GLADE, FLORIDA

Background. The QO Chemicals, Inc., plant is located near Belle Glade, Florida in the interior of South Florida, about 40 miles west of West Palm Beach. The facility manufactures furfural from sugar cane bagasse. The underground disposal system was installed concurrently with the construction of the plant in 1965-66. Injection of wastewater from the furfural plant began in late 1966 (Black, Crow & Eidsness, 1969). Wastewater from the adjacent sugar mill was injected from late 1968 until early 1975, when the sugar mill discharge was diverted to surface treatment.

The furfural plant wastewater comprises a 0.25 to 1.5 percent acetic acid solution, with 0.2 to 0.5 percent sugar, and traces of furfural and formic acid (CH2M HILL, September 1985). The sugar mill waste stream contained sugar and spent acid and caustic cleaning agents (Black, Crow & Eidsness, 1969).

The injection system now includes the main injection well, identified as IW-3, a combination multi-zone monitor/standby injection well identified as DWW-1/IW-4, and a shallow monitoring well (base of USDW) identified as SMW-2. Surface pretreatment includes provisions for cooling the waste to a maximum of 120°F (QO Chemicals, Inc., 1983). Other surface equipment includes three injection pumps and continuous recording instruments for injection flow and pressure, and effluent temperature. Chemical analysis is performed monthly on the waste stream, the three zones of DMW-1/IW-4, and SMW-2. Monitoring reports are submitted monthly to FDER. Mechanical integrity tests are run after every 12 months of well operation (Florida Department of Environmental Regulation (FDER), April 1984).

The plant operates seasonally, averaging 6 months per year. Typical injection flows range from 0.5 to 1.75 mgd. Permitted well capacity is 2 mgd. Surface injection pressures range from 25 to 45 pounds per square inch gauge (psig).

The original system consisted of a primary injection well (IW-1), a standby well (IW-2), and a shallow monitoring well (SMW-1). The original wells were plugged and abandoned in October 1977, and permanently plugged in August 1981 (CH2M HILL, August 1981).

The original wells (IW-1 and IW-2) were constructed to comply with rules in effect in 1965, before the definition of a USDW. An aquifer was not considered usable for drinking water if the chloride content of the water was over 1,500 mg/L or about 3,500 mg/L total dissolved solids (TDS). The wells were therefore completed in a stratum that by current standards is a USDW (10,000 mg/L TDS or less) (Black, Crow & Eidsness, 1965). The shallow monitoring well (SMW-1) was completed in the upper part of the same stratum, about 75 feet from IW-1. Evidence of the presence of waste was detected in SMW-1 about 3 years after injection began. The wells were deepened in 1972, but continuing mechanical integrity problems and the need for additional injection capacity ultimately caused the wells to be abandoned (Black, Crow & Eidsness, September 1974). Replacement Wells IW-3 and DMW/IW4 were constructed to meet current regulations, and have been operating successfully since October 1977 (CH2M HILL, August 1985).

Site Description. The QO Chemicals Belle Glade plant is located in the northern Everglades (White, 1970) of south Florida. The area is flat and marshy, with organic soils to a depth of 4 to 15 feet. Land use is primarily for sugar cane growing and processing, and pasturage for cattle.

Potable groundwater is limited generally to the upper 50 feet of Quaternary-age sandy limestone and shell deposits that underly the organic soil. Even in the shallow deposits the water is of marginal quality and sporadic occurrence (Parker, 1955).

The regional aquifer is the Floridan aquifer system, consisting of several thousand feet of early Tertiary-age carbonates that underlie the area at an approximate depth of 1,000 feet. This aquifer system includes several water-producing zones (aquifers) that are separated by relatively impermeable dolostone and limestone (Black, Crow & Eidsness, 1965). Groundwater flow in the aquifer system is predominantly east and southeast (Healy, 1974).

Aquifer zones in the upper part of the system, to a depth of about 1,700 feet, contain water with a TDS content generally between 1,500 and 4,500 mg/L. Around a depth of 1,800 feet, the aquifer system is filled with saltwater (TDS 10,000 to 45,000 mg/L). Strata typical of the "Boulder Zone" of south Florida, characterized by extremely high transmissivity, begin at approximately 2,200 feet in depth (Black, Crow & Eidsness, March 1972).

The new injection well (IW-3) and the standby well (IW-4/DMW-1) are completed in Boulder Zone strata between depths of 2,800 and 3,200 feet. The new shallow monitoring well (SMW-2) is located about 2,750 feet east (downgradient) from the main injection well. This well monitors the uppermost USDW not affected by waste invasion from the pre-1977 operation.

Well Construction Details. A summary of the construction of Wells IW-1, IW-2, and SMW-1 as originally completed, is presented in the accompanying table. Eight-inch (ID) Type

316L stainless steel tubing (Schedule 10) with a Brown Oil Tool Type D packer (also stainless steel) was set in each well. The packers were set in compression in the bottom stainless steel section of the 12-inch casing. A 30-foot stainless steel tailpipe extended below the packer in each well. Fresh water was circulated in the annulus, and annulus pressure was maintained 5 to 10 pounds per square inch (psi) above injection pressure. An expansion joint was provided at each wellhead to accommodate expansion and contraction of the liner from temperature variations in the injection waste stream. The range of expansion and contraction was about 4 feet.

In 1971, IW-1 was recompleted below the upper USDW by deepening to 2,242 feet and installing an 8-inch stainless steel liner from 1,520 to 1,938 feet (Black, Crow & Eidsness, March 1972). A high-density acid resistant cement was used to cement the liner. Connection of the liner and injection tubing was via a Brown Oil Tool polished-bore receptacle and tie back extension, also constructed of stainless steel.

In 1974, the annulus in IW-2 was found to be leaking. Subsequent investigations showed that the inner casing had separated at the packer seat. The packer could not be reset. Therefore, the injection tubing was permanently cemented in place as an interim repair measure, pending construction of a replacement well.

The annulus pressure system in IW-1 malfunctioned in July 1975, and it subsequently determined that its liner was partly collapsed. In November 1975, the liner in IW-2 was also found to be partly collapsed. Injection into both wells continued, through the partly collapsed liners, until March 1977 when the new injection well (IW-3) came on line. Wells IW-1 and IW-2 were permanently plugged with cement in August 1981 (CH2M HILL, August 1981).

Chronology of Operational Problems. The first indication of a possible injection system malfunction was an increase in COD and BOD at Monitoring Well SMW-1 in early 1971, about three years after the system was placed in operation. The liner and packer were removed and inspected, and the packer was rebuilt at this time. It was determined at this time that a significant amount of the waste was entering a permeable zone between 1,500 and 1,600 feet in depth.

The increase in COD and BOD, and decrease in pH in SMW-1 continued during the 1971 operating season, and it was decided to deepen and recase IW-1 below the USDW. During deepening and recasing of the well in August 1971, an undetermined amount of waste backflowed from the well, and was discharged to the local irrigation and drainage canal system. Because of delays in the completion of modifications to IW-1, waste disposal was into IW-2 during the 1972 and 1973 operation seasons (Black, Crow & Eidsness, September 1974). Geophysical log data from IW-2 indicate that most of the waste injected into this well entered a non-USDW zone below 1,800 feet. However, the zone from 1,500-1,600 feet probably received some waste.

Shortly after Well IW-1 was returned to service for the 1974 season, the annulus pressure system failed to hold pressure, and flow was again directed to IW-2.

The liner and packer were removed from IW-1, and the liner was determined to be damaged by stress corrosion cracking (Southwest Research, 1974). The liner and packer were replaced and IW-1 was returned to service.

In July 1975, the liner collapsed in IW-1 and flow was once again diverted to IW-2.

During the 1974 injection into IW-2, the annulus system was found to be leaking. The packer could not be reset, and the liner was then cemented permanently in the well.

Attempts to pull the damaged liner from IW-1 were unsuccessful, and planning for a replacement well was begun.

In November 1975, the liner in IW-2 was found to be partly collapsed. Since this liner was cemented in place, it could not be removed for repair.

Both wells remained usable, but the collapsed liners resulted in higher than usual injection pressure. Also the mechanical integrity of the wells could not be confirmed, and it was suspected that wastewater might be entering an unpermitted injection zone in the upper part of the Floridan aquifer.

Use of Wells IW-1 and IW-2 continued through the 1976 operating season. The present wells (IW-3, DMW-1/IW-4) were placed in service at the beginning of the 1977 season. No malfunctions or non-compliances have been experienced in relation to the new wells. Wells IW-1 and IW-2 were permanently plugged in 1981.

These wells were ultimately replaced for the following reasons:

1. The tubing set in compression was subjected to a high buckling stress. This stress was exacerbated by the growth of the tubing at high injection temperature. The final collapse of the tubing IW-1 may have occurred because the expansion joint at the well head was inoperative.

2. The wide range of temperatures, and resulting expansion-contraction cycles "worked" the packer and expansion joints excessively.

3. The high injection temperature, combined with the stressed condition of the liner, and occasional presence of high chlorides in the waste stream, promoted stress corrosion cracking of the tubing.

4. The surge protection system for Wells IW-1 and IW-2 was not adequate at the injection rates finally attained.

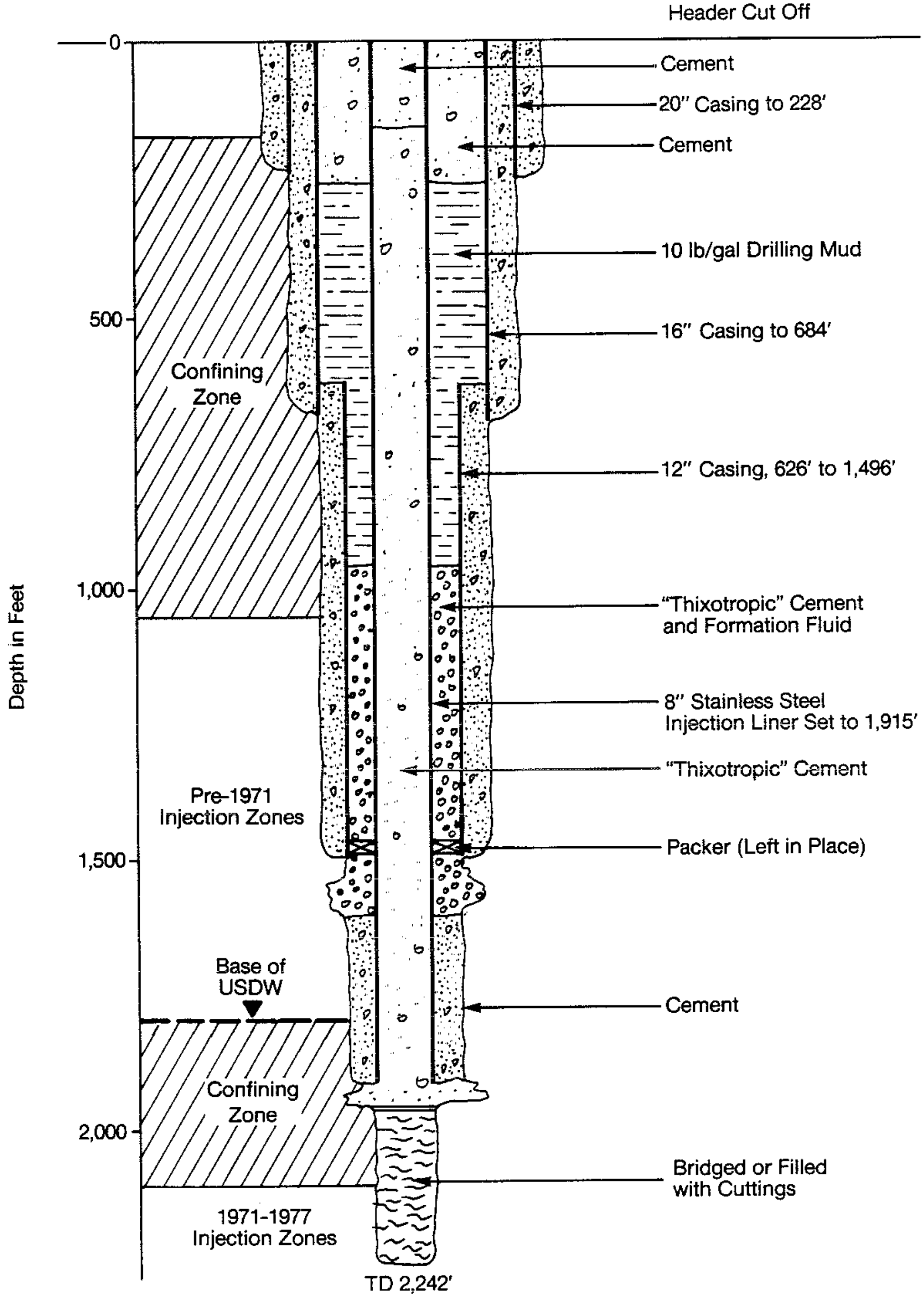
5. Although not fully confirmed, it is believed that waste which periodically invaded the annulus may have attacked the carbon steel to stainless steel joint at the bottom of the long casing string, allowing the stainless steel packer-seating section to separate from the well casing.

Operation of these wells caused the local contamination of the USDW. Contamination of the USDW cannot be deemed to be due entirely to a well failure since the permitted injection zone was not a USDW under the rules in effect at the time.

SUMMARY OF WELL CONSTRUCTION
QO CHEMICALS, INC.
BELLE GLADE, FLORIDA

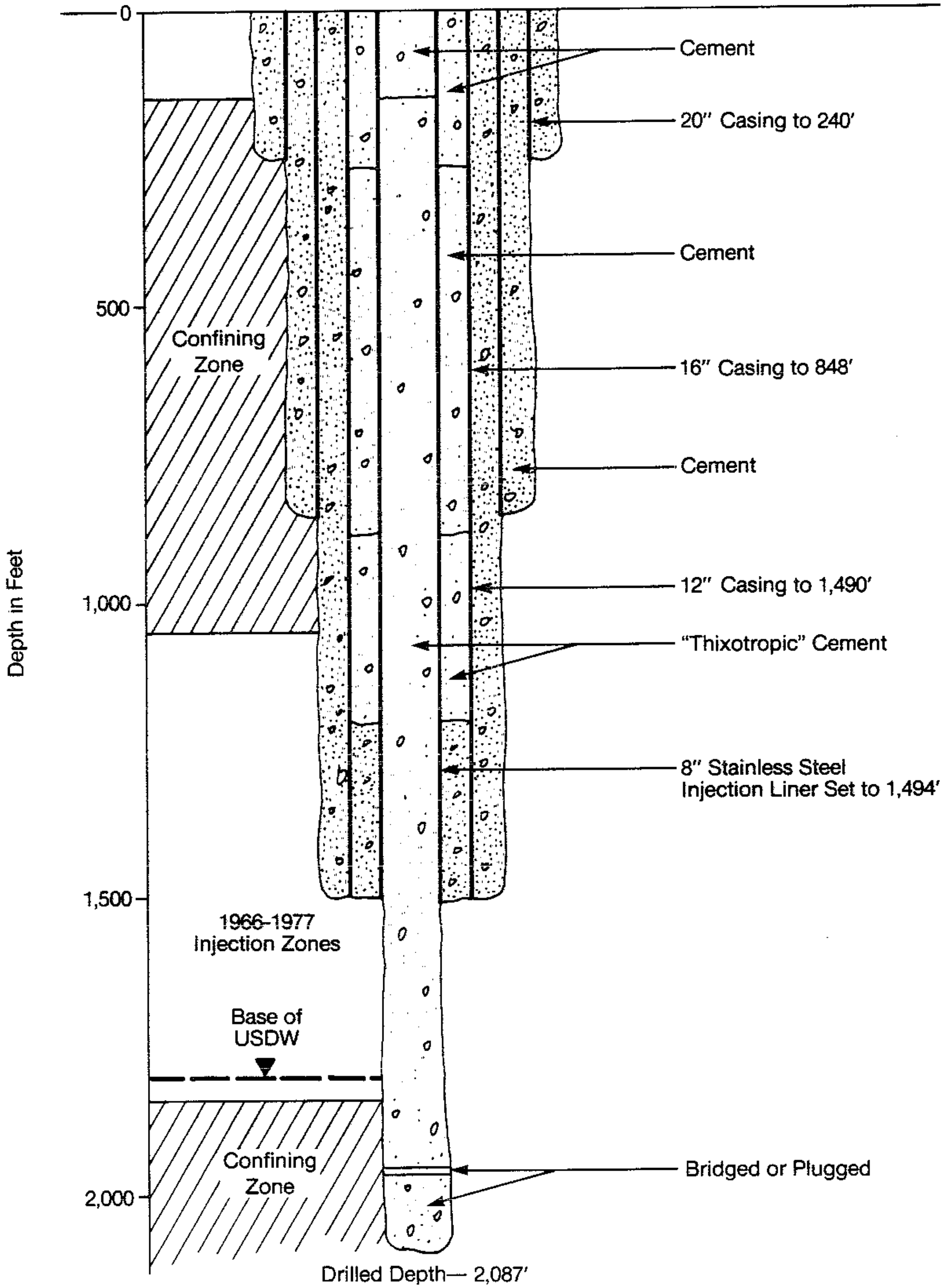
Description	Diameter (Inches)	Depth in Feet From	Depth in Feet To	Material
Well IW-1				
Outside casing	20	0	228	Black steel*
Middle casing	16	0	684	Black steel*
Inner casing	12	626	1,480	Black steel*
Inner casing	12	1,480	1,496	SS 316 ELC**
Open hole	12	1,496	1,840	Limestone
Open hole	9	1,840	1,940	Dolomites and limestone
Injection tubing	8	0	1,610	SS 316 ELC, Sch. 10
Well IW-2				
Outside casing	20	0	240	Black steel*
Middle casing	16	0	848	Black steel*
Inner casing	12	0	1,474	Black steel*
Inner casing	12	1,474	1,490	SS 316 ELC*
Open hole	12	1,490	1,840	Limestone
Open hole	9	1,840	2,067	Limestone and dolomites
Injection tubing	8	0	1,496	SS 316 ELC, Sch. 10
Well SMW-1				
Outside casing	12	0	180	Black steel*
Inside casing	6	0	648	Black steel*
Open hole	6	648	1,400	Limestone

*Cemented outside with 2 inches of neat cement, ASTM Type II
**Cemented with Pre-Krete G-8 acid-proof mortar



QUAKER OATS CHEMICALS, INC.
Belle Glade, Florida

WELL IW-1 (After Abandonment)



QUAKER OATS CHEMICALS, INC.
Belle Glade, Florida

WELL IW-2 (After Abandonment)

SOUTH CROSS BAYOU POLLUTION CONTROL FACILITY PINELLAS COUNTY, FLORIDA

Background. Pinellas County operates the South Cross Bayou pollution control facility. Pinellas County is the peninsular county west of Tampa Bay in west-central Florida. The South Cross Bayou facility is located adjacent to Joe's Creek and west of U.S. 19 in the southern central portion of the county.

The pollution control facility is a 27-million-gallon-per-day (mgd) secondary effluent sewage treatment plant with nitrification capabilities (Seaburn and Robertson, Inc., 1979). Strict state surface water discharge limitations encouraged the county to explore the deep well disposal option.

The South Cross Bayou injection well system currently consists of four injection wells, only one of which has been used. The other three have been used as additional interim monitoring wells. Onsite monitoring wells consist of two well series, designated "A" and "B", and an offsite monitor well complex has also been installed. Injection well depths range from 1,080 to 1,084 feet below land surface.

Pretreatment consists of a conventional activated sludge process with contact stabilization. Raw sewage passes through aerated grit chambers, primary clarifiers, contact stabilization, secondary clarifiers, and chlorine contact chambers prior to injection. Average daily flow from the plant in 1979 was 17 to 18 mgd (Seaburn and Robertson, Inc., 1979). Average yearly suspended solids for 1978 was 17 mg/L (Seaburn and Robertson, Inc., 1979). Each injection well has a design capacity of 10 mgd injected at an approximate pressure of 16 pounds per square inch (psi), but can accommodate 16 mgd at a maximum injection pressure of 32 psi (SWFWMD, 1976).

Well construction permits issued by SWFWMD required a comprehensive monitoring program "to determine the rate and direction of movement of the injected fluid, the response of the hydrologic system to injection stress, the effects of injection upon the advance of saltwater into freshwater zones, and the changes in water quality of the injected fluid with migration through the aquifer" (SWFWMD, 1976). Five separate monitor well locations were established, with a 2-month period of background water samples scheduled prior to sampling during a 28-month test injection period. An elaborate monitoring program was established for typical effluent parameters and viruses, with sampling frequencies ranging from continuous through daily, weekly, and monthly.

Injection testing occurred only in Injection Well A-1. In January 1985, the 28-month test was stopped after 145 days because of pressure buildup in Well A-1 and apparent leakage through overlying confining units (Seaburn and Robertson, Inc., 1985). Since then, the well has been inactive, and further testing is being conducted.

Site Description. As of 1977, Pinellas County was the most densely populated area per square mile in Florida. Principal well fields for the county are located inland in the northeast corner of Pinellas County and in Pasco and Hillsborough Counties. The well fields are completed in the Floridan aquifer and are located up to 40 miles to the northeast of the site (Rosenshein and Hickey, 1977).

A surficial sand aquifer that is less than 85 feet thick exists at the site (Hickey, 1981). The Hawthorn formation, consisting primarily of clay and marl, provides upper confinement for the Floridan aquifer. The Floridan aquifer consists of limestone and dolomites ranging in age from middle Eocene to lower Miocene. The injection zone occurs in the lower part of the aquifer within the Avon Park Limestone, and consists of dolomite and dolomitic limestone (Hickey, 1981 and 1982). The injection interval at the site is from 761 to 1,080 feet (Seaburn and Robertson, Inc., 1978). Total dissolved solids in the injection zone were approximately 38,100 mg/L. Confinement is provided by the overlying limestones of the Suwannee and Ocala limestones and by the Hawthorn Formation.

Well Construction Details. Fifteen wells were constructed at the South Cross Bayou site from 1973 to 1979 (Seaburn and Robertson, Inc., 1979). The original exploratory well (E-1) was drilled in January 1973 to a total depth of 3,280 feet. A 16-inch casing to 374 feet and an 8-inch casing to 1,863 feet were installed. The well was plugged back with gravel and a cap of cement to 1,600 feet (Hickey, 1979), and completed as the B-series monitor wells. This "cluster monitor well" consists of 2-inch diameter monitor tubes (within the original 8-inch casing perforated across the monitoring intervals) that are designated as Wells B-1, B-2, B-3, and B-4. Monitored zones are from 1,210 to 1,224 feet, 1,025 to 1,055 feet, 780 to 815 feet, and 463 to 520 feet, respectively (Seaburn and Robertson, Inc., 1979). Wells B-5 and B-6 are shallow aquifer monitor wells that are less than 150 feet from the B-series cluster well.

Injection Well A-1 was drilled as the last well approximately 900 feet northwest of the B-series well. A 36-inch casing was set to 380 feet and cemented back to surface, while the 24-inch casing set to 961 feet was only cemented back to 500 feet. The original cement job was not continuous, and a remedial squeeze-grouting operation was performed in the 689- to 697-foot interval. The well was completed as open-hole between 961 and 1,080 feet (Hickey, 1979). Originally, the open annulus between 380 and 500 feet was designed for water level and quality monitoring, but this method was later changed to define the sampling point depth more closely (Seaburn and Robertson, Inc., 1979). Three monitor wells--A-2, A-3, and A-4--were constructed within 100 feet from Injection Well A-1 to monitor the transmissive zones between 746 to 800 feet, 473 to 521 feet, and 200 to 250 feet, respectively. All three have 6-inch final casings cemented back to the surface (Hickey, 1979). Remedial squeeze cementing was required on Well A-2 in the intervals 695 to 697 feet and 670 to 672 feet.

In 1978, an additional monitor well, Well A-5, was constructed to determine the top of the injection zone. The well was then plugged back to 665 feet and completed as a monitor well in the zone 661 to 665 feet to monitor the low permeability confining unit above the injection zone. Numerous tests were conducted during the construction of Well A-5 to determine the top of the injection zone, which was located at 761 feet below land surface (Seaburn and Robertson, Inc., 1978).

Injection Wells C, D, and E are nearly identical in construction, and were completed in the fall of 1978. A 42-inch diameter conductor was set to approximately 50 feet in each hole and cemented to surface. Thirty-six-inch casings were set and cemented to 471 feet, and 24-inch casings were set from 703 to 705 feet, and cemented to surface. The final string of 18-inch casing was set from 714 to 756 feet. Total depths ranged from 1,080 to 1,084 feet.

Chronology of Operational Problems. After the construction of Well A-1 and the A- and B-series monitoring wells, a 30-hour dye test was performed on Well A-1. The dye was detected only in Monitor Well A-2 which monitors the upper part of the injection zone, at 750 to 800 feet in depth.

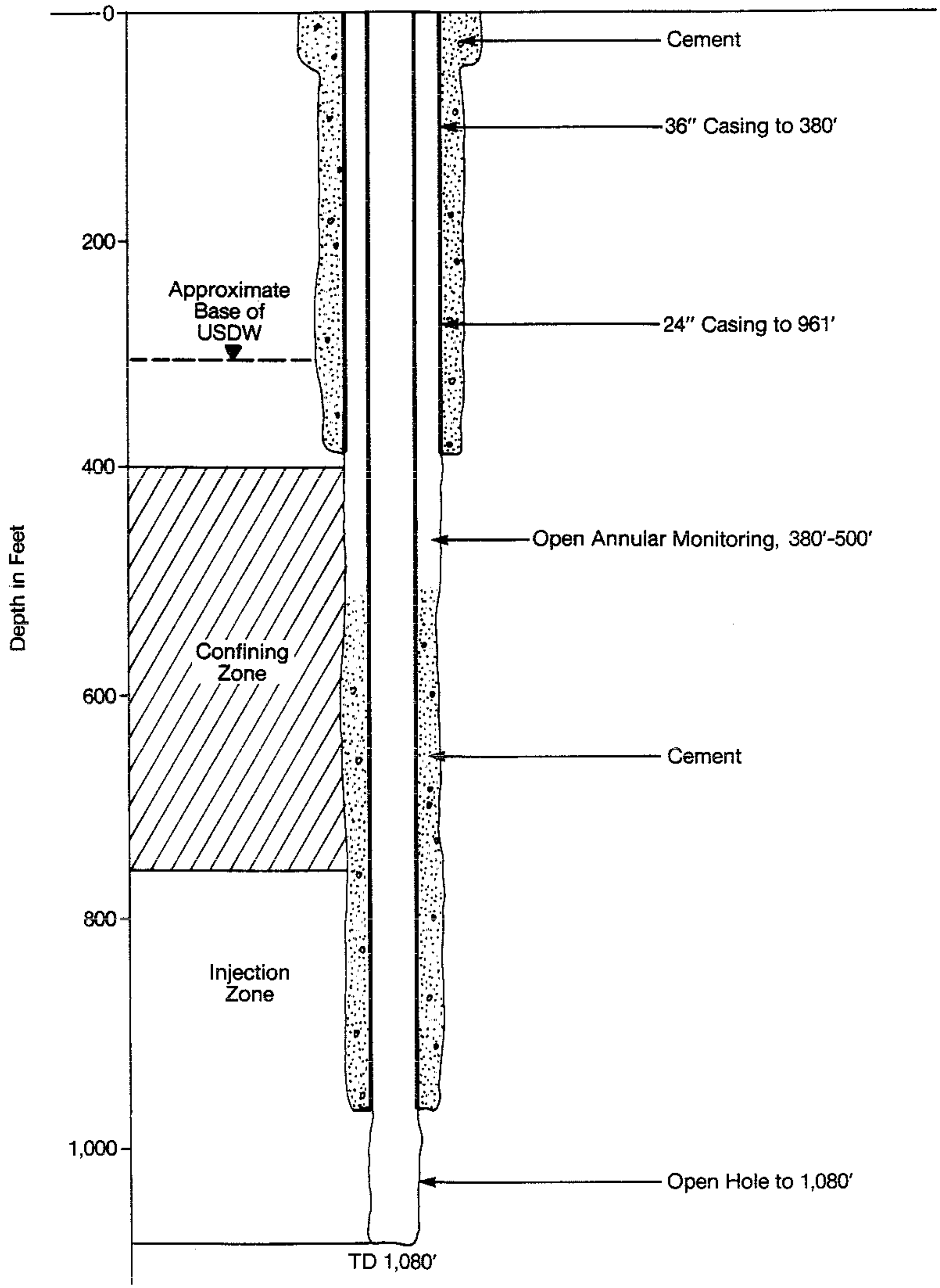
Regulatory response to these results was to require construction of an additional monitor well (A-5) to determine the top of the injection zone more accurately, squeeze grout the annular spaces in Wells A-1 and A-2, and perform a 7-day injection test. Well A-5 was satisfactorily installed, the squeeze grouting of Wells A-1 and A-2 was successful, and the 7-day injection test detected dye in the A-2 zone, but not in the zone monitored by Well A-5. Construction of Injection Wells C, D, and E was allowed to occur concurrently with the remedial work on Wells A-1 and A-2.

In May 1978, SWFWMD issued an order that delayed startup of the 28-month injection test until the nature of flow in the injection zone was more clearly established. Construction of an offsite monitoring complex, acquisition of two months of background data, and minimum injection pressures and rates of 55 psi and 4 mgd, respectively, were required prior to startup. The final casings on Wells C, D, and E were installed in 1981-1982, background sampling began in January 1983, and the 28-month injection test finally began on May 30, 1984. After 145 days, in January 1985, the test was stopped after increasing injection pressures and possible upward leakage of injected fluid through the confining zone were noted (Seaburn and Robertson, Inc., 1985). In February, the FDER denied the county's operating permit application in part because the mechanical integrity of Injection Wells C, D, and E has not been satisfactorily demonstrated, and because the annulus of Well A-1 had not been properly plugged.

The county developed a program to determine the cause of upward leakage through the confining units and the cause of pressure buildup. The casing integrity of Wells A-1 and A-2 will be established through pressure testing, radioactive tracer surveys, and noise logs. Sidewall cores were taken in A-1 in May 1985 to determine the cause of the clogging.

Only a single core sample was recovered from approximately 1,031 feet below land surface. The sample was a carbonate cemented sand, somewhat iron encrusted, and with no evidence of bacterial or other organic growth (Seaburn and Robertson, Inc., 1985a). Cloth-like materials were recovered from the coring tool and a black sludge-like material containing algae was also recovered from the well. A possible explanation for the algae might be that the initial injection test used creek water. Causes of the clogging could have been injection of solids and growth of bacterial mats, although these mechanisms were not clearly proven (Seaburn and Robertson, Inc., 1985a).

Currently, no wells are operational at this site. The test-injection program may be resumed after verifying the casing integrity and cleaning out the well boreholes.



SOUTH CROSS BAYOU
Pinellas County, Florida

INJECTION WELL A-1

CITY OF ST. PETERSBURG
NORTHEAST WASTEWATER TREATMENT PLANT
ST. PETERSBURG, FLORIDA

Background. The City of St. Petersburg operates four regional wastewater treatment plants: the Northeast, the Northwest, the Southwest, and the Albert Whitted Plant (Southeast). The Northeast plant is located on the east central coast of the Pinellas County peninsula, less than one mile from Tampa Bay. In 1972, the City Council committed to upgrading all plants from secondary treatment by providing additional filtration and chlorination. The City Council resolution involved eliminating sewage effluent to surface waters and treating the effluent to a level suitable for irrigating parks, golf courses, and private lawns. The injection wells were necessary as backup capacity for the wastewater reuse system to be successful. The Northeast plant came on-line in 1980, and has a total injection well capacity of approximately 30 million gallons per day (mgd). Depending on spray irrigation demand, the effluent is pumped to either the irrigation system or the injection wells.

The disposal well system consists of three injection wells (IW-1, IW-2, IW-3), a cluster monitor well that monitors four different zones, and four single-zone observation wells designated as the "M-series". These wells monitor permeable intervals above the injection zone from 105 to 612 feet in depth (CH2M HILL, 1983). The cluster well is 508 feet west of IW-3; the "M-series"--M-2, M-3, M-4 and M-5--are 76, 111, 146, and 181 feet north of IW-3, respectively.

The Northeast plant is permitted for an average day design flow of 16.0 mgd activated sludge process with modified AWT sewage treatment. Alum is added prior to dual media filtration. Alum improves the suspended solids removal, which, along with maintaining an effective chlorine residual, helps to increase the virus inactivation rates (CH2M HILL, 1983). The maximum injection rates of IW-1, IW-2, and IW-3 are each 10.2 mgd, with corresponding wellhead pressures of approximately 65, 45, and 65 pounds per square inch (psi).

The Southwest Florida Water Management District (SWFWMD) Order No. 79-46 outlined an elaborate water quality monitoring plan as part of the 3-year injection test. The water quality sampling program was designed to determine the rate of horizontal movement of the injected fluid, to monitor for vertical movement of injected fluid, and to determine water quality changes of injected fluid (CH2M HILL, 1983).

The cluster monitor well has been leaking from an injection zone (C-7) into the 370- to 400-foot zone monitor zone (C-4), causing injected fluid to migrate into a non-USDW (FDER, 1985). No migration into any USDW's has been detected by shallower monitor wells (Florida Department of Environmental Regulation (FDER), 1985e). The leaking zones of the cluster monitor well have been completely plugged as of December 1985.

Other incidents at the site include pressure buildup in IW-3 and the M-3 monitor well flowing at the surface from November 1983 to December 1984. Current status of the injection well system is that IW-1 and IW-3 have been acidized, and the M-3 monitor well has been capped. Continued water quality monitoring will take place to determine the effectiveness of the cluster well plugging in preventing effluent migration to the non-USDW aquifer at 400 feet in depth.

Site Description. The St. Petersburg Northeast site is situated on the eastern coast of the densely populated Pinellas County peninsula. Fresh groundwater supplies are limited on the peninsula, and municipal well fields tapping the Floridan aquifer are located in the extreme north section of Pinellas County, and in Pasco and Hillsborough counties.

A shallow surficial sand aquifer containing potable water exists at the site at depths less than 100 feet. The Hawthorn Formation, which provides upper confinement to the Floridan aquifer, is present at the site at depths less than 100 feet. The Tampa, Suwannee, and Ocala limestones that form the upper limestones of the Floridan aquifer are interbedded with semi-confining beds composed of limestone, dolomitic limestone, and dolomite. The injection zone is in the Avon Park Limestone, in the interval 725 to 1,000 feet, and is composed primarily of dolomite, and of dolomitic limestone and limestone (CH2M HILL, 1983). Background total dissolved solids (TDS) and chlorides in the injection zone are 38,900 mg/L and 20,000 mg/L, respectively.

Extensive water quality sampling was performed during construction and prior to operation to establish background water quality. At 105 to 150 feet, the TDS was 4,110 mg/L and, at 200 feet, it exceeds 10,000 mg/L. Background chlorides and TDS concentrations are much higher than values for those parameters in the injected fluid (500 mg/L and 1,200 mg/L, respectively). Consequently, injected fluid movement can be detected easily by freshening of a monitored zone (CH2M HILL, 1983).

Well Construction Details. All three injection wells were constructed similarly, from July 1977 to February 1978. Typical construction includes a 30-inch casing set at 263 feet and cemented to the surface, a 20-inch casing set to 726 feet and cemented to the surface, and open hole from 726 to 1,000 feet.

The cluster well was completed to isolate and monitor the four major water producing zones identified at the cluster well site from 206 to 1,171 feet in depth. The zones monitored include the injection zone (C-7), which is a dolomite and limestone interval of the Avon Park Formation from approximately 730 to 1,000 feet; one interval below the injection zone (C-10), which is also a dolomite section of the Avon Park Formation from approximately 1,050 to 1,170 feet; and two intervals above the injection zone which monitor portions of the Suwannee and Tampa limestones at 400 (C-4) and 260 feet (C-7), respectively. The different zones are isolated by the use of casings of different diameters set and cemented in the well at various intervals. The annulus between casings mark the monitoring intervals, except at the 400-foot zone. This zone is monitored with a 2-inch PVC tubing with a stainless steel screen gravel packed and cemented above the gravel to the next shallowest monitor zone at 267 feet in depth.

In addition to the cluster well, four single-zone observation wells were constructed at the Northeast site to monitor various depths. These wells are designated as M-2, M-3, M-4, and M-5, and monitor water producing intervals above the injection zone from 612 to 105 feet in depth, respectively. The M-series observation wells were constructed to detect upward movement of the injected fluid through the confining layers at a stressed location close to an operating injection well (CH2M HILL, 1980).

Chronology of Operational Problems. A 90-day injection test was begun on June 9, 1980, using IW-3 as the injection well and IW-2, IW-1, and C-7 as injection zone monitoring wells. Chlorides measured at C-7 dropped from 20,000 to 12,000 mg/L after 10 days of injection, while only slight freshening trends were noted at IW-1 and IW-2.

The cluster well also monitors zones above and below the injection zone. Monitor Well C-2 and Monitor Well C-10, below the injection zone, did not show freshening effects, indicating that the fresher, injected effluent moves horizontally near the top of the injection interval from 725 to 1,000 feet. Monitor Well C-4 (370 to 400 feet) experienced a drop in chlorides from approximately 18,100 mg/L to 10,000 mg/L after 100 days of injection (CH2M HILL, 1980).

After 100 days of testing, except for C-4 monitor zone, the injected effluent had been confined below the top of the injection zone at 725 feet. Data analysis suggests that the injected effluent arrived at Monitor Well C-4 through a cross-connection in the cluster well between the C-7 zone and the C-4 zone. This cross-connection seems to be through the cluster well 16-inch casing rather than the cement around the 16-inch casing or the confining layers above the injection zone. The presence of effluent in this zone does not pose a threat to the water resources of the region because the effluent in the 400-foot zone is fresh, highly treated, and confined to the area around the cluster well.

A three-year injection test was conducted at the site from June 1980 to June 1983. Injection pressures were fairly stable during the first two years of the injection test, with some increase in injection pressure observed at IS-1 and IW-2 during the third year of injection testing.
The pressure increase at IW-1 and IW-2 suddenly increased by approximately 8 to 12 psi after a large amount of suspended solids was injected into the wells when a failure in the filter tiles resulted in the filter media and unfiltered effluent being injected. The suspended solids level was fairly high in the treated effluent because of a rare plant upset in the treatment system when injection testing began at the Northeast site. After the initial suspended solids

increase, no major increases in the injection pressure have been observed at IW-3 during most of the 3-year injection test.

Observation Well M-3 monitors the same zone as C-4 and has experienced a gradual decrease in chlorides from approximately 19,000 to 13,000 mg/L. This chloride decrease is much smaller and gradual than that observed at C-4, suggesting that the injected fluid which appeared at C-4 after one month of injection is gradually migrating horizontally to M-3. Observation Well M-2 monitors a minor transmissive zone at 600 feet which is between the injection zone and the 400-foot zone monitored by C-4 and M-3. M-2 has experienced a slight decrease in chloride concentrations from approximately 19,000 to 16,000 mg/L after 3 years of injection testing. This decrease in chlorides could be the effect of the presence of the injected fluid at M-2 through either upward movement from the injection zone to 600 feet in depth at the cluster well or through the lower confining interval. However, the chlorides measured at M-3 are lower than those at MW-2, suggesting that the freshening of M-2 and M-3 is not totally the result of upward movement through the confining interval from 720 to 612 feet. As at C-4, the injected effluent is of much better water quality with respect to most parameters than the natural background water quality at M-2 and M-3.

Water quality sampling during the 3-year injection test was done to determined the character and extent of the horizontal and vertical movement of the injected effluent. Considerable mixing between the injected fluid and the native saltwater is occurring at the injection zone observation well, C-7. Some vertical movement of the injected fluid has been observed and is believed to be occurring at the cluster well from C-7 at 727 feet to C-4 at

400 feet. The vertical movement at the cluster well has resulted in freshening of the water sampled at C-4. Further limited horizontal movement of the injected fluid in the 400-foot zone has been observed from C-4 to Observation Well M-3 at a distance of approximately 520 feet. Background total dissolved solids measured before injection in the 400-foot zone were approximately 40,000 mg/L. However, plugging zone C-7 and the annulus between C-7 and C-4 at the cluster well with cement should eliminate this man-made vertical cross-connection between the injection zone and the 400-foot monitoring zone. Continued monitoring of observation well M-3 after the cementing of the cluster well will provide information on the effectiveness of plugging the leaking cluster well annulus.

FDER issued an operating permit to the City in January 1985, with a specific condition that Monitor Well C-7 be plugged within six months. An abandonment permit for Wells C-7 and C-10 was issued in August 1985. The C-2 zone would remain open for additional monitoring.

The 600-foot monitoring zone (M-2) has shown additional freshening since the 3-year test ended, which may be an effect of the injected fluid. However, until after the cluster well is plugged, the travel path of the injected fluid cannot be determined. Monitoring will continue for one year after the cluster well plugging. The leaking monitor well was not considered an imminent hazard to a USDW because the leak occurred into a confined permeable zone containing fluids with greater than 10,000 mg/L TDS (FDER, 1985e).

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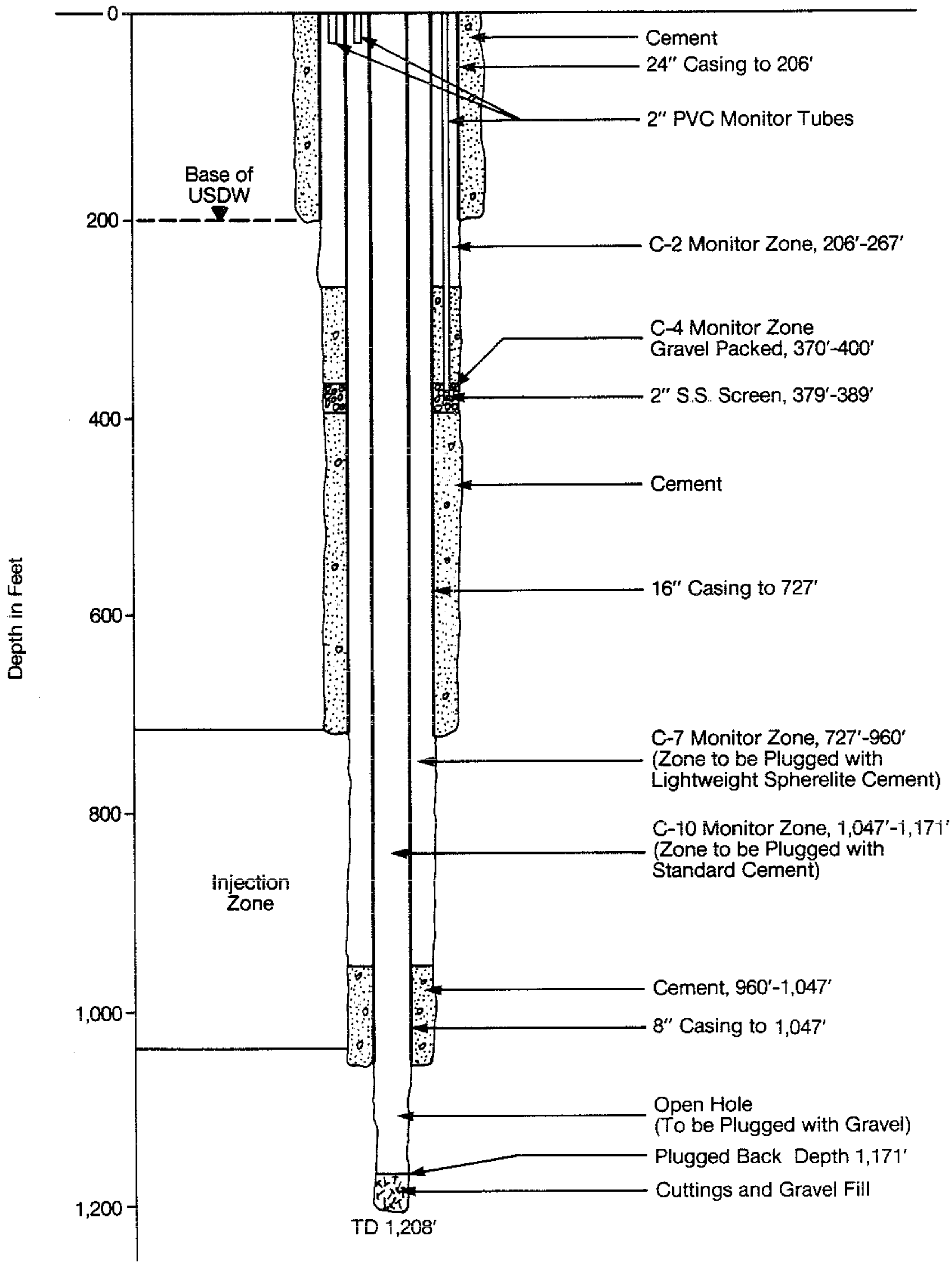

ST. PETERSBURG NORTHEAST
St. Petersburg, Florida

CLUSTER MONITOR WELL (Prior to Plugging)

CITY OF ST. PETERSBURG
SOUTHWEST WASTEWATER TREATMENT PLANT
ST. PETERSBURG, FLORIDA

Background. The City of St. Petersburg operates four regional wastewater treatment plants; the Southwest, the Northwest, the Northeast, and the Albert Whitted Plant (Southeast). The Southwest plant is located on the southern tip of the Pinellas County peninsula, west of U.S. 19, northeast of Eckerd College, and approximately one-half mile from Tampa Bay. In 1972, the City Council committed to upgrading all plants from secondary treatment by providing additional filtration and chlorination. The City Council resolution also involved elimination of sewage effluent to surface waters, and treating the effluent to a level suitable for irrigation of parks, golf courses and private lawns. The injection wells were necessary as a backup capacity for the wastewater reuse system to be successful. The Southwest plant was completely upgraded as of 1977, and began supplying reclaimed water for irrigation that year. The injection well system has a total injection capacity of approximately 39 million gallons per day (mgd). The effluent is pumped to either the irrigation system or the injection wells, depending on rainfall and spray irrigation demand.

The disposal well system consists of three injection wells (IW-1, IW-2, IW-3), four single-zone observation wells (B-6, B-7, B-8, B-9), and one multi-zone cluster well monitoring five separate zones (B-1, B-2, B-3, B-4, B-5). These were constructed during March 1975 through June 1977. Three additional single-zone observation wells (C-1, C-2, C-3) were constructed in 1978. The B-series cluster well was completed to monitor from 257 to 1,286 feet in five major intervals (below the injection zone, in the injection zone, and three zones above the injection zone). The B-6, B-7, B-8, and B-9 wells were installed during initial construction and used during hydraulic testing. All single-zone monitor wells are designed to monitor the horizontal movement of the injected fluid and to detect any vertical movement of injected fluid. The wells are located in a linear pattern, except for C-3, which is located offsite 1,500 feet south of IW-3.

The Southwest Plant provides secondary treatment followed by filtration and chlorination, producing a high-quality effluent with low suspended solids ($\leq$ 5 mg/L) and virus inactivation rates approaching 100 percent. Surface facilities include aeration basins, clarifiers, and a mixed media filter. Alum is added prior to filtration as a filter aid. Depending on irrigation demand, the waste is then pumped to the spray irrigation distribution system or to the well.

The total injection rate for the three wells shall not exceed 39 mgd (design flow of 13 mgd each), and the maximum permitted well head pressure at each well is 60 pounds per square inch (psi) (Florida Department of Environmental Regulation (FDER), 1983). The monitoring program includes quarterly water level/pressure measurements and semi-annual water quality sampling and analyses from Monitor Wells C-2, C-3, B-1, B-8, and B-9. The parameters sampled include fecal coliform, total organic carbon, total nitrogen, and chloride.

Upward migration of waste into the non-USDW 600-foot monitor zone (B-7) occurred through IW-3 five days after injection began in September 1977 (FDER, 1985c). Agreement on the cause of the unexpected migration has not yet been reached. The injected waste has not been detected at any observation wells monitoring USDW's at the site.

As of June 1985, the system was operating satisfactorily, except that Monitor Wells C-1, B-3, B-4, B-5, B-6, and B-7 are no longer being used. The City is negotiating with the Department on the methodology for demonstrating mechanical integrity, and on the status of the unused monitoring wells.

Site Description. The St. Petersburg Southwest site is situated on the southern tip of the densely populated Pinellas County peninsula. Fresh groundwater supplies are limited on the peninsula, and municipal well fields tapping the Floridan aquifer are located in inland Pinellas County, and in Pasco and Hillsborough counties.

A surficial sand aquifer exists at the site to a depth of 85 feet. The Miocene Hawthorn Formation, consisting chiefly of 80 feet of clay and marl, provides upper confinement to the Floridan aquifer.

The Floridan aquifer at the site consists of four permeable zones alternating with three semi-confining beds (Hickey, 1984). The semi-confining beds consist of limestone, dolomitic limestone and dolomite. The injection zone is approximately 323 feet thick at the site and consists of dolomite and dolomitic limestone, with the top of the injection zone occurring at approximately 725 feet. Water quality in the injection zone is similar to sea water, with chloride concentration ranging from 19,000 to 20,000 mg/L (Hickey, 1981 and 1984) and total dissolved solids (TDS) values ranging from 38,000 to 41,800 mg/L (FDER, 1985e).

Well Construction Details. Three injection wells were constructed at the site from August 1975 to June 1977. All injection wells are multi-cased with a 42-, 36-, and 24-inch casing configuration. For IW-3, casing setting depths were 92, 310, and 927 feet, respectively, with all casings cemented back to surface. In all three wells it was difficult to cement the 24-inch casing past the 750- to

830-foot zone, a transmissive dolomite and limestone interval. On IW-3, a gravel pack had to be used to complete the cementing operation.

The cluster well was completed to isolate and monitor the five major water-producing zones from 257 to 1,286 feet in depth. The injection zone, a permeable zone below it, and three intervals above the injection zone are monitored.

The remaining B-series monitor wells, and the C-series monitor wells, were completed as single-zone observation wells at various depths.

Chronology of Operational Problems. A 91-day injection test using IW-3 began on June 21, 1977, in accordance with SWFWMD Order No. 77-1. Average injection rate for the test was 2,830 gallons per minute. Effluent mixed with Rhodamine WT as a tracer was used during the testing.

Results of the 91-day injection test indicate that the dye was detected in Monitor Wells B6, B7, and B3. Wells B6 and B3 are open to the top of the injection zone, at 50 and 730 feet, respectively, from IW-3. The dye arrived in Well B-6 between 0.03 and 1.2 days and in Well B-3 between 6 and 14 days from the start of the test (Hickey, 1982).

Dye was detected in B-7 between 5 and 6 days from the start of the test (Hickey, 1982). Several explanations have been offered for the arrival of effluent in the 600-foot zone B-7 monitor well. The original depth of B-7 was 650 feet, but it was plugged back to a depth of 632 feet. This overdrilling may have created a localized flow path for upward fluid migration. Well B-4, which monitors the same zone 730 feet away, has not detected any dye. Hickey (1984) postulated that the early arrival of effluent in the 600-foot zone was associated with the gravel pack across the interval 750 to 830 feet in the IW-3 annulus. Another possible explanation is related to a construction problem with B-6, which is located 50 feet from IW-3 and is completed open hole in approximately the same interval as the gravel pack in IW-3 (FDER, 1985g).

SWFWMD Order No. 78-1 authorized a 32-month injection well test program. At the conclusion of that test, the injected fluid had been detected in all observation wells monitoring the injection zone, and except for the localized appearance at B-7, has remained confined vertically to the injection zone. No significant horizontal movement of the injected fluid in the 600-foot zone had been observed (CH2M HILL, 1982).

IW-3 was acidized in September 1983 to increase its injection capacity from 4 to 13 mgd.

At a regulatory meeting in February 1985, two issues concerning this site were discussed. The cause of the upward migration at B-7 will be investigated in conjunction with the City's demonstration of mechanical integrity of the injection wells required by the State every 5 years. Although the 600-foot zone contains water with TDS greater than 10,000 mg/L, and no USDW has been affected, this upward migration still does not conform to state regulations.

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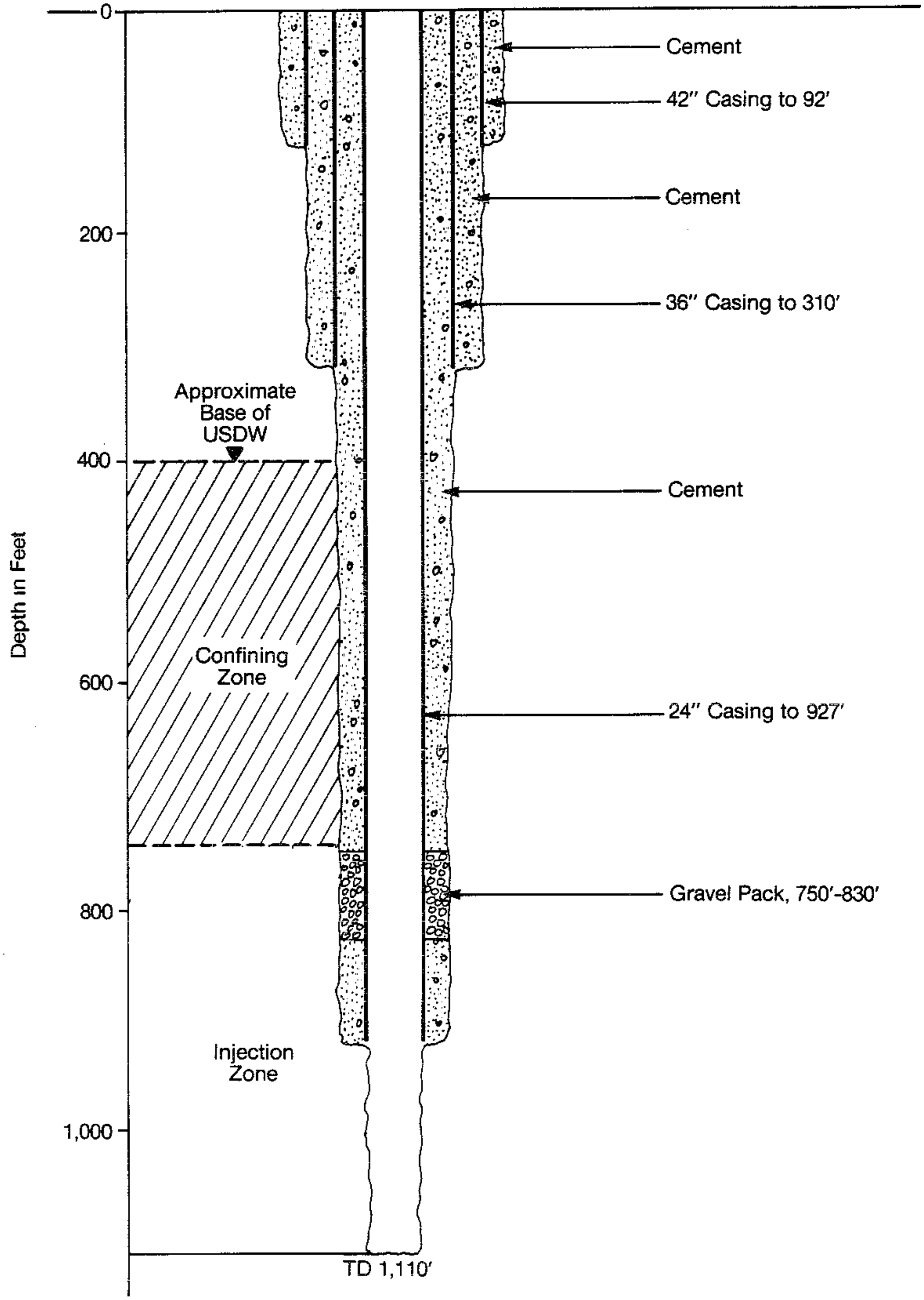


ST. PETERSBURG SOUTHWEST
St. Petersburg, Florida

INJECTION WELL NO. 3

UIPC

CITY OF STUART
WASTEWATER TREATMENT PLANT
STUART, FLORIDA

Background. The Stuart Wastewater Treatment Plant (WWTP) is located on the south side of the St. Lucie River, approximately three miles inland on the Florida east coast, in Martin County. The WWTP has one Class I municipal injection well to dispose of chlorinated secondary treated wastewater. Originally, treated effluent was discharged to the St. Lucie River and was limited to one million gallons per day by the Florida Department of Pollution Control. As a result of the community's growth, an injection well system was the city's most cost-effective alternative in light of the State's increasing restrictions on surface water discharge. Consequently, the city was granted a permit for the construction of one injection well and one deep monitoring well.

The Stuart WWTP injection well system has been in operation since December 1982. Reporting data collected through April 1984, indicates that the well is functioning properly. The system disposes of an average daily flow of 1.6 mgd. Water levels in the injection well monitoring annulus and the monitoring well remain within the background levels and established seasonal variations. Water quality also remains within background levels in both monitoring intervals.

The only problem that the plant has repeatedly experienced is the malfunction of the influent flowmeter-totalizer. All other operating data suggests that the injection well system is functioning properly and in an environmentally safe manner (CH2M HILL, May 1984).

Site Description. The Stuart WWTP is located on approximately 3 1/2 acres, south of the St. Lucie River. The wastewater is treated using the activated sludge process which requires the use of several above-ground structures (aerobic digesters, clarifiers, aeration basin, sludge drying beds, pump stations). An 18-inch outfall pipeline extends to the river for emergency disposal should the injection well system malfunction or require major maintenance. The effluent injection pumping station is comprised of two 2,100-gpm vertical turbine pumps and an emergency 2,000-gpm pump, a hydraulic surge protection system, and control and monitoring instrumentation.

In 1975, the City was using 15 water supply wells for public water distribution. The wells range in depth from 105 feet to 135 feet in depth and are located about one mile southeast of the WWTP. Another major user of groundwater in the Stuart area are flower farms. Eleven such wells exist (Black, Crow & Eidsness, Inc., 1975) and their completion depths range from 60 to 120 feet.

Potable water is present within the shallow aquifer which extends from the surface to a depth of approximately 165 feet. The shallow aquifer contains sand interbedded with shell and sandy limestone. The formations contained are the Pamlico, Caloosahatchee, Anastasia, and Tamiami, which range in age from Pliocene to Recent.

Underlying the shallow aquifer is a confining zone composed of the Hawthorn Formation. This unit contains highly plastic, phosphatic clay and soft limestone, which are Miocene in age and hydraulically separate the Floridan aquifer system from the shallow potable waters. The thickness of the Hawthorn is nearly 600 feet.

The Floridan aquifer in this area contains brackish and saltwater. This aquifer is composed of the Tampa, Suwannee, Ocala, Avon Park, Lake City, and Oldsmar formations. These rock units are all Miocene to Eocene carbonates which yield water under artesian conditions. The lowermost formation, the Oldsmar, contains dense cavernous dolomite and serves as the injection zone. Within the Avon Park and Lake City formations there are discrete zones of low permeability which contain chalk and fine-grained dolomitic limestone. These zones represent the upper confining units which separate the usable groundwater (those waters containing less than 10,000 mg/L total dissolved solids (TDS) above 1,800 feet from the injection zone.

The onsite monitoring well is open to the Lake City Formation between the depths of 2,027 to 2,093 feet. This interval produces saltwater. Continuous pressure instrumentation is installed to measure any variation in artesian pressure. Water samples are periodically tested to monitor any variation in water quality from background conditions.

Well Construction Details. The Stuart WWTP injection well was constructed by setting a 36-inch casing at 318 feet and cementing it to the surface, which isolated the potable shallow water aquifer. A 24-inch casing was set at 1,010 feet and cemented to the surface, isolating the confining clays of the Hawthorn Formation and soft limestone of the Tampa Formation. A 16-inch casing was set at 2,000 feet into the confining strata of the Lake City Formation and cemented back to 1,300 feet, providing an open annular monitoring zone in the Avon Park Formation. A 14-3/4-inch open hole was drilled to 3,000 feet. The well was completed to this depth and prepared for start up (Black, Crow & Eidsness, 1975).

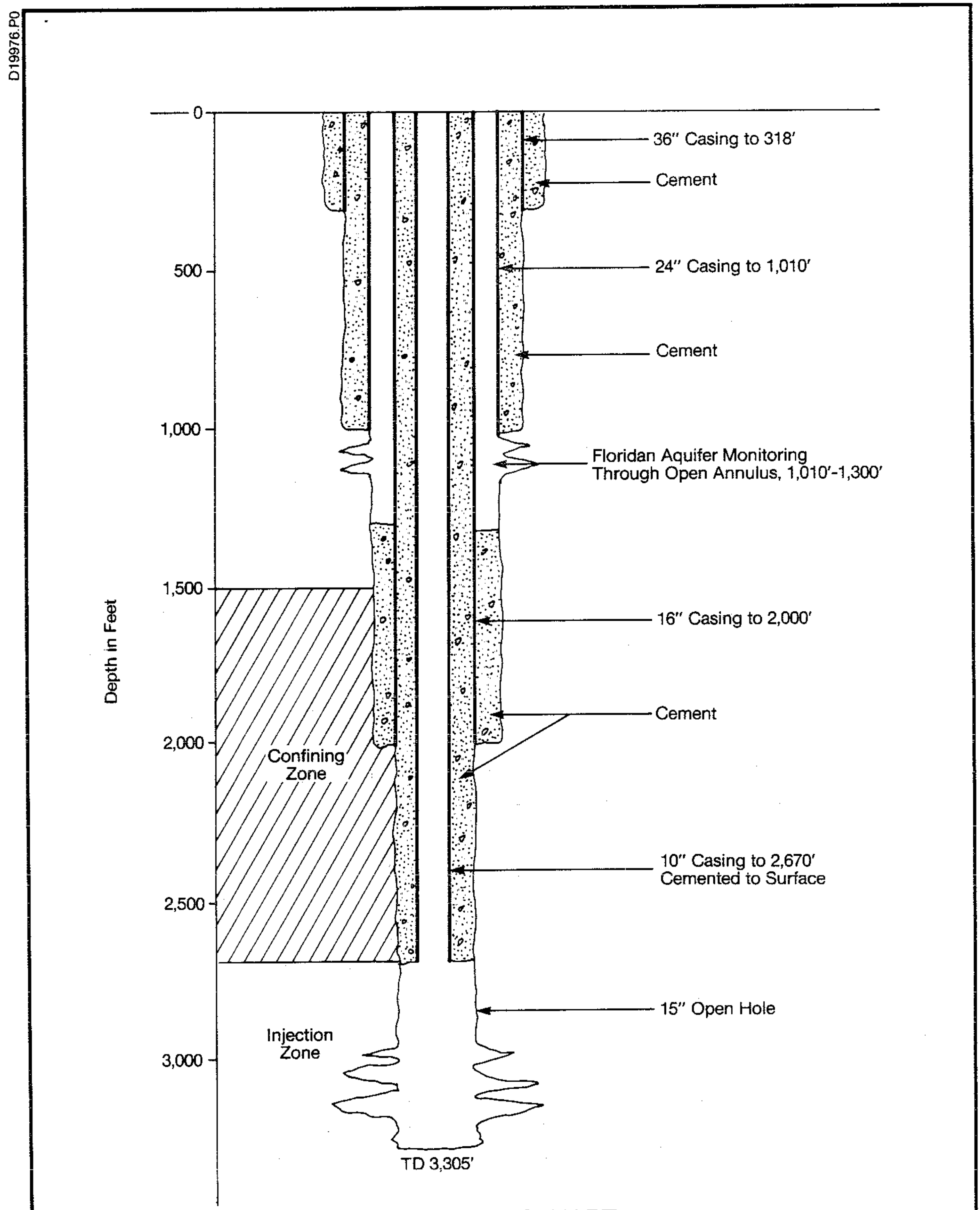
The well remained inactive for nearly eight years after its completion while obtaining an operating permit. After extended negotiations with the regulatory agencies, it was agreed to provide a deeper inner casing and to deepen the open hole. As a result, the well was deepened to 3,305 feet and a 10-inch liner was set at 2,670 feet and cemented to the surface. The well was completed as an open hole to 3,305 feet and put into operation (CH2M HILL, April 1982). The monitoring well was also operational, providing continuous monitoring of the upper Floridan aquifer.

Chronology of Operational Problems. The injection well system was completed in June 1974. The well remained idle for 4 years thereafter, when, in January 1978, negotiations with the regulatory agencies began to obtain an operating permit. The FDER and other agencies expressed concern over the depth to which the injection casing was set. They were concerned that the 2,000-foot setting depth may not be adequate to separate and isolate the injection strata from the possible sources of drinking water above. As a result, an agreement was reached to permit a short-term injection test. The test was conducted to determine the adequacy of the casing depth for preventing migration of wastewater out of the intended injection zone.

The injection test was started February 1977 and ran for 15 days, at which time the injection was stopped after an unexpected increase in injection pressure. The increase in injection pressure resulted from debris accumulated in the bottom of the open hole injection interval.

Throughout the test rhodamine WT dye was injected with the effluent. Water samples taken from the open hole monitoring annulus on the injection well were tested for the presence of dye. No dye was found in the annulus samples, and the water levels at the injection well annulus and monitoring well remained at background levels, indicating sufficient isolation of the injection zone (CH2M HILL, April 1982).

The plugging of the borehole bottom in the injection zone during testing made it necessary to clean out the well to reduce the surface injection pressure. As a result, the well was increased in depth and cased to the depth requested by the agencies.



CITY OF STUART
Martin County, Florida

INJECTION WELL NO. 1

SUNSET PARK WASTEWATER TREATMENT PLANT MIAMI, FLORIDA

Background. The Sunset Park Wastewater Treatment Plant (WWTP) and injection well system was owned and operated by the Peninsula Utilities Corporation prior to its transfer of ownership to the Miami-Dade Water and Sewer Authority (MDWSA). The WWTP is located in Dade County, Florida, and services the residents of the southwest Miami area.

The Class I municipal injection well was constructed in 1969 and was designed to dispose of chlorinated secondary treated wastewater from the plant's activated sludge treatment process. The design capacity of the well was 5.75 million gallons per day (mgd) with emergency disposal to the Snapper Creek Canal.

The original plant operation discharged the treated effluent to the Snapper Creek Canal, part of the Central and Southern Florida Flood Control District canal network. At that time the plant capacity was 2 mgd. The deep disposal well was put into service as a temporary solution to surface water discharge of the effluent until a larger collection and treatment system was made available.

State records indicate that the facility has operated successfully for 12 years with only minor effluent quality permit violations. The WWTP and injection well were taken out of service in January 1983 and all influent was diverted to MDWSA's newly constructed Regional South District WWTP. This new WWTP uses nine deep disposal wells.

Site Description. The Sunset Park WWTP is located in southwest Miami, on the Snapper Creek Canal, approximately six miles inland from Biscayne Bay. The plant is about

3-1/2-miles east of the Kendale Lakes disposal well. The Kendale Lakes well was constructed in 1972 after the completion of Sunset Park's well.

Originally, the Sunset Park facility discharged its treated effluent into the Snapper Creek canal which leads to Biscayne Bay. The injection well system, which included the injection well, deep monitoring annulus, surge control system, and monitoring and control instrumentation, allowed the discharge of effluent to Florida's surface waters to be discontinued.

The City of Miami's Alexander Orr well field is less than one mile northeast of the Sunset Park WWTP. The City's Southwest water well field is three miles west of the plant. Both well fields produce water from the unconfined Biscayne aquifer. The supply wells are shallow, generally completed to a depth of 100 feet. The Biscayne aquifer underlies all of Dade and Broward counties and parts of Palm Beach and Monroe counties. Lithologically, the aquifer is a highly permeable limestone in south and west Dade County, becoming increasingly sandy and less permeable toward the Atlantic coast and northward.

The sands and limestones of the Biscayne aquifer are separated from the highly mineralized Floridan aquifer system by the Hawthorn and Tampa formations. These units are composed of highly plastic phosphatic clay and soft limestones which serve as an aquiclude. Their total thickness is nearly 800 feet within the area of the disposal well.

The Floridan aquifer, composed of the Tampa, Suwannee, Avon Park, Lake City, and Oldsmar formations, underlies all of Florida, southern Georgia, and parts of Alabama and South Carolina. This aquifer is composed of nearly 3,500 feet of carbonate rocks. The upper Floridan aquifer is used only as a supply of water for irrigation purposes in southern Florida. Formation water contaiing total dissolved solids (TDS) of 10,000 mg/L occurs at approximately 1,800 feet, becomes more saline with depth, and eventually approaches seawater-like concentrations in the Oldsmar Formation. The Oldsmar is the target zone of injection throughout southern Florida.

Cavernous zones (Boulder Zone) within the dense dolomite of the Oldsmar allows injection of wastewater at rates exceeding 10,000 gpm with surface injection pressure around 70 pounds per square inch (psig). The chalks and dense dolomitic limestones and dolomites above the injection zone serve as confining strata isolating the injected fluids.

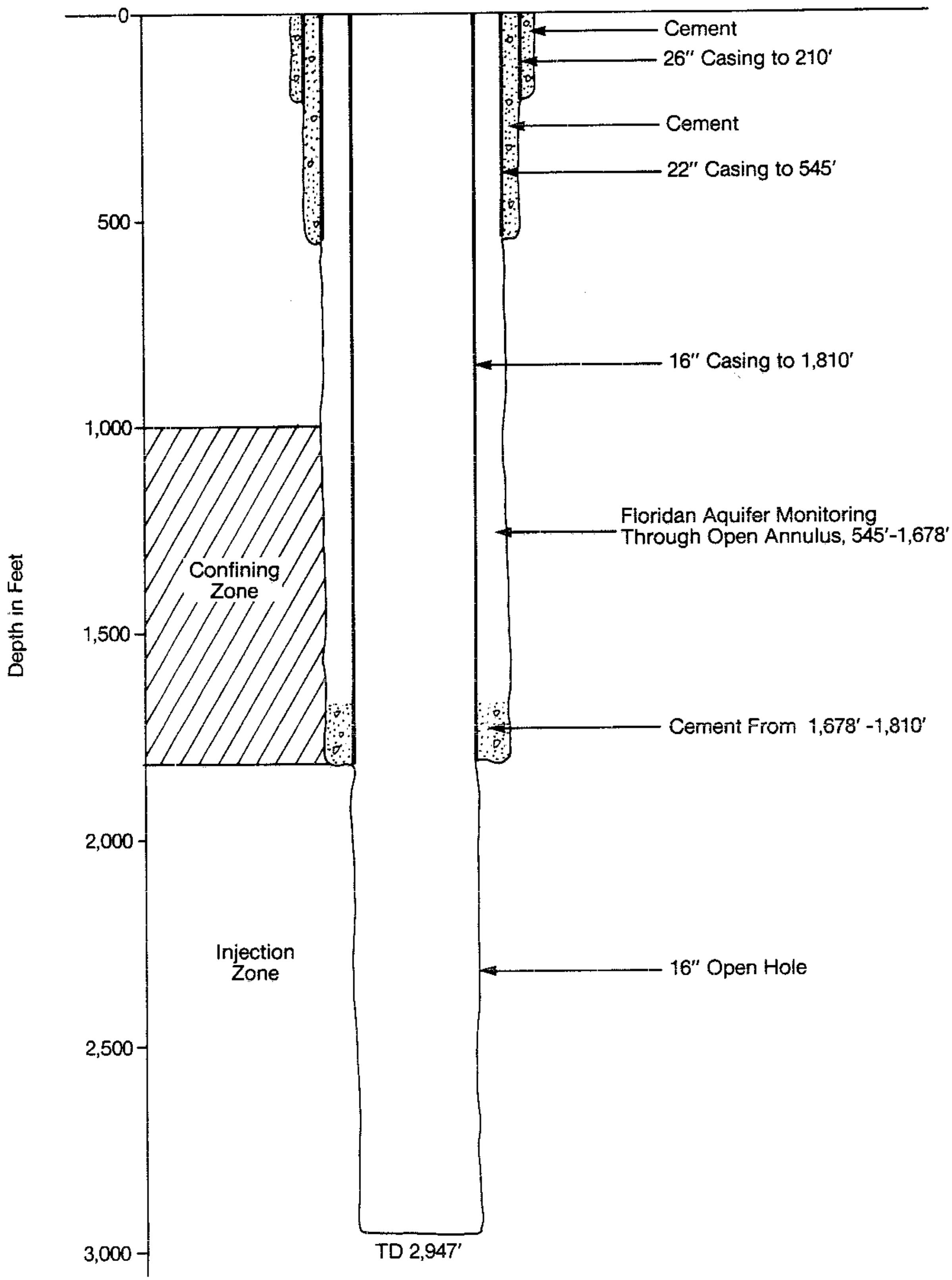
Well Construction Details. The Sunset Park disposal well was constructed under the Florida State regulations of 1969 which require that no wastewaters be injected into an aquifer with less than 1,500-mg/L chloride content. The Sunset Park injection well final casing was set at 1,810 feet. This depth is in an interval containing 10,000-mg/L TDS, which is required under present day regulations. The 1,500-mg/L chloride interface is at approximately 1,500 feet.

The injection well is constructed with three steel casings which were installed to isolate and conduct the treated wastewater into the injection zone. A 26-inch casing is set at 210 feet and cemented to the surface, isolating the Biscayne aquifer and the clays of the Hawthorn Formation. A 22-inch casing is set at 545 feet and cemented to the surface, isolating the aquiclude of the combined Hawthorn and Tampa formations. A 16-inch injection casing is set at 1,810 feet and cemented back to 1,678 feet, leaving an open annular monitoring interval. The annular monitoring zone between this depth and the bottom of the 22-inch casing permits the monitoring and periodic sampling of water produced from the upper Floridan aquifer. The well was completed open hole to a depth of 2,947 feet into the Oldsmar Limestone. The caliper log run on the open hole indicates that the cavernous Boulder Zone was penetrated at about 2,930 feet.

Chronology of Operational Problems. The Sunset Park WWTP and injection system was successfully operated from 1969 to 1983, when it was taken out of service upon startup of the Regional South District WWTP. This larger facility uses nine injection wells.

In November 1975, the plant capacity was exceeded after heavy rains which required the discharge of sewage to Snapper Creek Canal.

Annulus conductivity decreased from 9,000 to 5,000 μmhos/cm, and stabilized during 1981 and 1982. This information was originally thought to be the result of a casing leak. However, four TV surveys were conducted which revealed that the casing was intact and showed no sign of leakage.



SUNSET PARK
MIAMI-DADE WATER AND SEWER AUTHORITY
Dade County, Florida

VELSICOL CHEMICAL CORPORATION
MARSHALL, ILLINOIS

Background. The Velsicol Chemical Corporation Marshall Plant is located about one mile north of the City of Marshall, Clark County, in southeastern Illinois. Since manufacturing operations began at the site in the mid-1930's, the facility has produced various resins, solvents, and pesticides. The plant currently manufactures chlorinated hydrocarbon pesticides.

Prior to 1965, plant wastewaters and storm runoff were disposed of via unlined surface impoundments that subsequently overflowed into Mill Creek, a tributary of the Wabash River. The surface discharge was implicated in the contamination of both ground and surface waters in the area. In 1965, a deep injection well was constructed as part of a program to mitigate this contamination. A second deep injection well was constructed in 1971. Well No. 1, which had experienced operational problems, was designated as a standby well, and used infrequently to dispose of stormwater flows.

Surface facilities consist of two 450-gallon-per-minute (gpm) centrifugal pumps (one primary, one standby) and two holding tanks for wastewater. The surface equipment is shared with Well No. 2, the primary injection well. Well head injection pressure and flow monitoring is provided. The annulus pressure maintenance and monitoring system of Well No. 1 is inoperative. All transfer piping and monitoring equipment is scheduled for removal when the well is permanently abandoned.

The main USDW at the site is monitored by a series of shallow wells, 12 to 40 feet deep. The monitoring function of these wells is related primarily to the surface impoundments, rather than the injection well. However, periodic sampling of four of these wells, designated G-101, G-102, G-13S, and G-13D, plus sampling Mill Creek, is specified under the operating permit for Well No. 2. Construction details of these wells were not found in agency files. A deep monitoring well, to the Devonian Limestone, is located 1,700 to 1,800 feet north of Well No. 2. This well is 2,580 feet deep, and cased to 2,431 feet with 4-1/2-inch casing.

Continuing operational problems with Well No. 1 resulted ultimately in denial of an operation permit. Plans for permanently plugging the well are currently under review by the Illinois EPA (Withers, 1986, personal communication). Well No. 2 continues in operation, substantially in compliance with applicable regulations. The company is considering drilling a third well as a standby. So far as is known, no USDW has been directly affected as a result of well operation, but discharges of contaminated stormwater to surface water may have occurred during the time the well was unusable.

Site Description. The site is covered by glacial drift ranging in thickness from less than 10 feet to a maximum of about 45 feet. The drift lies on a bedrock surface consisting of Pennsylvanian shales and sandstones. The drift and sandstone in the upper few feet of the Pennsylvanian bedrock together comprise the USDW in the area. The 10,000-mg/L isopleth occurs within the Pennsylvanian rocks, which are predominately shales, at a depth of approximately 500 feet.

The Mississippian Salem Limestone at a depth of 1,260 feet is the uppermost potential injection zone, and is the zone into which Well No. 1 is completed. About 500 feet of shale and shaley sands in the lower part of the Pennsylvanian system constitute the upper confining bed. The lower confining bed consists of the shaley portion of the Salem Lime and the underlying Devonian New Albany Shale, an aggregate thickness of approximately 600 feet.

The primary injection zone is the Devonian and Silurian carbonate sequence between 2,200 and 3,000 feet in depth. Well No. 2 at Velsicol is completed in Devonian limestone in this unit, between 2,442 feet and 2,737 feet. The upper confining bed is the New Albany Shale, and shale in the lower part of the Mississippian system as previously described. The lower confining bed is the Maquoketa Shale, which is about 220 feet thick at this site.

Potential injection zones at greater depth were explored during the construction of Well No. 2. Ordovician and Cambrian-system carbonates were penetrated to a depth of 6,000 feet, but tests in this interval indicated inadequate disposal capacity.

Well Construction Details. Injection Well No. 1 was originally completed in 1965 with an 8-5/8-inch casing to a depth of 417 feet, and 4-1/2-inch casing to a depth of 2,390 feet. Both casing strings were grouted to the surface. The well was completed as an open hole to a depth of 2,634 feet, into the Devonian Limestone. A 2-7/8-inch plastic-lined tubing and packer assembly was set near the bottom of the 4-1/2-inch casing. A section of the 4-1/2-inch casing was aluminum to provide window to the Salem Limestone. Between 1966 and 1971, the window was opened by acidizing to dissolve the aluminum casing section.

In 1972, a shale stratum between the two injection zones apparently collapsed, necessitating a workover to recomplete the well to inject only into the overlying Mississippian Salem Limestone. The workover was accomplished by plugging the tubing. No leaks were found, and the well was retained on standby status. No repairs were made to the annulus at this time.

In November 1983, Permit No. 1983-2-IOP was issued for operation of Well Nos. 1 and 2. Special conditions of the permit required confirmation of mechanical integrity of tubing and casing of both wells (IEPA, 1985), and maintenance of annulus pressure higher than injection pressure. Since the tubing and packer could not be removed from Well No. 1 and the annulus would not hold pressure, these requirements could not be met. Consequently, renewal of the operating permit was denied. The well is available as an emergency standby. It was not operated in 1985, and Velsicol reports that there are no plans to operate the well in the future.

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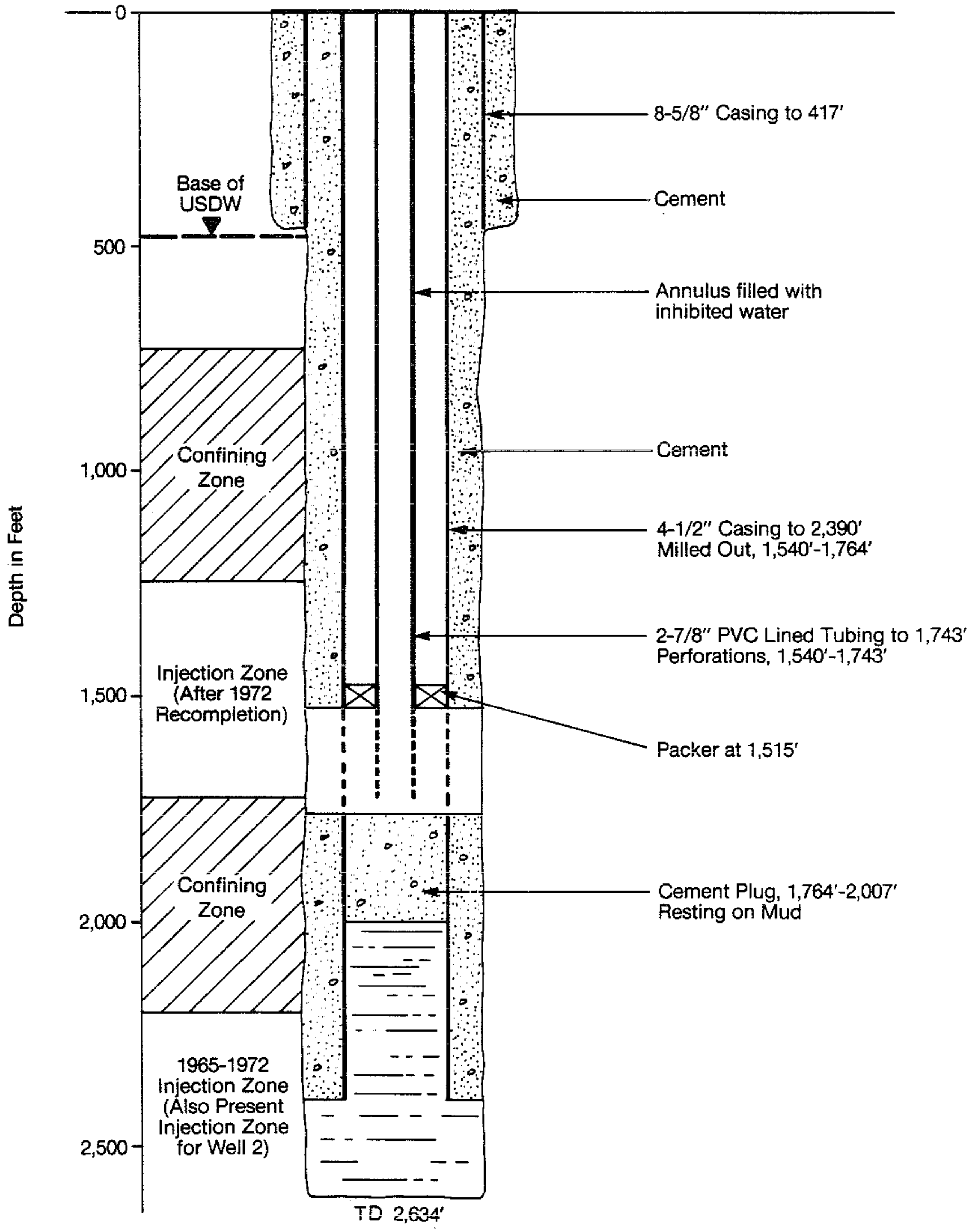


VELSICOL CHEMICAL
Marshall, Illinois

DISPOSAL WELL F1

VULCAN CHEMICALS
WICHITA, KANSAS

Background. Vulcan Chemicals operates a chloroalkali and chlorosolvent manufacturing facility in Wichita, Kansas. Wastewater produced from the facility is plant process wastewater, stormwater runoff, and recovered groundwater. The waste stream consists primarily of sodium, calcium and magnesium chloride brines, acidic wastes, sodium hydroxide and trace organic compounds.

Five Class I hazardous waste injection wells are currently operated at Vulcan. Approximately 1,200 gpm of wastewater is generated at the plant and disposed of down the injection wells. The wells are operated at gravity flow conditions, with zero pressure or a vacuum at the well head (Kansas Department of Health and Environment (KDHE), 1985).

The well head pressure and annulus pressure are monitored every 2 hours. The recordings are averaged to give a daily reading. The annulus pressure varies from well to well but the average pressure range is 135 to 145 pounds per square inch (psi). These data, along with the volume injected in each well, are summarized in monthly reports and submitted quarterly to the Kansas KDHE.

Site Description. The Vulcan wells are located in the Arkansas River lowlands section of the Central Lowlands physiographic province. The surface drainage trends eastward into low gradient tributaries of Cowskin Creek. The site is fairly level, with a relief of approximately three feet across the site.

Injection is into the Arbuckle, a highly porous limestone and dolomite formation overlying the basement rock. The injection interval is approximately 4,000 to 4,600 feet.

Natural fluids in the Arbuckle Formation have a total dissolved solids concentration in excess of 70,000 ppm and are considered brine.

The deepest potable water zone is reported at 100 feet. This aquifer contains water with a TDS of approximately 1,000 ppm. Numerous confining layers between the injection zone and this aquifer are reported in the UIC permit application.

Well Construction Details. A total of eight different disposal wells were operated at the Vulcan site over the life of the facility. Vulcan drilled the first well in 1957 and currently operates five wells. All of Vulcan's wells are operated with injection tubing and incorporate a packerless hydraulic seal.

Well No. 1 was drilled in 1957. This well is also known as Well No. 5 because of a miscommunication between Vulcan and the KDHE. The well is reported to be constructed the same as Well No. 3 with an injection zone from 4,000 to 4,750 feet. Well No. 1 was plugged on April 28, 1961, by cementing to the surface from 1,388 feet.

Well No. 2 was constructed in 1961 by setting and cementing 10-3/4-inch casing to 395 feet. New 7-inch casing with internal coal tar epoxy coating was set to 3,965 feet. Below the new casing, 157 feet of used uncoated 7-inch casing was installed. The bottom 600 feet of the casing was cemented with Dowell "cealment" cement. Above the Dowell cement is Halliburton Pozmix "A" for an unknown distance. It is not known if the casing was cemented to the surface. The casing was perforated from 3,990 to 4,115 feet. Fiber-cast tubing, with a nominal diameter of 4-1/2 inches, was set to 3,994 feet and two Teflon discs were installed at 3,974 feet. The annulus was filled with oil (Frontier Chemicals Co., 1961). The well was plugged with cement in January 1973 (State of Kansas Corporation Commission, 1973).

Well No. 3 was constructed in 1966 by setting and cementing a 10-3/4-inch casing in a 14-3/4-inch borehole to 401 feet. A 7-inch injection casing was then set and cemented in a 8-3/4-inch borehole to 4,125 feet. Both casings were cemented to the surface. The 7-inch casing was perforated from 3,954 to 4,125 feet. A 4-1/2-inch fibercast tubing was installed in the well to 3,949 feet.

Well No. 4 was constructed in 1973 by setting and cementing a 16-inch casing in a 22-inch borehole to 164 feet. A 10-3/4-inch casing was then set and cemented to 939 feet in a 15-inch borehole. The 7-inch injection casing is set and cemented to 3,970 feet in a 9-inch borehole. The casings were cemented to the surface. An open hole exists from 3,970 to 4,600 feet. A 4-1/2-inch fibercast tubing was installed in the well to 4,000 feet.

Well No. 6 was constructed in 1974 by setting and cementing 16-inch casing to 161 feet. A 10-3/4-inch casing was set and cemented to 952 feet. The 7-inch injection casing was set and cemented to 3,949 feet. A 6-1/4-inch open hole was drilled from 3,949 to 4,635 feet. A 5-1/2-inch steel tubing, epoxy coated, was run to 3,958 feet. The 5-1/2-inch steel tubing was later replaced with 4-1/2-inch fibercast tubing.

Well No. 6 was later recompleted and believed to sidetrack between 3,500 and 3,949 feet. The hole was advanced to 4,072 feet. The 4-1/2-inch fibercast tubing was reinstalled to 3,959 feet. After further problems, this well was plugged with cement in 1982.

Well No. 7 was constructed in 1976 by setting and cementing a 16-inch casing in a 22-inch borehole to 156 feet. A 10-3/4-inch casing was then set and cemented to 981 feet in a 14-3/4-inch borehole. The 7-inch injection casing was set and cemented in a 8-3/4-inch borehole to 3,950 feet. A 6-1/4-inch open hole was drilled from 3,950 to 4,250 feet. A 4-1/2-inch fibercast tubing was set to 4,000 feet.

Well No. 8 was constructed in 1980 by setting and cementing an 18-inch casing in a 26-inch borehole to 161 feet. A 10-3/8-inch casing was set and cemented in a 17-1/4-inch borehole to 959 feet. The 9-5/8-inch injection casing was set and cemented in a 12-1/4-inch borehole to 3,947 feet. All the casings were cemented to the surface. An open hole was drilled from 3,947 to 4,591 feet. A 4-1/2-inch fibercast tubing was run in the well to 4,000 feet.

Well No. 9 was constructed in 1982 by setting and cementing an 18-inch casing in a 26-inch borehole to 167 feet. A 13-3/8-inch casing was set and cemented in a 17-1/4-inch borehole to 950 feet. The 9-5/8-inch injection casing was set and cemented to 3,953 feet. All casings were cemented to the surface. An 8-3/4-inch open hole was drilled from 3,953 to 4,590 feet. A 4-1/2-inch fibercast tubing was run to 4,000 feet.

Chronology of Operational Problems. Well No. 1, also known as disposal Well No. 5, was drilled in 1957. An operational history of this well could not be found. The well is reported to have been plugged by cementing on April 28, 1961 (State of Kansas Department of Health, 1972).

Well No. 2 was drilled in 1961. The well was acidized on June 1, 1961, and placed in service. After 2 days of service, flow into the well could not be maintained. The well was acidized again with 3,760 gallons of muriatic acid. The well was returned to service with the injection rate varying between 200 and 400 gallons per minute (gpm). In April 1972, Vulcan reported no operational problems with the Well No. 2. In December 1972, Vulcan requested approval to abandon Well No. 2 because the well was badly plugged. The well was cleaned out to 700 feet and plugged with cement in January 1973.

Well No. 3 was drilled in 1966. No operational difficulties were reported through 1976. The injection rate in early 1976 was 325 to 570 gpm. In March 1977, the annulus pressure was observed to vary erratically. The tubing was pulled, inspected, and each joint pressure tested. Casing logs were run, which showed possible corrosion between 500 and 700 feet (Noller, May 1977). The tubing was reinstalled and the annulus pressure tested. The annulus again failed to hold pressure. A large volume of impounded wastewater forced Vulcan to return the well to service, injecting alkaline waste only (Noller, April 1977).

In April 1977, the casing in Well No. 3 was pressure tested using a RTTS packer set at 11 different locations. No leaks were found. The tubing was inspected and pressure tested. Again, no leaks were found. Some of the tubing was replaced after imperfections were found during a visual inspection. The casing was swabbed and scraped, the tubing installed, and the annulus filled with oil. The annulus held a pressure of 62 pounds per square inch gauge (psig), and the well was returned to service (Noller, 1977).

In January 1980 and in April 1980, the tubing in Well No. 3 became plugged with what was reported as calcium carbonate sludge. On both occasions, the tubing was pulled, cleaned out, and reinstalled. The well was then returned to service.

In October 1980, Well No. 3 experienced reduced flow rates due to a reported bottom blockage. In February 1981, the tubing was pulled and a hard blockage at 3,980 feet was drilled through. New tubing was installed and the well was returned to service. Later in February 1981, the tubing again became blocked. This was cleared by partial removal of the tubing and the well was returned to service.

In October 1984, a pressure mechanical integrity test was run on the Well No. 3 annulus. The well proved satisfactory.

In June 1985, Well No. 3 was taken out of service when high annulus pressure was observed. A blockage of asphaltic material was found below 2,000 feet. The tubing was stuck in this material and was cut off at the 2,000-foot level. The work was still in progress when this information was obtained during the site visit on September 19, 1985.

Well No. 4 was constructed in 1973. In July 1982, a reduction in annulus pressure was observed. The tubing was pulled and found separated at approximately 2,800 feet. The tubing left in the hole was fished out and found covered with a very thick black sludge. Holes were also found in the tubing. The casing was logged, pressure tested, and proved to be tight at normal annulus pressure. A refurbished tubing string was installed in the well. The tubing became hung up at 3,938 feet. Eleven feet of movement was possible but the tubing could not be moved beyond that interval (Metzger, 1982). The tubing being hung up was not considered to pose a problem to the well operation and the KDHE approved placing the well back in service. It was planned to install only 4,000 feet of tubing and the 3,938 feet of tubing installed extends 40 feet into the injection zone.

In October 1984, a pressure mechanical integrity test was performed on the Well No. 4 annulus. The annulus held 144 psi for 60 minutes.

Well No. 6 was constructed in 1974. In August 1979, a loss of annulus oil pressure was observed. The tubing was pulled and only 3,240 feet out of 4,000 feet was recovered. The tubing left in the well had to be milled out. This operation was performed until the end of September. Casing logs run in October 1979, indicated severe casing damage below 3,130 feet. The casing was squeezed with cement, drilled out, and the well returned to service by the end of December 1979. While drilling out the cement on Well No. 6, the borehole reportedly sidetracked. The consulting geologist supervising the job believed that the sidetrack occurred at approximately 3,949 feet (Fair, 1980). Others have reported that the sidetrack could have begun as high as 3,500 feet (Noller, 1981). The tubing is also reported to have become stuck after installation.

In March 1980, Well No. 6 became plugged. The annulus monitor system indicated communication between the tubing and annulus. The well was acidized and perforated through the tubing and the well returned to service.

Well No. 6 became completely plugged in April 1981. A wire line run inside the tubing found mud and sand around 190 feet. The tubing was pulled and found separated at about 90 feet. The 7-inch steel casing was reported to be completely missing from 82 feet to 109 feet. The 10-3/4-inch casing seemed to be intact (Noller, 1981). The well was drilled out to 3,462 feet where the drilling became very slow and it was decided to abandon the well and drill a replacement. In April 1982, Well No. 6 was plugged with cement.

Well No. 7 was constructed in 1976 and placed in service in April 1977. During construction of this well, a single stage cementing was attempted on the 7-inch casing. No cement returns were observed at the ground surface. The remainder of the cement was placed from the surface through one-inch tubing. The cemented bond log does not indicate continuous bonding throughout the entire length of the hole. The Kansas Department of Health and the Environment as well as a consulting engineer hired by Vulcan found the cement job adequate (Fair, 1976).

In September 1980, a loss in annulus pressure was observed in Well No. 7. The tubing was replaced and the well returned to service.

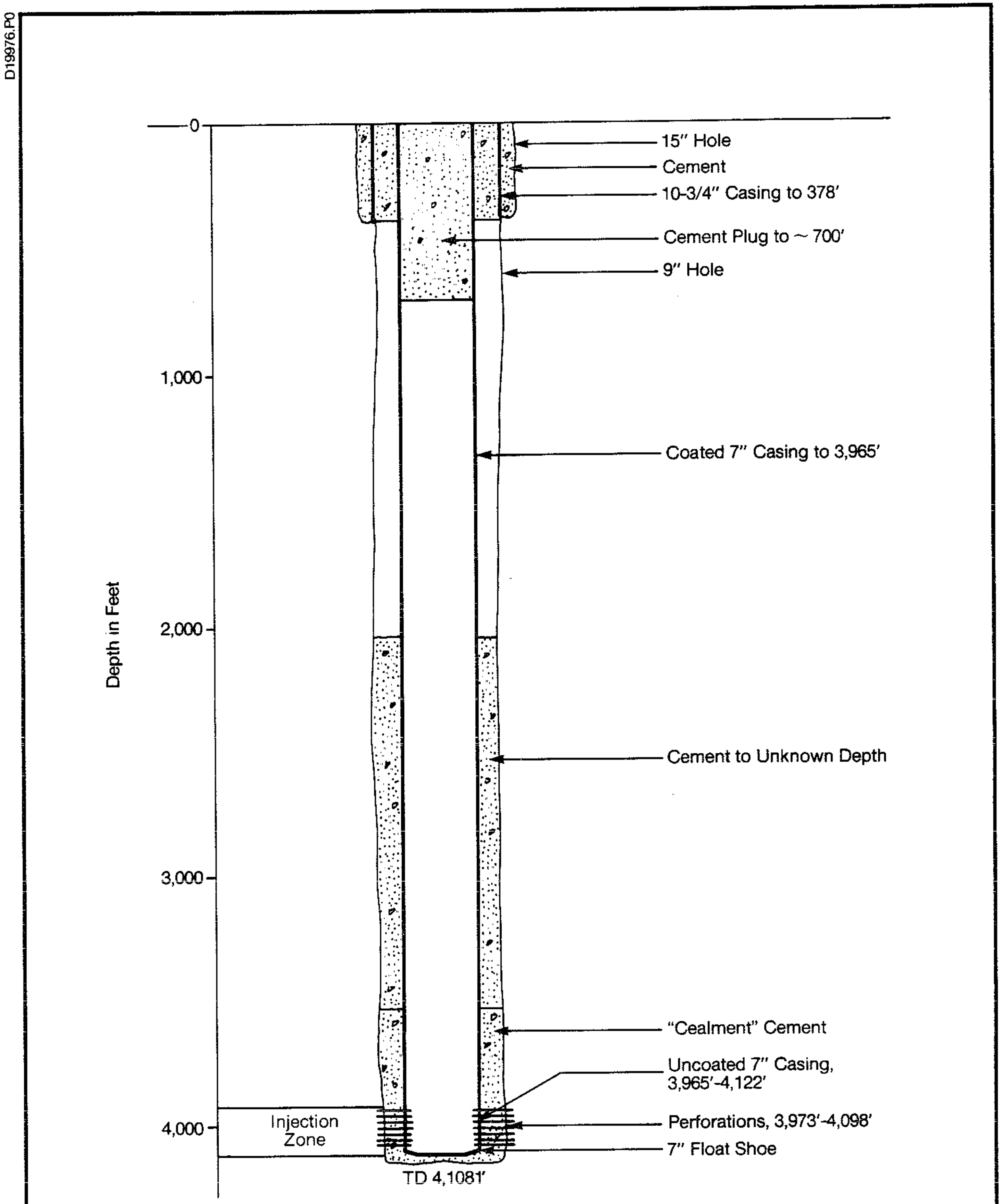
In October 1984, Well No. 7 was subjected to an annulus pressure mechanical integrity test. The annulus held 160 psi for 60 minutes.

In April 1985, Well No. 7 was taken out of service after a drop in the annulus pressure. The tubing was removed and a split near the bottom was found. The casing was pressure tested and held 167 psig for one hour. The faulty tubing was replaced and the well returned to service.

Well No. 8 was constructed in 1980. In December 1983, a loss in annular pressure was observed. The tubing was found separated at the 30th joint. The tubing was repaired with some reported to be left in the hole. The well was returned to service.

In May 1985, the annulus pressure decreased. A pressure mechanical integrity test was performed and the annulus held 166 psi for 60 minutes. The annulus oil was determined to have water in it, causing the observed pressure drop.

Well No. 9 was constructed in 1982 as a replacement to Well No. 6. No operational problems have been reported at the time the information was collected during the site visit on September 19, 1985.



VULCAN MATERIALS COMPANY
Wichita, Kansas

WASTE DISPOSAL WELL NO. 2 (Plugged 1/24/73)

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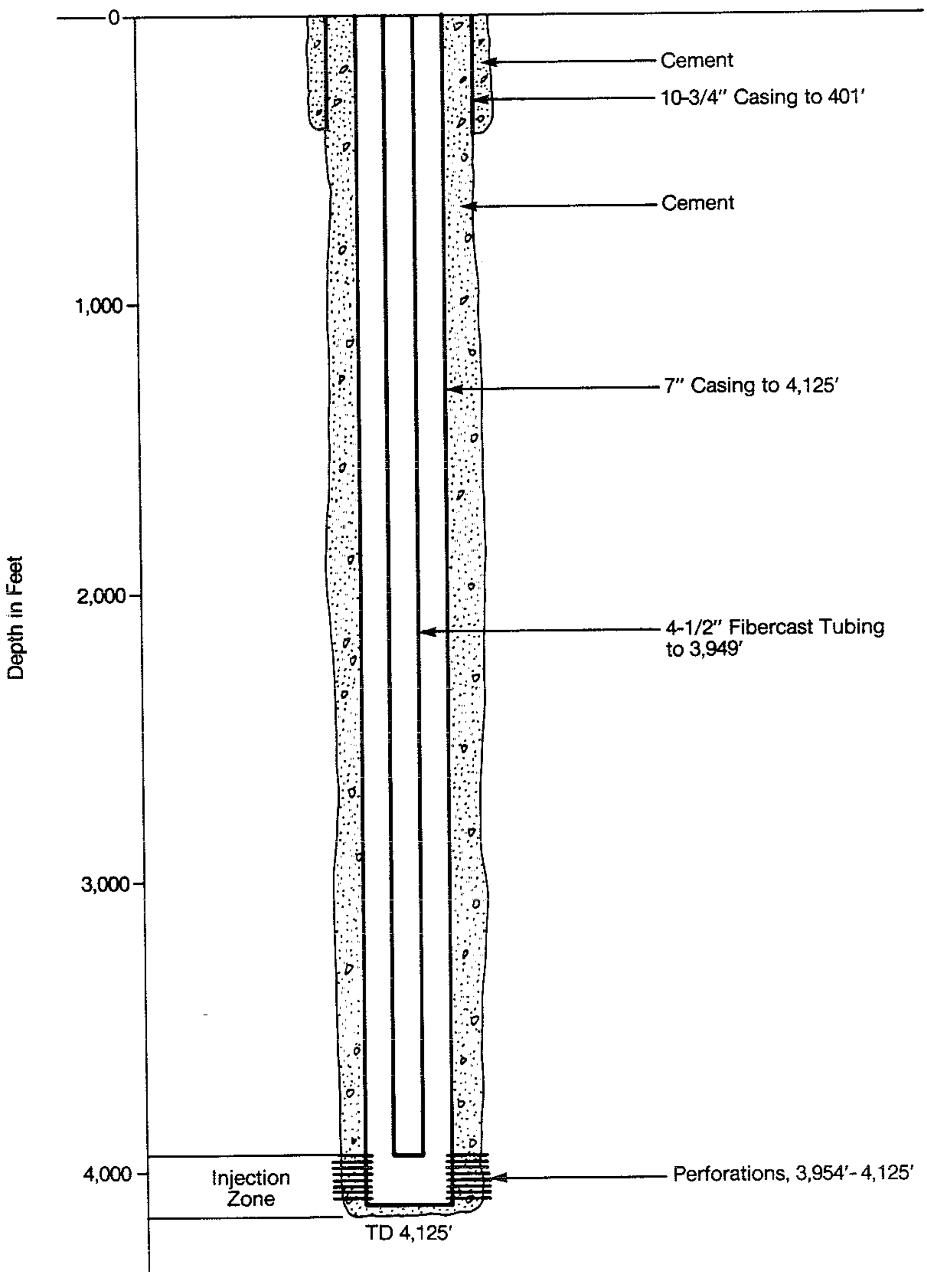

VULCAN MATERIALS COMPANY
Wichita, Kansas

WASTE DISPOSAL WELL NO. 3 (As of 12/10/74)

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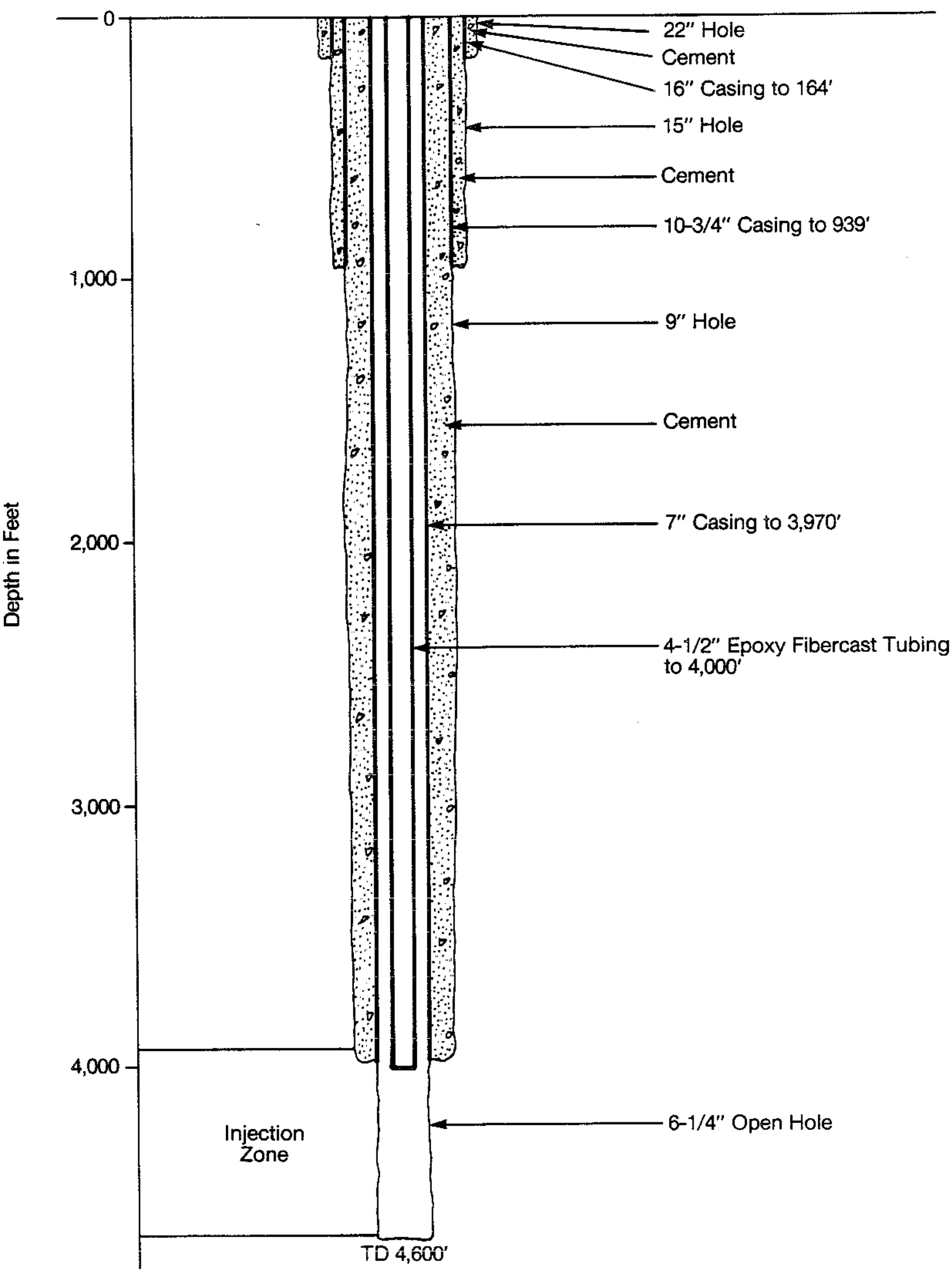
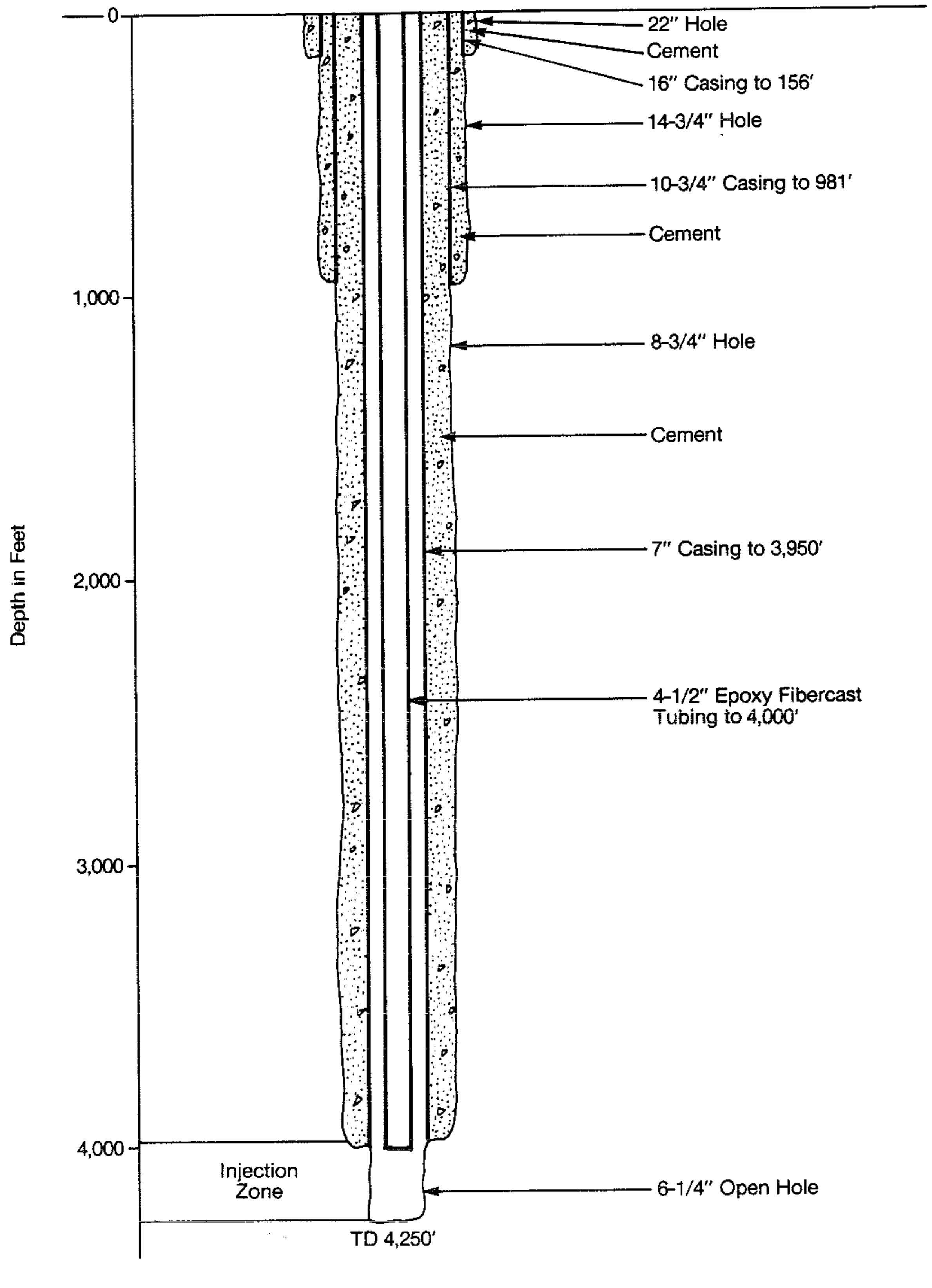


VULCAN MATERIALS COMPANY
Wichita, Kansas

WASTE DISPOSAL WELL NO. 4 (As of 4/30/76)

UIPC

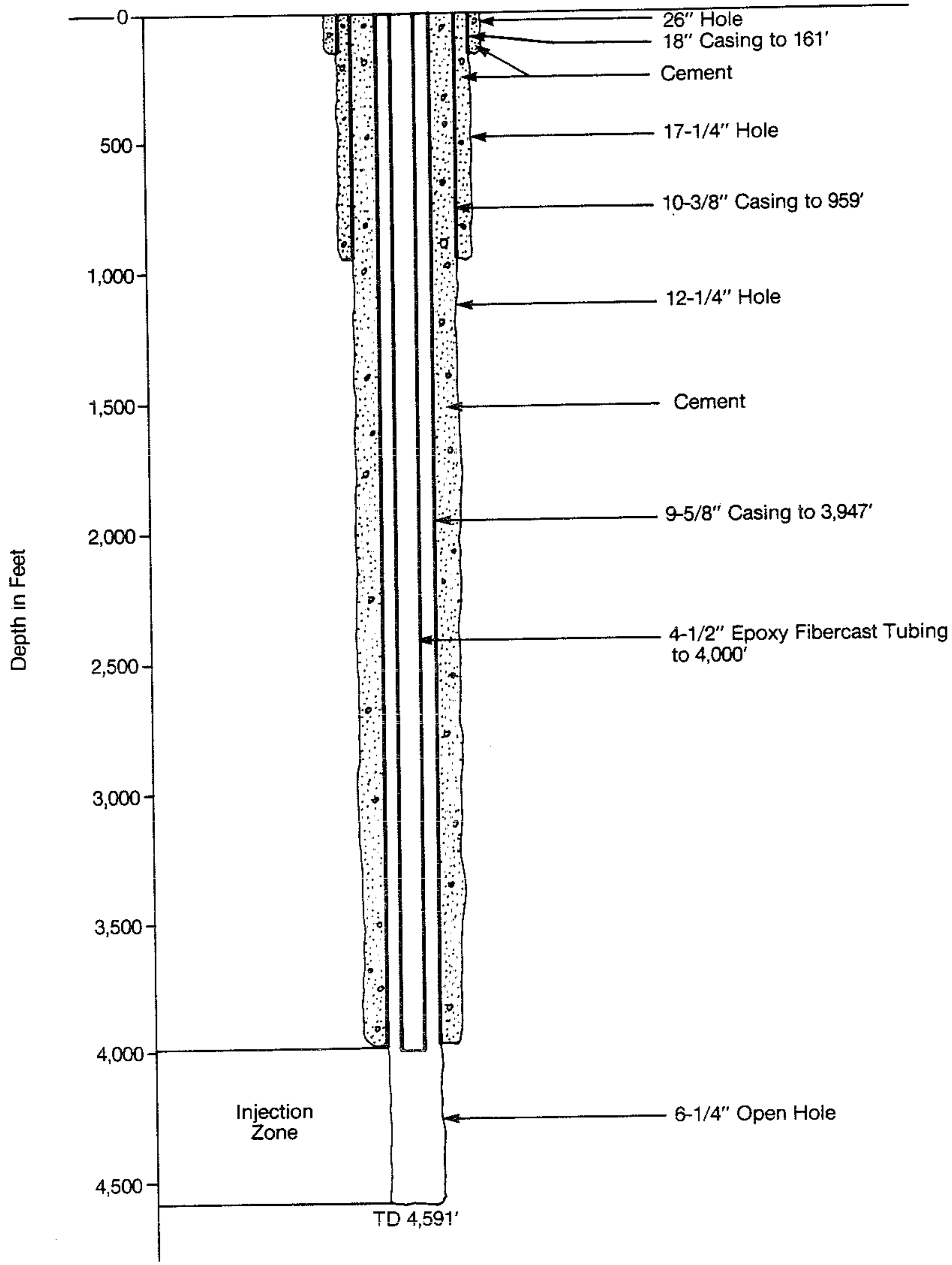
D19976.P0



VULCAN MATERIALS COMPANY
Wichita, Kansas

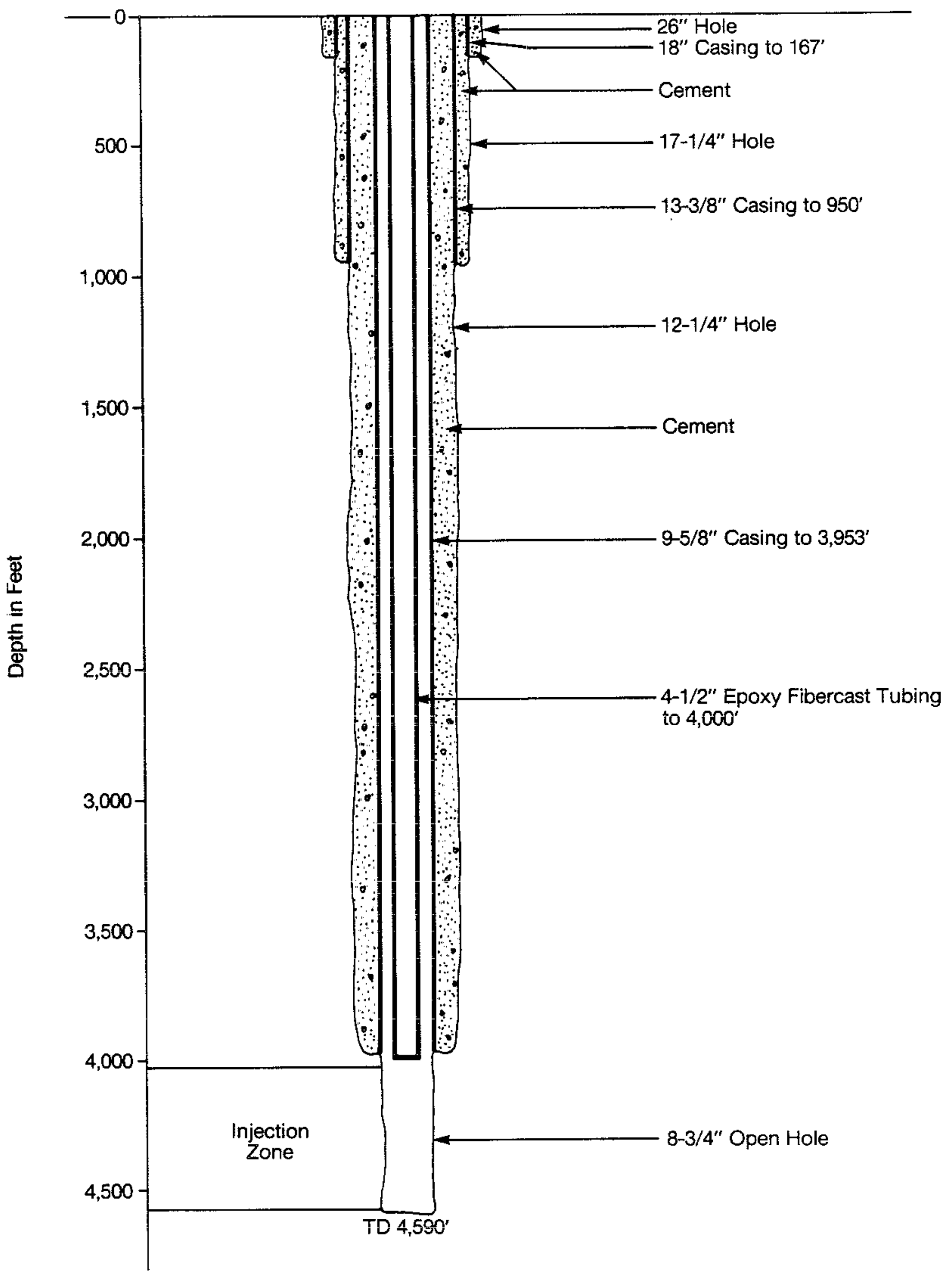
WASTE DISPOSAL WELL NO. 7 (As of 4/30/76)

UIPC



VULCAN MATERIALS COMPANY
Wichita, Kansas

WASTE DISPOSAL WELL NO. 8 (As of 4/30/76)



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VULCAN MATERIALS COMPANY
Wichita, Kansas

WASTE DISPOSAL WELL NO. 9 (As of 4/30/76)

WASTE MANAGEMENT, INC.
FURLEY, KANSAS

Waste Management Inc. (WMI) operates a hazardous waste disposal facility near the Town of Furley, Kansas, in southeastern Kansas, about 10 miles northeast of Wichita. Operations at the site include burial of solid wastes in trenches excavated in the Wellington Shale, and treatment of liquid wastes in lagoons also excavated into the shale.

In 1981 and 1982, contamination of the local shallow aquifer was detected. The contamination was attributed to groundwater circulation along thin permeable zones in the upper 30- to 50-foot zones of the weathered Wellington Shale.

Following confirmation of groundwater contamination, the site was closed, and cleanup and aquifer restoration activities were begun. As part of the cleanup activity, WMI applied for a permit to drill a 3,300-foot injection well into the Arbuckle Dolomite to dispose of waste remaining in the treatment lagoons and contaminated groundwater generated during restoration of the shallow aquifer.

Because of widespread public opposition, and the lack (at the time) of clear rules and guidelines governing deep well injection of hazardous waste in Kansas, the application for permit was denied.

No well was drilled at the Furley site. Waste from the cleanup and restoration of the site was hauled to Arkansas for deep well disposal at the Chemical Resources Inc. facility.

CECOS INTERNATIONAL, INC.
LAKE CHARLES, LOUISIANA

Background. CECOS International, Inc., a wholly owned subsidiary of Browning-Ferris Industries, operates a commercial hazardous waste disposal well at a site approximately eight miles north-northwest of Lake Charles, Calcasieu Parish, Louisiana. The CECOS facility receives waste streams from numerous businesses and industries that generate insufficient quantities to warrant onsite disposal systems. The injected waste normally has a low pH (3-7), low suspended solids (10-20 mg/L), high COD (3,000-10,000 mg/L), and dissolved solids to 60,000 mg/L.

The commercial waste disposal facility has been in operation since December 1976, and includes an injection well to a total depth of 4,300 feet, a monitor well to 1,145 feet, a mixing area, two lined waste receiving or pH adjustment basins, a lined equalization basin, and landfill cells. Some of the unlined open pits and lagoons received hazardous wastes, and some of the old lagoons containing hazardous wastes were closed by adding kiln dust and covering. Since April 1984, injection rates have been approximately 60 gpm, and injection pressures at the wellhead have ranged from 200-400 psi.

The facility has had a controversial operational history since 1978, when citizen complaints prompted the first groundwater investigation. Although this study concluded that no groundwater pollution was indicated and that the well was designed and operated in an environmentally acceptable manner (EPA, September 1978), onsite surficial contamination was detected in late 1982 (Louisiana Department of Environmental Quality, February 1984). At a public hearing in January 1985 to re-permit the injection well, the existence of shallow aquifer contamination from past operations was an issue. The injection well has been considered a potential source of this shallow aquifer contamination. A deep monitor well was drilled and, although all sources of contamination could not be identified, the available data indicated that the injection well is not a source of contamination (Louisiana Office of Conservation, June 1985). The well is currently operating, with Office of Conservation approval. The well was repermitted on October 24, 1985.

Site Description. The site is underlain by a shallow permeable zone less than 50 feet deep consisting of sands, silty clays, and clays of Recent age. This "50-foot permeable zone" has been contaminated with oily wastes and volatile and base-neutral extractable compounds (Louisiana Department of Environmental Quality, February 1984). Groundwater flow in this zone is to the southeast.

The Chicot aquifer is the principal potable water producing aquifer in the vicinity, and consists of the "200-foot" sand, the "500-foot" sand, and the "700-foot" sand. The "200-foot" sand supplies water for irrigation and public uses, and is approximately 100 feet thick and 100 feet below the site. Groundwater flow is generally to the south (Ken E. Davis and Associates, December 1984). Contamination has been detected in the "200-foot" aquifer in a monitor well between the equalization basin and an old lagoon. The "500-foot" sand supplies groundwater for industrial and agricultural uses, and is approximately 200 feet thick. The "700-foot" sand supplies drinking water for Lake Charles. The Evangeline aquifer, consisting of sand beds of Pliocene and Upper Miocene age, underlies the Chicot aquifer at depths of greater than 1,000 feet, and is a USDW at the site. The depth to the lowermost USDW at the site is 1,164 feet, as determined from the deep monitor well drilled for that purpose (Louisiana Order No. WD85-10 and Conger, 1985).

Miocene-age clays and shales of the Burkeville confining beds separate the Evangeline aquifer from the underlying Jasper aquifer, which contains salty water at the site. The top of the Jasper aquifer occurs at a 3,200-foot depth. The current injection interval is in the Miocene Zone A Sands at depths of 4,120-4,295 feet, but the original injection interval was in the Zone B Miocene Sands at depths of 4,490-4,610 feet. No evidence of faulting was found above 8,000 feet within the site vicinity. Lack of faulting was also verified during drilling of an adjacent test oil well (Conger, 1985).

Well Construction Details. The W.W.F. Oil Corporation originally drilled the Gus and Edna Anderson Well No. 1 as a wildcat oil well in the 1950's. The well was completed as a condensate well at a depth of 9,501 feet in June 1958, but because it became uneconomical to produce, the well was subsequently plugged in May 1961. In late 1975, Browning-Ferris Chemical Services requested approval to recomplete the well for waste disposal. The well was recompleted into Zone B of the Miocene Sands at 4,490-4,610 feet with a screen and gravel pack completion (Subsurface, Inc., 1976).

Zone B was used for the injection interval until April 1984, when the well was recompleted into Zone A at 4,120-4,285 feet (Ken E. Davis and Associates, November 1982). The current well configuration is as follows:

- A 10-3/4-inch O.D. steel casing set at 2,554 feet and cemented to surface

- A 7-inch O.D. steel casing set at 8,553 feet, cemented to the surface and perforated in the 4,120- to 4,220-foot and 4,255- to 4,285-foot intervals

- A 3½-inch O.D. fiberglass reinforced pipe injection tubing with a screen and liner set at 3,997 feet with gravel pack completion

- A packer set at 3,985 feet

- A pressurized, corrosion inhibiting brine-filled annulus

A surge/contraction system was added to the annulus in July 1981 to maintain constant annular pressure.

Prior to injection, two large waste receiving ponds are used to equalize the pH. The waste is then pumped through sand filters and guard filters before being placed in an elevated 10,000 gallon filtered water storage tank. Two injection pumps rated at 60 gpm each pass the effluent through polishing filters prior to injection (Ken E. Davis and Associates, October 1982).

Chronology of Operational Problems. Injection began on December 4, 1976. In August 1977, January 1978, and February 1978, the well needed to be cleaned out, acidized, and backwashed with nitrogen (Ken E. Davis and Associates, November 1982).

A series of events led to the first major workover in 1980, which was completed in July. A caliper survey performed in April indicated that as much as 40-60 percent of the steel tubing wall thickness was corroded. A pressure test of the annulus indicated possible communication between tubing and annulus. After completion of the workover to replace the original tubing, it was concluded that the tubing failure occurred 2-4 hours after an injection tubing pressure test conducted February 13, 1980. The 7-inch casing was successfully pressure tested during this workover (Ken E. Davis and Associates, November 1982). Improved daily pressure and periodic corrosion monitoring, recording, and reporting procedures were implemented as a result of this incident.

The well was shut in again when a tubing leak was discovered April 14, 1981. A caliper survey run April 18 indicated considerable reduction in tubing wall thickness. The injection tubing was replaced in May.

Suspected communication between the tubing and annulus was confirmed in May 1982 when the well was shut down and the tubing was pulled. A small leak was detected in the 7-inch casing between 4,111 and 4,112 feet, which was within an interval that was block squeezed during the original 1976 recompletion to an injection well. The leak was repaired, casing integrity was verified, and the old steel injection tubing was replaced with a new 3½-inch-diameter fiberglass reinforced plastic (FRP) tubing. The well was successfully tested and placed back in service in June 1982 (Ken E. Davis and Associates, November 1982).

On August 10, 1983, the well became plugged and would no longer receive fluids. A workover was completed in August. Screen and liner damage was noted, but liner repair was postponed. Mechanical integrity was satisfactorily demonstrated, and the well was put back in service on September 8, 1983 (Ken E. Davis and Associates, October 1983).

High, unstable annulus pressures in early March 1984 preceded increasing injection pressures that approached 1,350 psi. On March 27, the flow became so restricted the well was shut down. As a result, a workover performed to restore injectivity was completed by plugging Zone B and recompleting the well in the Miocene Sands at 4,120-4,285 feet (Ken E. Davis and Associates, July 1984).

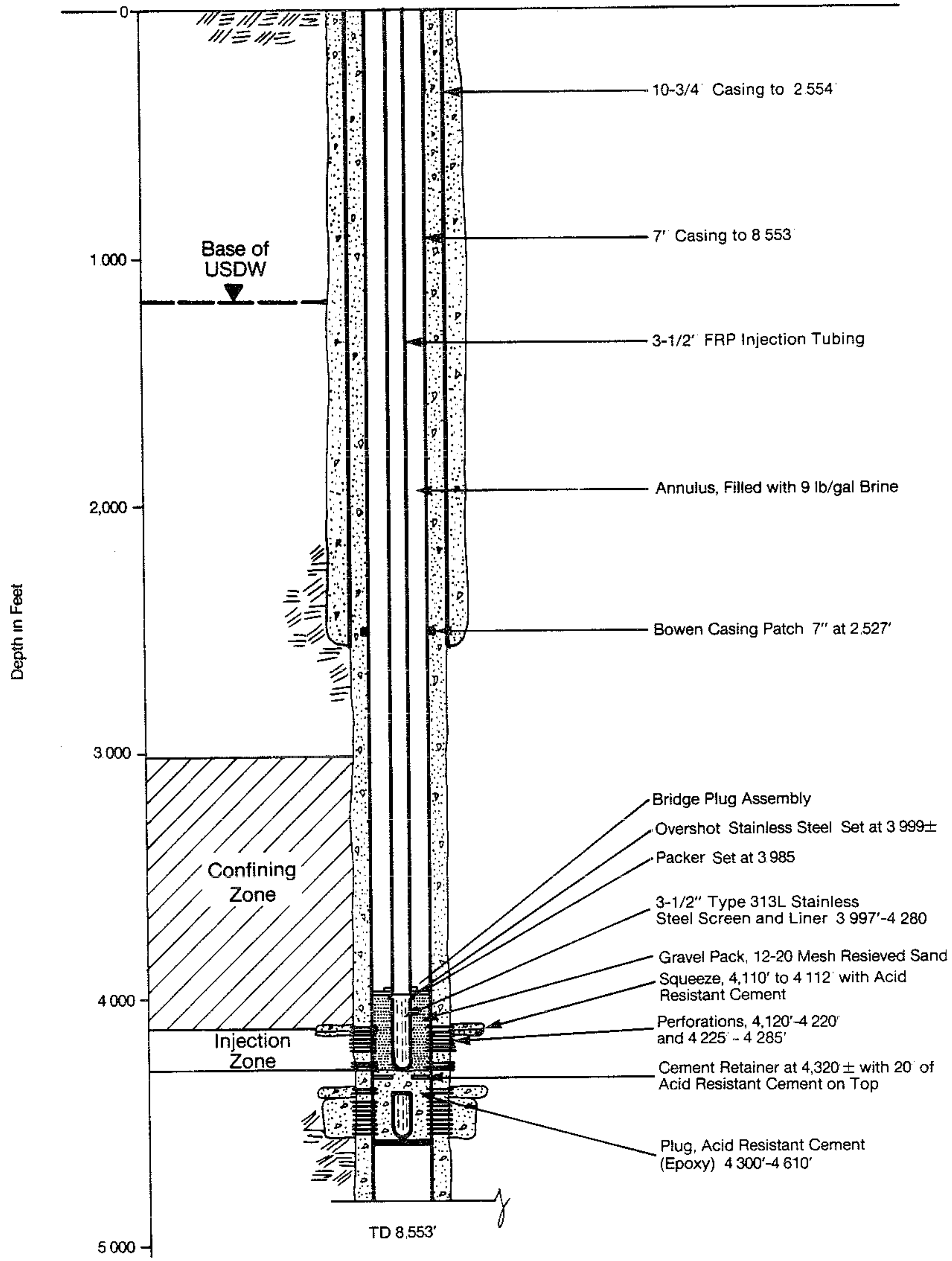
After recompletion, the original re-permit application submitted in November 1982, was updated to include the new well design and resubmitted in December 1984 (Ken E. Davis and Associates, December 1984).

When sufficient citizen concern was voiced at the January 1985 public hearing over the injection well re-permit application, the Louisiana Commissioner of Conservation issued a compliance order prior to issuing the permit (State of Louisiana, 1985). The compliance order required that CECOS demonstrate that the injection well was not responsible for any USDW contamination. Until a satisfactory demonstration was made, no injection other than that related to cleanup operations could occur.

As part of the compliance order, a Conservation Monitoring Plan was submitted and approved in April 1985, which recommended that a single monitor well be constructed approximately 500 feet south-southwest of the injection well (Ken E. Davis and Associates, April 1985). The monitor well was drilled to a total depth of 2,255 feet to evaluate the sand at 2,170 feet. This sand unit was the deepest interval that might be considered a USDW; however, total dissolved solids in this interval were determined to be greater than 13,000 mg/L. The well was plugged back to monitor the lower 50 feet of interval between 974-1,160 feet, which was determined to be the lowermost USDW (Ken E. Davis and Associates, May 1985). Samples from the formation water, drilling mud, drilling water, and drill cuttings from the target and completion intervals were analyzed for priority pollutants. Results indicated no evidence of contamination in any of the samples related to the well operations (Ken E. Davis and Associates, May 1985).

Results of the analyses were evaluated by the Louisiana Office of Conservation, EPA Region VI, and the U.S. Geological Survey. All agencies concurred that the data showed no evidence of USDW contamination from the injection well, and no evidence of any hazardous wastes in the groundwater sampled. Consequently, the compliance order was modified to allow CECOS to resume injection until a final permit decision was made. The Commissioner also recommended that CECOS close their surface pits which were used in conjunction with the injection well (State of Louisiana Compliance Order, February 1984).

In mid-1985, the Office of Conservation approved the drilling of a test oil well a distance of 1,600 feet from the CECOS well. The owners of the test oil well agreed to gather information while drilling to assist the Office of Conservation in pinpointing the contamination source at the CECOS site. During drilling, the exact depth to the USDW was determined to be at 1,160 feet, and the absence of faulting and lack of formation pressure buildup were verified. The Office of Conservation repermitted the well on October 24, 1985.



CECOS INTERNATIONAL INC.
Willow Springs Facility, Calcasieu Parish, Louisiana

WASTE DISPOSAL WELL NO. 1

D19976.P0

ROLLINS ENVIRONMENTAL SERVICES OF LOUISIANA INC. IBERVILLE, LOUISIANA

Background. Rollins Environmental Services Iberville Plant Disposal Well No. 1 is located in the Iberville Parish of southern Louisiana near Baton Rouge. The Iberville plant has one Class I hazardous waste disposal well. The facility handles a variety of offsite wastes that are either trucked or barged to the site and stored for disposal. These wastes are industrial and oilfield aqueous waste products of both hazardous and non-hazardous classification. Typical waste-streams to the well contain combinations of anodizing chemicals, caustic soda, spent caustic, neutralized cleaning solutions, alkaline cleaning solutions, potassium carbonate, alkaline degreasers, spent potassium hydroxide, caustic sulfide, naptha-gasoline firewater, thionate wash, brine, and cooling wastewaters. Prior to injection, the liquid waste is pumped from the storage tanks through a series of bag filters to remove solids (Golden Strata Services, Repermit Application, n.d.).

At the wellhead, there are continuous recording instruments for injection pressure, annulus pressures, and flow. There are no monitoring wells located at the Rollins facility to determine pressure or water quality changes (Golden Strata Services, Repermit Application, n.d.).

Clean Land, Air and Water (CLAW) purchased an abandoned oil well (Schwing S/L 1883 #1) in 1976 and recompleted it as an injection well. CLAW operated the well for approximately two years prior to its purchase by Rollins Environmental Services in July 1978. The estimated waste disposal volume is nearly 20 million gallons per year (Louisiana Office of Conservation, Rollins Correspondence File, 1976-1985).

A loss of annular pressure at the well resulted when a small casing leak occurred above the tubing packer. All wastewater was injected into the permitted injection zone, through the injection tubing (Louisiana Office of Conservation, Rollins Correspondence File, 1976-1985).

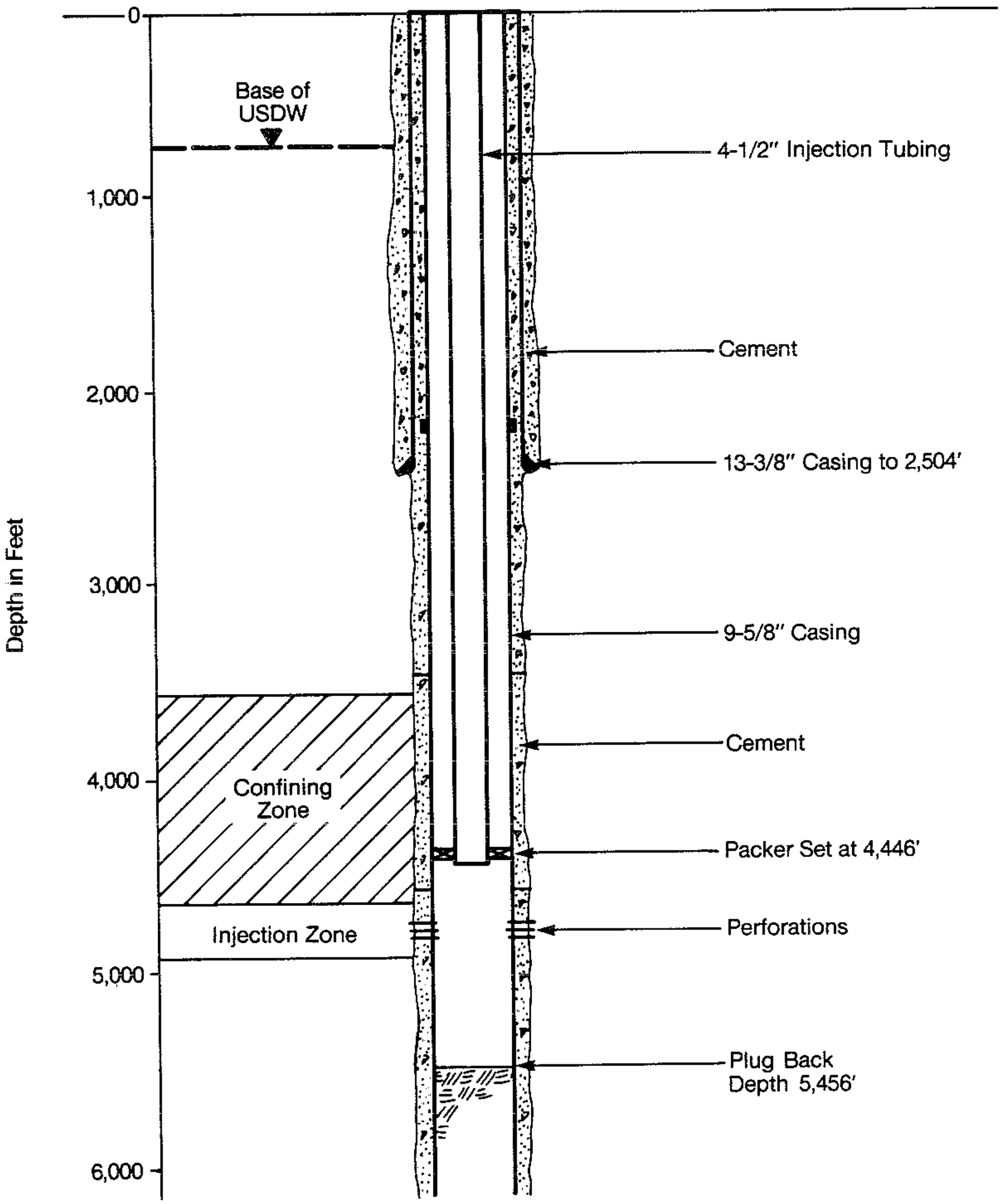
Site Description. The injection zone is located in the Miocene deltaic sand below 4,640 feet. The principal confining unit is a thick shale deposit from 3,560 to 4,640 feet. The injection zone contains formation waters with greater than 10,000 mg/L total dissolved solids (TDS). The 10,000-mg/L TDS interface occurs at approximately 750 feet within the Plaquemine aquifer. The combined shale and sand thickness of nearly 4,000 feet is adequate to prevent the vertical migration of waste into the USDW's of the Plaquemine aquifer. Structural faulting within these shallow deposits have not been reported within the area of review. However, the plastic nature of the shale units would cause the sealing of any penetrating faults (Golden Strata Services, Repermit Application, n.d.).

Well Construction Details. The injection well is constructed from three concentric steel casings. A 20-inch casing was driven to a depth of 133 feet. A 13-3/8-inch casing was set at 2,505 feet and cemented to surface. A 9-5/8-inch casing was originally set to 11,670 feet and during recompletion, 2,400 feet was pulled back for recovery. The remaining casing was cemented in place with epoxy resin cement. A 4-1/2-inch injection tubing and packer assembly was installed to a depth of 4,426 feet. The well was completed by perforating below 4,426 feet (Golden Strata Services, Repermit Application, n.d.).

Chronology of Operational Problems. The injection well was unable to hold annular pressure in August 1978. The pressure loss was caused by a hole in the injection casing between 2,405 and 2,424 feet. At this depth, the formation water contains greater than 10,000 mg/L TDS. This leak posed no threat to human health or a USDW. No wastewater was able to escape through the leak since the annulus contained only inhibited brine isolated by a packer. The casing was repaired during a workover and the well was put back into service (Louisiana Office of Conservation, Rollins Correspondence File, 1976-1985).

Waste spills at the receiving facility occurred in October 1977 and waste fluids were also noted around storage tanks during an inspection in August 1980. As a result of the improper handling of the waste materials, the facility was shut down for a short period to improve and clean up the surface facilities. The well was put back into service and is now in operation (Louisiana Office of Conservation, Rollins Correspondence File, 1976-1985).

In December 1984, the injection pressure increased gradually as sand entered the perforations and caused plugging. The well was reworked by nitrogen jetting and installing a new packer. Subsequently, the well was put back into service and operated at its normal injection pressures.



ROLLINS ENVIRONMENTAL SERVICES OF LOUISIANA, INC.
Iberville Parish, Louisiana

INJECTION WELL (1985)

UIPC

TENNECO OIL COMPANY
CHALMETTE, LOUISIANA

Background. Tenneco Oil Company operates a refinery in Chalmette, St. Bernard Parish, on the Mississippi River in southeast Louisiana. Injection wells have been used at the site since the early 1960's to dispose of onsite hazardous wastes.

A complex waste stream is produced at this refinery during the production of gas, LPG, fuel oils, sulfur, coke and aromatic hydrocarbons. Production of these materials yields the typical refinery "sour water." Water that has been contaminated, typically with phenols, sulfides, ammonia, organic carbon, and lower concentrations of other contaminants, during its use in various refinery processing units, is known as sour water. Small quantities of spent caustic and spent water-soluble solvents are contained in sour water. A total of six injection wells have been used at the plant. Well Nos. 1 and 2 operated from late 1960 to February 1981 and from early 1963 to August 1981 respectively. Well Nos. 3 and 4 were constructed in January 1981 as replacement wells, while Well Nos. 5 and 6 began injection in November and December 1984, respectively.

Compatibility tests were performed on the formation and waste fluids. A potential incompatibility between the two fluids resulted in injection of a buffer solution prior to waste fluid injection. Injection pressures range from 250-325 pounds per square inch (psi) at an injection rate of 300 gallons per minute (gpm), depending on which injection interval is being used.

Injection Well Nos. 1 and 2 have had suspected leaks to an underground source of drinking water. Both wells have been permanently plugged and abandoned. The remaining wells are currently operational.

Site Description. Five sand aquifers found beneath the Tenneco site are USDW's: the "shallow" or "100-foot" sand, the "200-foot" sand, the "400-foot" sand, the "700-foot" sand, and the "1,200-foot" sand. The "700-foot" sand contains slightly brackish water with a total dissolved solids (TDS) of 2,000 mg/L. The "700-foot" sand is a major water source to the north and west of the site. The depth to the USDW interface occurs within the "1,200-foot" sand at a depth of 1,005 feet below land surface.

The current injection zone at the site is into the 2,400-foot zone and 2,700-foot zone of the undifferentiated Pliocene sands. Well Nos. 1 and 2 injected into the 1,900-foot Pliocene sands. Overlying shale beds provide confinement (Underground Resources Management, Inc., 1983).

Well Construction Details. Well No. 1, originally Bay Petroleum Disposal Well No. 1, was constructed with 87 feet of 10-3/4-inch, 40-lb/ft surface casing, and 2,016 feet of 7-inch casing perforated between 1,922 and 1,964 feet. The total depth was 2,074 feet. State records do not contain an original well history, but it is assumed the well was completed with a tubing but without a packer.

Well No. 2 was also completed without a packer. An 11-3/4-inch casing was driven to 103 feet. A 7-inch casing of variable weight was originally set to 2,209 feet, but was plugged back to 2,163 feet, and perforated between 1,920 and 1,950 feet. A 4-1/2-inch, 9-1/2-lb/ft backwash tubing was set to 1,923 feet, and a packer was installed at 1,835 feet.

Well No. 3 was constructed in 1981 to current UIC standards. A 20-inch conductor casing was set to 141 feet, followed by a 13-3/8-inch surface casing set to 1,320 feet. An 8-5/8-inch protection casing was set to 2,850 feet, and perforated in the 2,686- to 2,760-foot interval. A 5-1/2-inch injection tubing was set with a packer at 2,585 feet, with the annulus between the tubing and 8-5/8-inch casing filled with brine. Total well depth was 3,000 feet, with a plugged back total depth of 2,843 feet (Subsurface Disposal Corp., 1981).

Well No. 4 originally included an open hole gravel pack completion with an injection interval from 2,720 to 2,750 feet. However, in September 1984, the well was recompleted into a higher injection zone with perforations in the 2,425- to 2,500-foot interval. The existing 5-1/2-inch liner was reinstalled and a new packer was set at 2,343 feet. A 20-inch conductor casing to 214 feet, a 13-3/8-inch casing to 1,375 feet, the 8-5/8-inch protection casing (with the new perforated intervals) and a 2-3/8-inch backwash tube completed the well (Golden Strata Services, 1984d).

Well Nos. 5 and 6 were designed and constructed with the same casing sizes and approximate casing setting depths and perforation intervals as Well Nos. 3 and 4 (Golden Strata Services, 1984a, 1984b). They passed mechanical integrity tests in September and October 1984, and were placed in service at the end of 1984. Well Nos. 5 and 6 have operated without incident since.

Chronology of Operational Problems. Well Nos. 1 and 2 were not designed with packers, which resulted in the state agency requiring a demonstration of mechanical integrity in 1979. No leaks were detected during this test, but in June 1980, Well No. 1 was immediately shut-in when injected fluids appeared at the ground surface near the well. A leak in the long-string casing was suspected. After pressure testing Well No. 1 in February 1981, leaks were located at depths between 140 and 147 feet and 160 and 212 feet below land surface. No leaks in the casing were detected below 212 feet. The well was abandoned in February 1981 by setting cement plugs between 250 and 1,976 feet and between 30 and 250 feet.

The Louisiana Office of Conservation required that a groundwater contamination investigation be conducted to determine the extent to which contamination might have occurred. Both the "100-foot" sand and the "700-foot" sand were suspected of being contaminated. The Office of Conservation approved the plan in October 1981, and monitor well installation began in November 1981. Contamination in the "100-foot" sand was readily confirmed with a radial extent of less than 100 feet, which is still within Tenneco's property boundaries. A groundwater recovery system was installed, which, by December 1984, had recovered over 5.2 million gallons of contaminated water (Underground Resources Management, 1985). The concentration of phenols in these sands has been reduced from an initial value of 1,600 ppm since recovery operations began in 1982 (Tenneco Oil Company, December 1985).

Possible contamination of the "700-foot" sand was studied from 1981-1984 by drilling two monitoring wells into that zone and using an existing fire-water supply well completed in that sand. None of these wells detected any contamination, and the study concluded that leakage from Well No. 1 never affected the "700-foot" sand aquifer (Underground Resource Management, 1985). The Office of Conservation is requiring one additional year of monitoring the "700-foot" sand as a precautionary measure.

Monitor wells were also installed in the "200-foot" and "250-foot" sands. The state agency attributed the small values of indicator parameters found in these sands to cross-contamination while drilling the monitor wells. The state is not requiring continued monitoring of these sands.

Operating permits were obtained for Well Nos. 3 and 4 in August 1981, and Well No. 2 was taken out of service. Well No. 2 was not plugged then because it was considered for use in the Well No. 1 contamination investigation. While testing in preparation for plugging and abandoning Well No. 2 in January 1984, it was discovered that a casing leak had occurred at a depth of 188 feet below the casing head flange. A radioactive tracer survey indicated that most of the radioactive material went into the formation at the depth of the leak, but some downward migration also seemed to be occurring. Further testing demonstrated that the 300-foot and 1,545-foot sands were not contaminated.

A groundwater investigation conducted after plugging the leak concluded that only the depth interval from 180 to 200 feet had been contaminated, and the contamination was confined to the immediate vicinity of the wellbore.

The well was plugged in February 1984 after pulling 1,935 feet of the 4-1/2-inch tubing. The 7-inch casing was filled with cement from 2,048 feet to 3 feet below land surface (Louisiana Plug and Abandon Report, 1984; Golden Strata Services, Inc., 1984c).

In March 1982, Tenneco had difficulty maintaining annular pressures over 250 pounds per square inch gauge (psig) in Well No. 3, which resulted in a workover in April 1982 to repair an annulus leak. The well was repaired by acidizing and installing a new packer at 2,590 feet. The well operated without further incident until February 1985.

In February 1985, Well No. 3 experienced declining annular pressures which led to mechanical integrity testing. The mechanical integrity test indicated that the 8-5/8-inch protection casing had mechanical integrity, but the packer had failed. A new packer was set at 2,585 feet, and the well was cleaned out and returned to service. The incident was attributed to extremely cold temperatures on January 21 and 22 that caused the recording instruments and gauges to freeze up. The cold effluent apparently caused the packer to unseat (State of Louisiana files, 1985).

Well No. 4 has had two incidents of remedial action since injection began in 1981. Work permits were issued on April 6, 1982, to perform a workover and to squeeze cement a leak at 1,360 to 1,365 feet. The leak was successfully cemented and pressure tested. The leak was believed to have developed during the workover (State of Louisiana files, 1982). In September 1984, the well was plugged back and recompleted into a new injection zone, with a perforated interval between approximately 2,425-2,500 feet.

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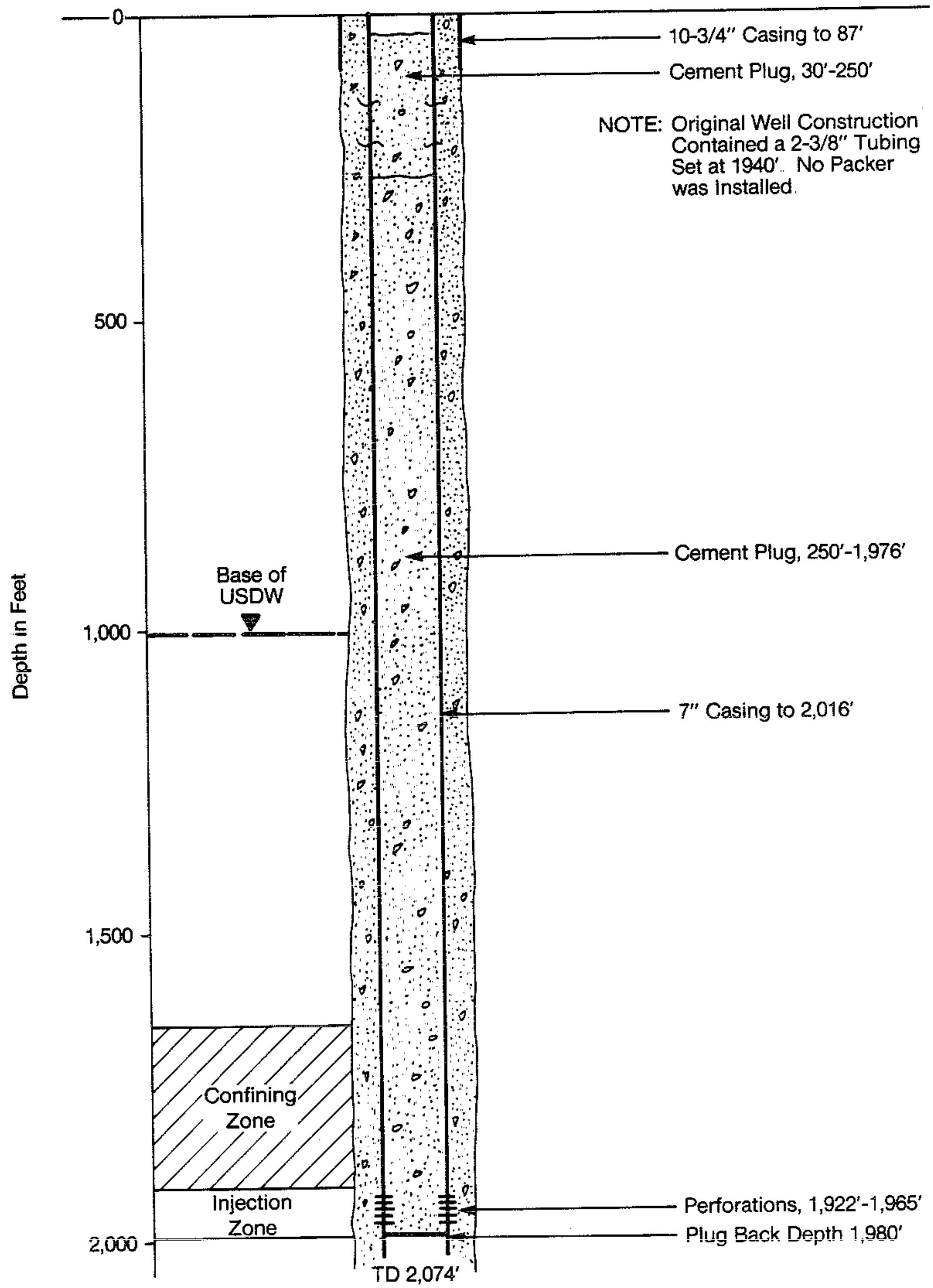
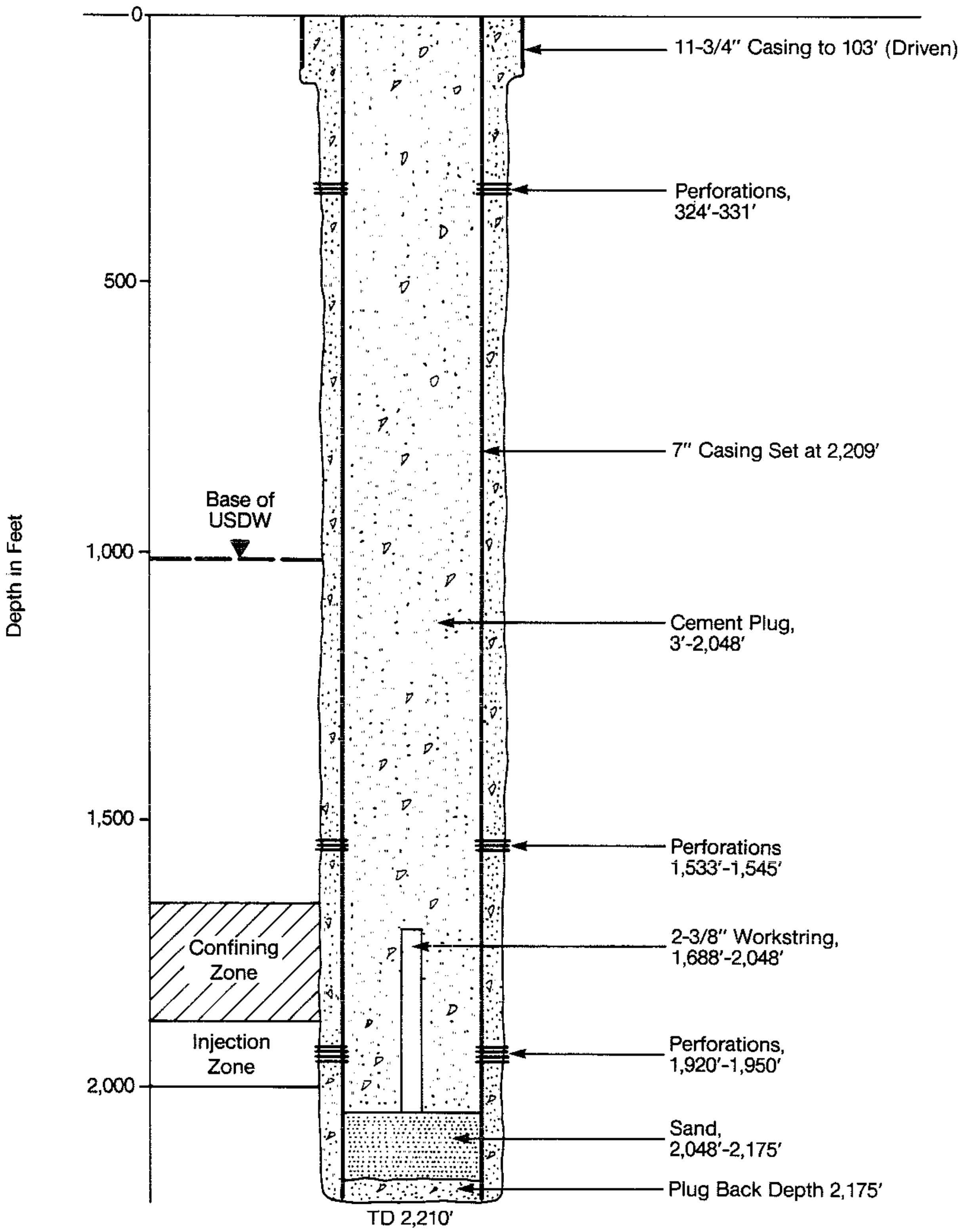


TENNECO OIL COMPANY
Chalmette Refinery, St. Bernard Parish, Louisiana

DISPOSAL WELL NO. 1 (Plugged February 1981)

UIPC

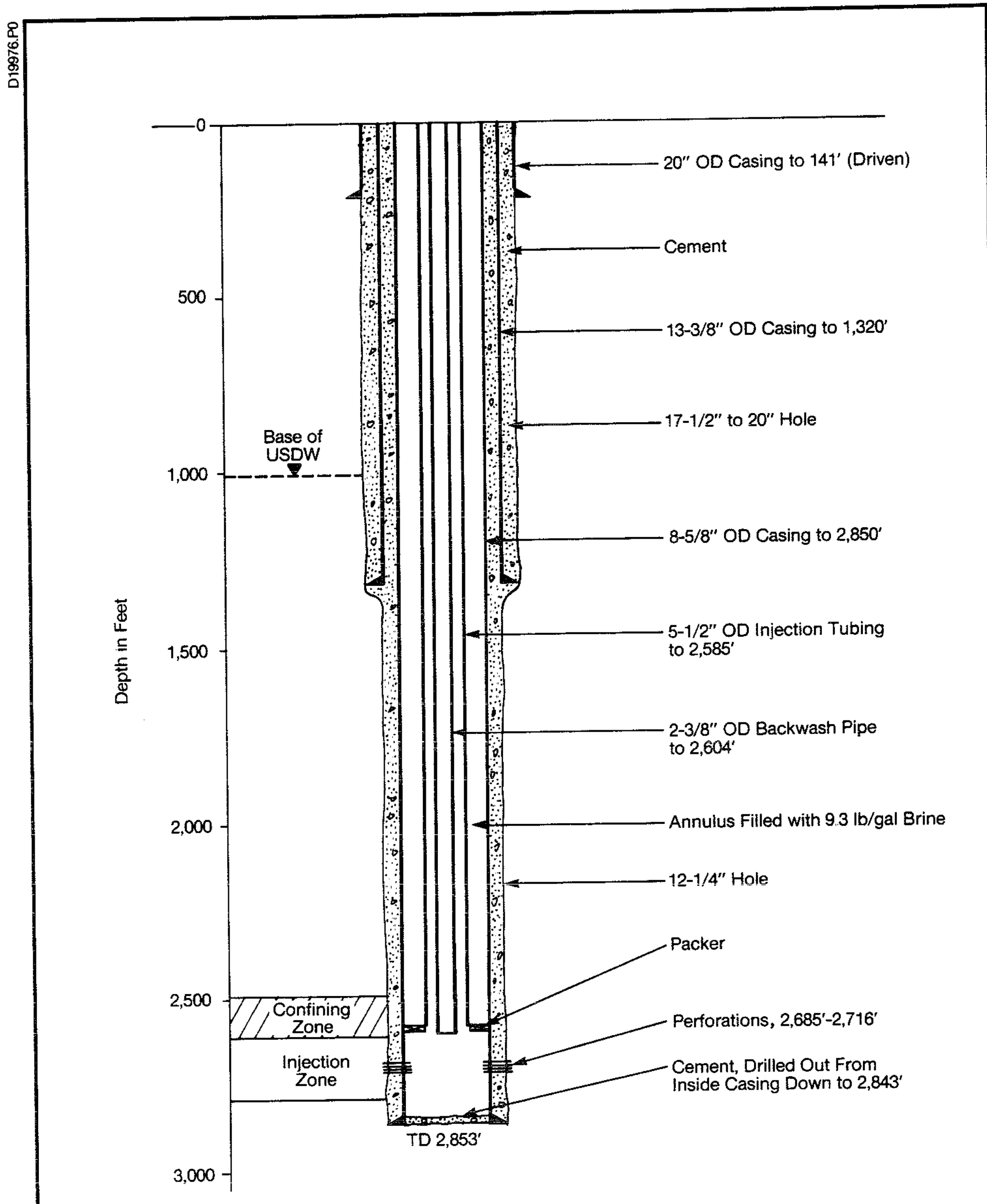
D19976.P0



TENNECO OIL COMPANY
Chalmette Refinery, St. Bernard Parish, Louisiana

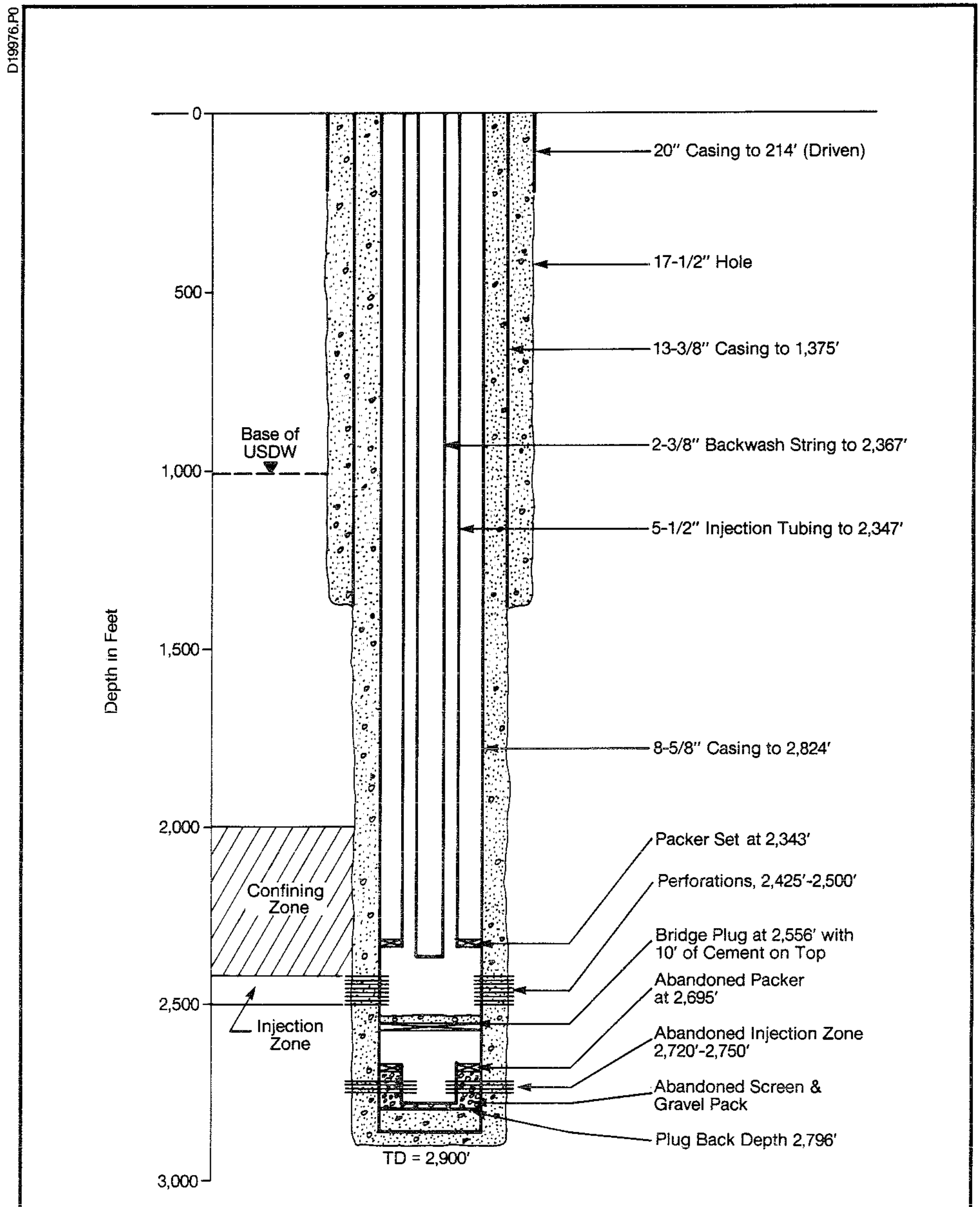
DISPOSAL WELL NO. 2 (Plugged February 1984)

UIPC



TENNECO OIL COMPANY
Chalmette Refinery, St. Bernard Parish, Louisiana

DISPOSAL WELL NO. 3



TENNECO OIL COMPANY
Chalmette Refinery, St. Bernard Parish, Louisiana

DISPOSAL WELL NO. 4

UIPC

DOW CHEMICAL COMPANY
MIDLAND, MICHIGAN

Dow Chemical Company, in Midland County, Michigan, operates 36 brine injection wells. According to EPA, Region V, none of the wells are permitted as Class I industrial wells. The wells have all been reclassified as Class V injection wells. The reclassification of the wells was provided under 40 CFR Part 146.05(e)(14) which states (Lovett, 1985):

> Class V injection wells include wells used to inject spent brine into the same formation from which it was withdrawn after extraction of halogens or their salts.

Since the Dow injection wells are not considered by the EPA as Class I industrial wells, no assessment of the operational histories of these wells will be presented.

HERCOFINA
WILMINGTON, NORTH CAROLINA

Background. The Hercofina (formerly Hercules Incorporated) plant is located about 4 miles northwest of Wilmington, North Carolina. The plant manufactures dimethyl terephtalate (DMT) which is used in the production of polyester fibers. The waste stream is principally an organic acid wastewater containing acetic, formic, and phthalic acids.

From May 1968 until December 1972, wastewater from the plant was injected into a Cretaceous-age clastic aquifer underlying the site at a depth of 800 to 1,050 feet.

The facilities included two injection wells, ten injection zone observation wells, three 700-foot zone observation wells, and a 300-foot zone (USDW) observation well. Injection into two of the injection zone observation wells was permitted on an emergency basis.

During the injection operation, injection pressures and flow rates for each injection well, as well as pressure, temperature, and chemical quality data for each observation well were reported monthly to the North Carolina Department of Environmental Management (NCDEM). Post-injection monitoring of the facility continues to the present.

The wastewater production rate when the injection wells were in use was 300,000 gallons per day. The waste stream was treated with lime to a pH of 4.0 and filtered prior to injection.

About one year after injection began, the injection pressure in the primary injection well exceeded the permitted pressure of 150 pounds per square inch (psi), and the NCDEM permitted injection into two injection zone observation wells on an emergency basis. Pressures continued to rise, and attempts to rehabilitate the injection well were unsuccessful. In 1970, a second injection well was drilled as a temporary facility until surface treatment facilities were operational. Injection pressure in this well soon exceeded the permitted limit. Leakage of waste into an unpermitted zone was detected in February 1971 about 2-1/2 years after injection began.

Because of these problems, the NCDEM notified Hercofina that Injection Permit No. 1395 would not be renewed when it expired on July 1, 1973 (Shiver, 1984). Injection at the facility was terminated by the owner in December 1972. Since December 1972, the DMT wastewater has been treated in a conventional wastewater treatment plant and discharged to surface water and to a land spreading site.

The State of North Carolina no longer permits disposal by deep well injection.

Site Description. The Hercofina plant is located in the Atlantic Coastal Plain physiographic province. The site is on a peninsula between the Cape Fear and Northeast Cape Fear Rivers. The surface is nearly flat with a typical "dune and swale" topography.

At the site, 50 to 75 feet of surficial sand, shell and sandy clay, probably of Pleistocene age, overlie Cretaceous strata that extend to a depth of several thousand feet.

The only potable water in the vicinity is obtained from the surficial sands. The Cretaceous strata, which include, in ascending order, the Tuscaloosa, Black Creek, and Pee Dee formations (Shiver, 1984), contain only salty to brackish water.

The Cretaceous strata are comprised of alternating beds of clay, silty sand, sand, and limestone. Clay is the predominant material, and these strata have a low overall permeability. The sand units are relatively permeable, but thin. The individual sands are locally designated as "zones", based on their depth of occurrence. In the Wilmington area, the zones present are the 300- to 400-foot zone, the 500-foot zone, the 700-foot zone, and the 1,000-foot zone.

The 1,000-foot zone is the injection zone, and corresponds to the Tuscaloosa Formation. The 500- and 700-foot zones are in the Black Creek Formation, and contain water with more than 10,000 mg/L total dissolved solids (TDS). The 300-foot zone corresponds to the upper part of the Pee Dee Formation and contains water with approximately 3,000 mg/L TDS.

The principal confining zone is the 100 to 150 feet of clay and clayey sand in the lower part of the Black Creek Formation. Interbeds of clay within the Tuscaloosa also function as confining beds between individual permeable zones.

Well Construction Details. The initial well system consisted of one injection well (I-6) and four observation wells (OB-1, OB-2, OB-4, and OB-5). All of the wells were constructed with steel surface casings, fiberglass inner casings and stainless steel screens.

Injection Well I-6 had 85 feet of 26-inch steel surface casing set through the Pleistocene-age sands and cemented with regular Portland cement. An 18-inch steel intermediate casing was set at 850 feet in the top of the Tuscaloosa Formation. It was cemented from 850 feet to the surface