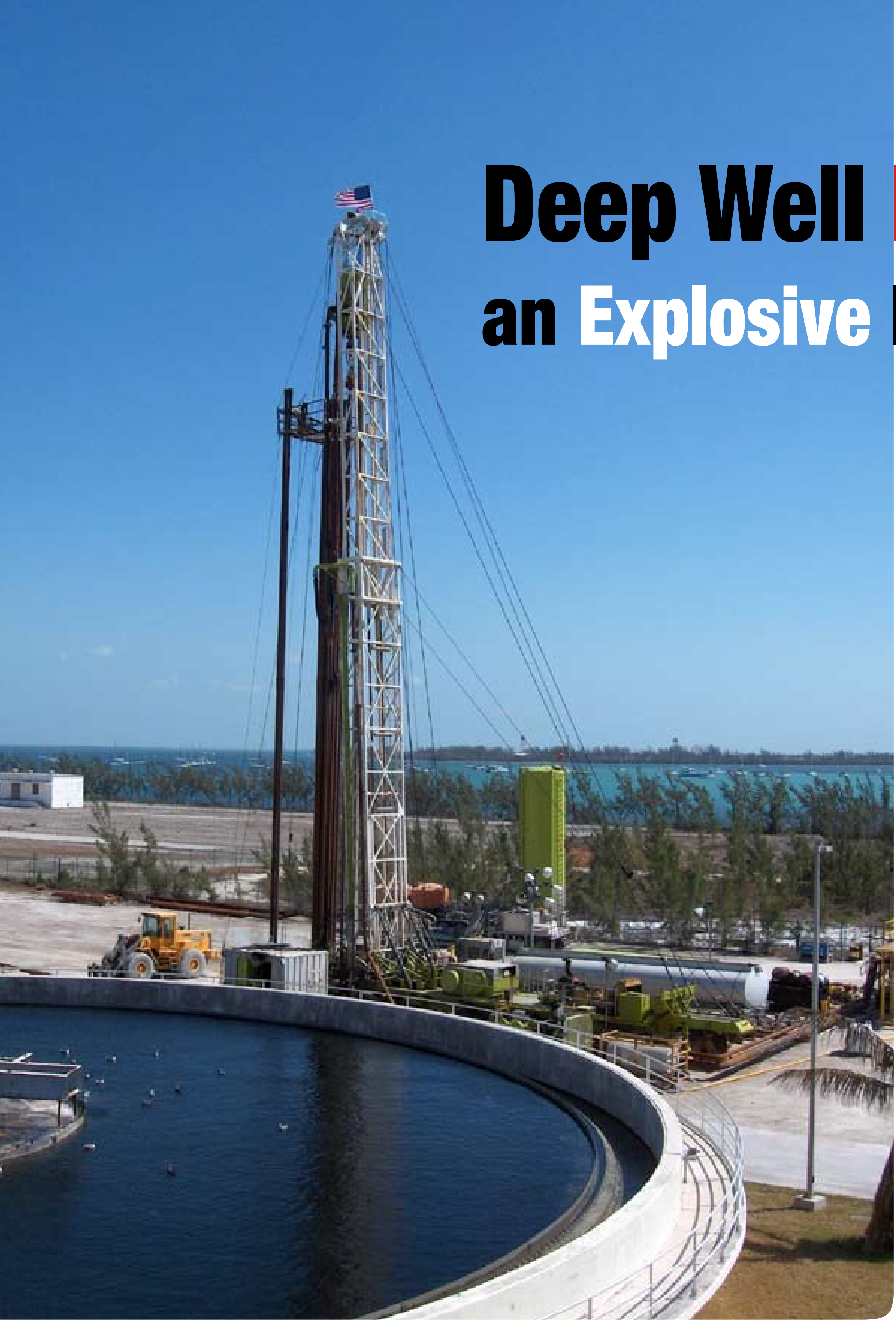
Deep Well Injection
an Explosive Issue



CHEJ

Center for Health, Environment & Justice
P.O. Box 6806, Falls Church, VA 22040-6806
703-237-2249 chej@chej.org www.chej.org

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Heather Simpson
Stephen Lester

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P.O. Box 6806 Falls Church, VA 22040-6806 703-237-2249 chej@chej.org www.chej.org

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P.O. Box 6806 • Falls Church, VA 22040 • Phone: 703.237.2249 • Fax: 703.237.8389 • www.chej.org

Mentoring a Movement

Empowering People

Preventing Harm

About the Center for Health, Environment & Justice

CHEJ mentors the movement to build healthier communities by empowering people to prevent the harm caused by chemical and toxic threats. We accomplish our work by connecting local community groups to national initiatives and corporate campaigns. CHEJ works with communities to empower groups by providing the tools, strategic vision, and encouragement they need to advocate for human health and the prevention of harm.

Following her successful effort to prevent further harm for families living in contaminated Love Canal, Lois Gibbs founded CHEJ in 1981 to continue the journey. To date, CHEJ has assisted over 10,000 groups nationwide. Details on CHEJ's efforts to help families and communities prevent harm can be found on www.chej.org.

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Chapter 1

Introduction

Nearly 40 years after its explosion in popularity, deep well injection of hazardous wastes remains the most used waste disposal method in the United States. Though "out of sight," with much of the general public unaware of its existence, a number of communities have been deeply affected by this technology. Discussion of deep wells has waned in the last two decades, partly due to better regulations and fewer failures, but many key issues remain unresolved. While generally endorsed by government and industry as a safe and inexpensive waste disposal method, there remain uncertainties about long-term environmental impact of injecting liquid waste deep into the earth, as well as questions surrounding the effectiveness of the regulatory system governing the technology. How this disposal method will affect the sustainability and health of the public remains to be seen.

In this particular guide, we focus primarily on Class I wells, which handle hazardous, nonhazardous, and municipal liquid waste and wastewater. When speaking about any other class of well, it is specified as such. Some of the regulations are similar for different types of deep wells, but differences do exist. Each type of well varies in abundance, associated problems, failure rates, etc. For example, while few reported Class I wells have caused contamination of a drinking water source in recent years; many other classes (most notably there are many documented failures of Class II wells) continue to pollute potable aquifers (TCEQ 2005). Please be aware that differences do exist even between wells of the same class, so each well should be treated as unique.

In the following chapters, you will find information on the basics of deep wells, historical and current trends, the problems associated with deep well injection, case histories of communities who have dealt with deep wells, a comprehensive list of well failures, a detailed discussion of the applicable regulations and their inadequacies, as well as a list of arguments that can be used by groups involved with a deep well injection issue. Please refer to the Glossary at the end of the report for explanations of terminology and to the Reference section for further information.

Chapter 2

What is a Deep Well?

Deep injection wells are open-ended shafts which pump wastes 1,700-12,000 feet or more below the surface of the earth, depending on the region of the United States (USEPA 2001). The rock formations into which the wastes are injected are usually either sandstone or limestone/dolomite. These formations contain air spaces (pores) which contain liquids, gases or both. The idea is to pump wastes into these pores without fracturing the rock by maintaining just enough pressure to replace the existing fluids and relying on the existing rock formations to contain the wastes. Class I wells must be at least ¼ mile below any aquifer with drinkable water and in general, injection wells cannot be sited in areas with earthquakes, or in areas where the geology is not suitable for containment of wastes (USEPA 2001).

The Environmental Protection Agency (EPA) Underground Injection Program (UIC) program divides injection wells into five categories (USEPA 2006):

Class I wells are technologically sophisticated and inject hazardous and non-hazardous wastes below the lowermost underground source of drinking water (USDW). Injection occurs into deep, isolated rock formations that are separated from the lowermost USDW by layers of impermeable clay and rock.

Class II wells are oil and gas production brine disposal and other related wells. Operators of these wells inject fluids associated with oil and natural gas production. Most of the injected fluid is brine that is produced when oil and gas are extracted from the earth (about 10 barrels of brine for every barrel of oil).

Class III wells are wells that inject superheated steam, water, or other fluids into formations in order to extract minerals. The injected fluids are then pumped to the surface and the minerals in solution are extracted. Generally, the fluid is treated and re-injected into the same formation. More than 50 percent of the salt and 80 percent of the uranium extraction in the U.S. is produced this way.

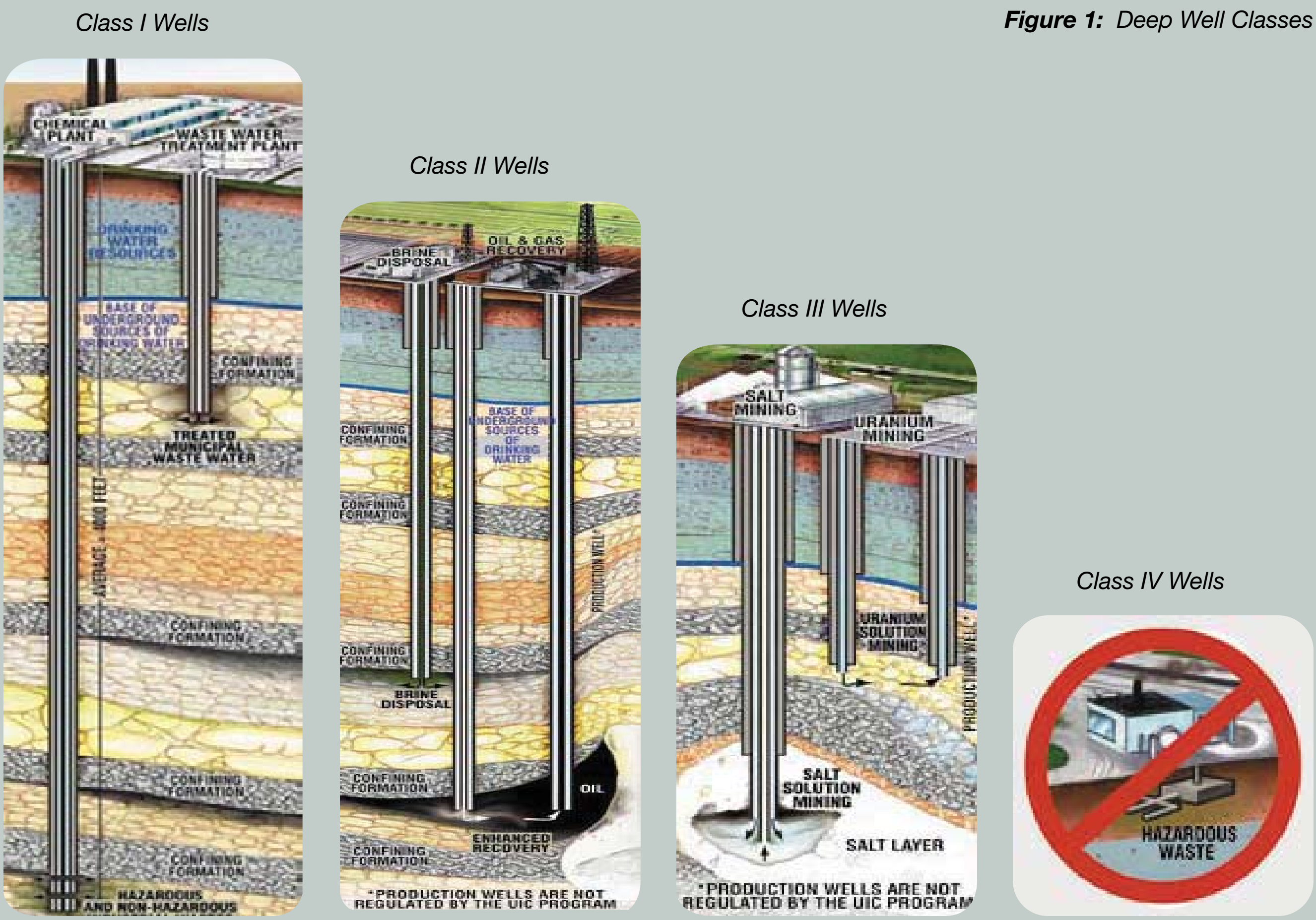
Class IV wells inject hazardous or radioactive wastes into or above underground sources of drinking water. These wells are banned under the UIC program because they directly threaten public health.

Class V wells are injection wells that are not included in the other classes. Some Class V wells are technologically advanced waste water disposal systems used by industry, but most are "low-tech" wells, such as septic systems and cesspools. Generally, they are shallow and depend upon gravity to drain or "inject" liquid waste into the ground above or into underground sources of drinking water. Their simple construction provides little or no protection against possible ground water contamination, so it is important to control what goes into them. These wells are not discussed in this guide because they are generally shallow wells.

Even with regulatory construction requirements, there are no standard criteria for constructing a deep well. Each well must be designed to address local geological conditions. A typical injection well is depicted in Figure 2. A well, 10-12" wide, is constructed from the outside in, by extending a series of three layers of concentric pipes, or casings. The casings consist of corrosion-resistant materials such as steel alloy or fiberglass. Between the outermost casing, also known as the surface casing, and the middle casing, or long string casing, is a layer of chemically resistant cement or epoxy resin, binding the casings together and creating a barrier for vertical waste escape (USEPA 2001).

The inner casing, also known as the injection tube, extends slightly further than the other casings, through a lower seal (the packer) to the point of discharge into the injection zone. Between the injection tube and the middle, long string casing is a space known as the annulus, which is filled with protective, noncorrosive fluid. The fluid is pressurized and monitored to determine if leakage has occurred, which is indicated by a loss in annulus pressure.

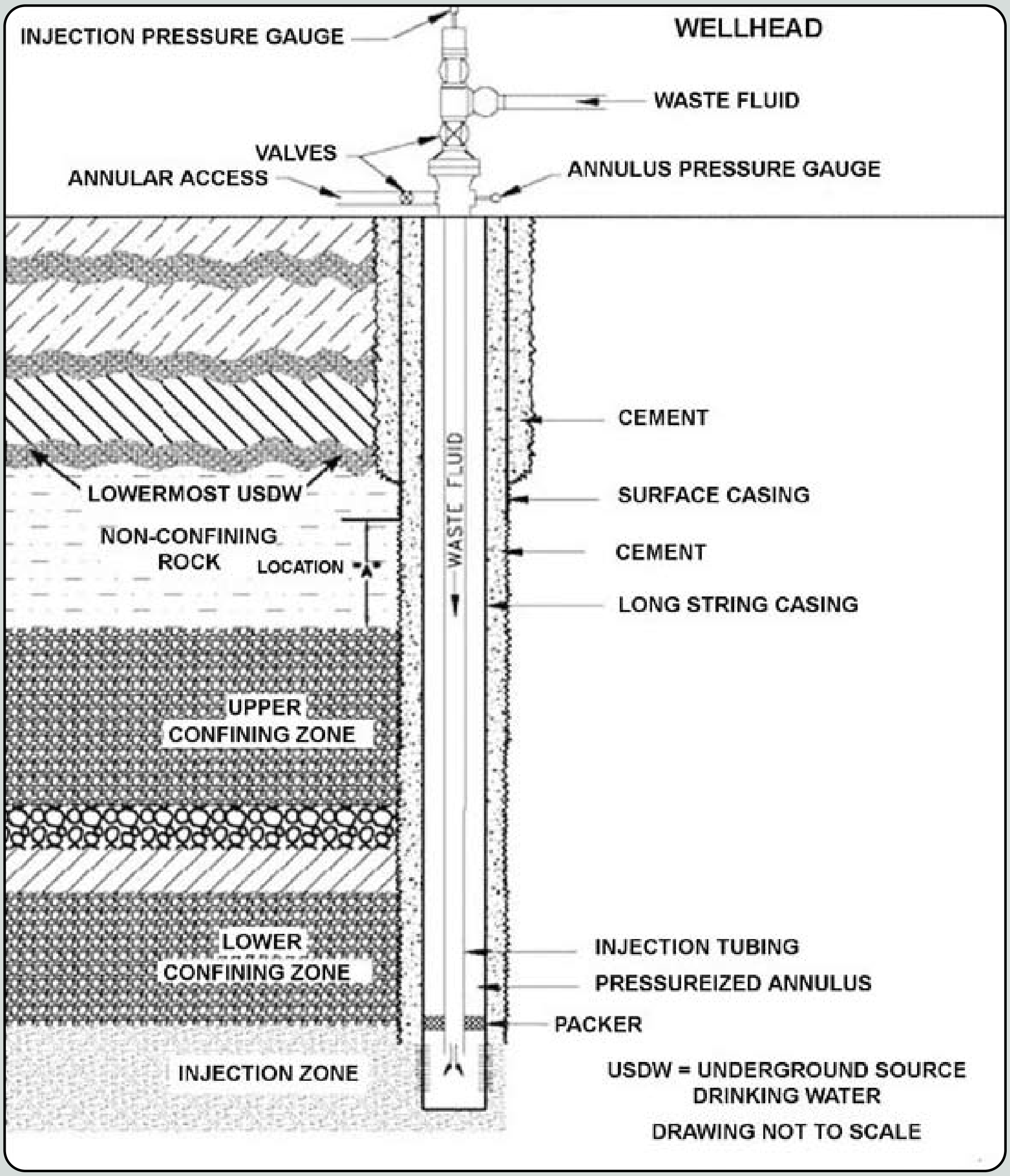
Figure 1: *Deep Well Classes*



In newly constructed wells, the annulus pressure is greater than the pressure in the injection tubing. This way, if a leak occurs, the liquid in the annulus enters the inner tubing rather than the other way around, which happened with many wells in the past. This additional pressure barrier to prevent waste escape is required for Class I hazardous waste wells.

In the past, many deep wells were made from old oil and gas wells and were not constructed with these considerations in mind. Some were nothing more than a hole in the ground without any casings or monitoring gauges at all! These wells can pose a problem if they are located in the area where a new well is to be built. Regulations require the identification and plugging of any such wells prior to new construction (see Chapter 7). The only other type class of well that may not have any casing or monitoring equipment are Class V wells, which as mentioned, are mostly shallow disposal wells.

Figure 2: *A Deep Injection Well*



Chapter 3

Background History

The underground injection of liquid wastes began in the U.S. in the 1930s. Initially, petroleum companies used them to dispose of brine (salt water) wastes from their drilling operations. Later, brine injection was used to increase yields by forcing remaining oil or gas out of the producing formation. This technique is called secondary hydrocarbon recovery, a method which continues to be employed today with Class II wells. The petroleum industry remains one of the largest users of underground injection wells for both enhanced recovery and disposal of brine wastes (USEPA 2006a).

The first industrial disposal well was drilled in Texas by the DuPont company and went into operation in the early 1950s (Clark 2005). The waste disposal method gained popularity in the 1960s and 1970s, with large increases between the 60s and 70s and then again between the 70s and 80s (Clark 2005). The users of these wells shifted to the chemical, steel and pharmaceutical industries, who found that this disposal method was one of the most economical.

Deep well disposal remains one of the least expensive disposal methods for high volumes of hazardous waste, particularly after the 1984 land disposal restrictions to the Resource Conservation and Recovery Act increased the cost of other methods by requiring pre-treatment of hazardous waste disposed on land (see Chapter 7 for more regulatory information). However, the costs of deep injection are dependent on the depth of the well, the types of wastes, the site properties and so forth (Herbert 1996).

In addition to being relatively cost-effective, deep well injection is generally accepted and sometimes endorsed by the government and the USEPA. The EPA believes the regulations for injection wells are appropriate and result in redundant safety systems, rendering the technology safe and effective (USEPA 2001).

Despite its popularity as a waste disposal method, deep injection remains an "out of sight" technology. As it has been historically, most disposal wells are located in a small number of states, often those involved in oil and gas exploration. In 1985, there were about 585 active disposal wells and 252 inactive wells. One hundred and ninety-five of these wells managed hazardous waste exclusively and were concentrated in the states of Louisiana and Texas (USEPA 1985).

Chapter 4

Current Trends in Deep Well Injection

The EPA maintains a biennial reporting system (BRS) as one method to track quantities of hazardous waste regulated by the Resource Conservation and Recovery Act (see Chapter 8 for more information about the RCRA). Based on the 2005 BRS report, deep well/underground injection still remains the most used waste management method in the United States, over methods such as aqueous organic treatment, incineration, land treatment, and so on. Deep well injection was used to dispose of about 22 million tons of waste, representing 49.7% of the total quantity of hazardous waste managed, although this waste is spread over far fewer facilities than other methods. Deep injection wells represent 3% of facilities, while solvents recovery represents 31.8% of facilities (USEPA 2005). Compared to the past, the amount of waste managed has decreased slightly, but deep well injection has a larger percentage of the hazardous waste stream. According to the 1995 BRS report, for example, about 24.6 million tons of waste was injected into deep wells, but this represented only about 12% of the total amount of waste managed by RCRA regulated facilities (NET 1998). Keep in mind that the amount of waste injected into deep wells often includes a lot of water, so this is part of the reason why injection represents so much more, quantity-wise, of waste managed than other non-aqueous disposal methods. However, in the past other aqueous treatments handled a larger percentage of total waste managed than deep wells and this is no longer the case (NET 1998, USEPA 2005).

According to the EPA, Class I wells are primarily used by the petroleum refining, metal production, and chemical production industries, with some usage by pharmaceutical, commercial disposal, municipal disposal, and food production industries. The wastes associated with deep wells are manufacturing process water, mining wastes, municipal effluent, and cooling tower and air scrubber blow-down (USEPA 2001, 2006b).

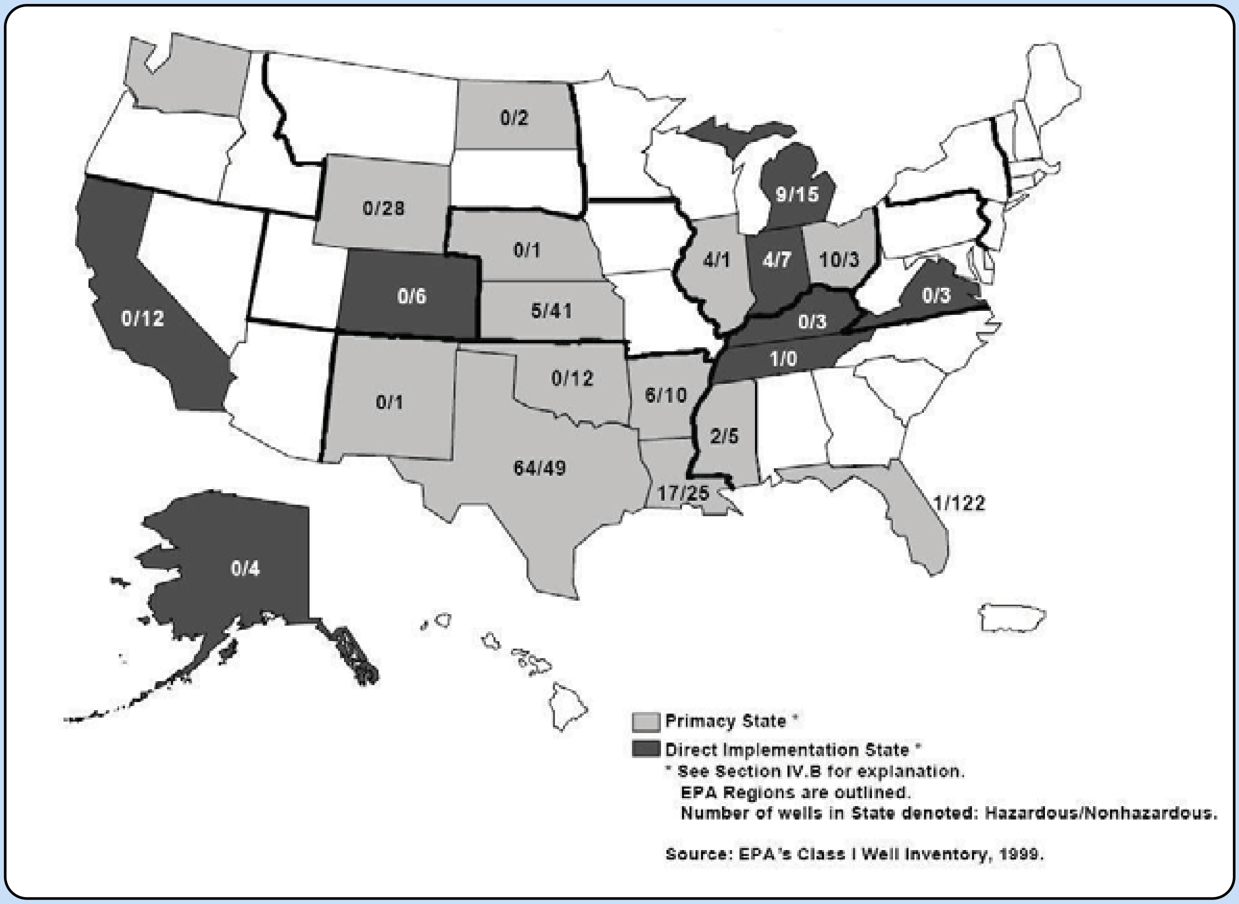
In the United States, there are 272 active Class I injection facilities, which operate roughly 529 injection wells. The wells are present in 19 states, but most are located in the regions of the Gulf Coast, the Great Lakes, and Florida. Of the Class I well facilities, 51 inject hazardous waste, representing 163 individual wells. Most of the hazardous wells are still located in Texas and Louisiana. The most recent EPA data states that there are eleven Class I commercial hazardous waste injection facilities, which can accept waste generated offsite and/or out of state (USEPA 2006b). One active commercial site is in Ohio, one is in Oklahoma USACE 2005); ten others are located along the Gulf Coast. However, this information may have changed; in fact, one of the Gulf Coast facilities (in Plaquemine, Louisiana) has closed since EPA's last update (Clean Harbors 2006). The 366 non-hazardous wells are most concentrated in Texas and Florida (USEPA 2006b).

The most recent state-by-state breakdown for wells dates from the 1999 EPA inventory (Figure 3 which depicts both hazardous/nonhazardous wells for each state). The numbers vary slightly from the totals now, as there have been a number of new wells installed in the past eight years.

Deep Injection of CO_2

One of the "hottest" topics in deep well disposal today is the disposal of carbon dioxide (CO_2) by deep well injection, also known as geologic sequestration. The idea is to capture CO_2 produced by power plants and other industries and inject it in much the same way as liquid waste is currently injected. This method would enable the removal of some carbon from the atmosphere and mitigate human impact on global temperatures. The CO_2 would be injected into saline aquifers, containing only water unsuitable for drinking. The CO_2 gas is less dense than the water in the rock formation, so it will

Figure 3: *Number of Class I Wells by State*



rise to the top of the formation, below the confining rock. As a result, it will spread laterally and may be able to migrate out of the confining zone, into other subsurface water bodies and potentially breach the surface. The migrating CO_2 could contaminate shallow aquifers containing drinkable water. Leakage would also have negative ecological effects, as the CO_2 could displace soil gas and damage plant roots (Wilson 2003).

More damaging than chronic, small leaks would be large single releases, which would pose risks to animal and human health, possibly resulting in death. These "worst case" large leakages are less likely, though still possible, and could occur in the instance of a well blowout or an earthquake (Bruant 2002). Stringent design, operation and monitoring would be needed to reduce the possibility of such events. Particularly important would be the development of leak detection methods, as low volumes of CO_2 are odorless, colorless and tasteless and thus difficult to detect by humans (Bruant 2002). Many believe the current UIC regulations would not be suitable for application to geological sequestration of CO_2, thus formulating appropriate regulations would require adequate research and discussion before implementation of CO_2 projects. Ironically, the current studies on the implications of CO_2 underground storage are more advanced than the available studies of the underground injection of liquid waste (Wilson 2003).

In March of 2007, EPA issued a guide for pilot geologic sequestration projects. In the next couple of years, EPA will allow permits for Class V "experimental technology" wells to begin some injection of CO_2, as part of a "validation" phase. In this phase, field tests will involve injecting smaller amounts of CO_2 and monitoring the fate of the gas. EPA predicts "deployment phase" projects will then begin injecting higher volumes, with full-scale commercial operations beginning around 2010. EPA stresses that continued research is necessary, focusing on particular topics including possible effects of CO_2 injection on groundwater and human health (USEPA 2007).

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Figure 4: *Workers at a Class 1 injection well*

Chapter 5

Deep Well Failures: What Can Go Wrong?

More damaging than chronic, small leaks would be large single releases, which would pose risks to animal and human health.

Several factors influence the safe operation of an injection well: site characteristics, design and construction, waste characteristics, and operational procedures. Specific regulatory requirements govern many of these factors; the regulations are discussed in Chapter 7. Design, construction and operational procedures are discussed there; here we will focus on the intricacies and importance of site and waste characteristics.

Site Characteristics

Before any site becomes a deep well, the makeup of the rock formation (geology) and the relationship with local and regional aquifers (hydrology) must be completely understood. The site operator should be able to provide detailed description of the different rock layers the well passes through, including thickness, size, position in the earth's crust (stratigraphy) and rock make-up (lithology), in addition to rock characteristics (fractures, fissures, joint patterns, fault lines, folds, domes and basins).

Receiving formations should also be traced to the nearest drinking water source. Some deep wells do extend through a source of drinking water, but the injection zone may not be in a USDW (USEPA 2001). Each characteristic should be mapped for each deep well site.

Proper well design must both contain the wastes on the way down and allow dispersion through the receiving formation. To design a well properly, one needs to know porosity, permeability, compressibility and subsurface stress characteristics for each rock unit. According to Dr. Patrick Sullivan of Ball State University, these data are "critical for evaluating injection well performance (i.e. the ability to inject liquids at a given rate), the ability of confining rock units to limit the migration of waste liquids, and for determining the structural stability of each rock unit to hydraulic fracturing" (Sullivan 1983).

Characteristics of the geology and hydrology are incredibly important for determining the risk of induced seismicity (i.e. earthquakes) from injection.

Most of the wells associated with injection-induced earthquakes are those that inject water for enhancement of hydrocarbon recovery (Class II), due to the fact that these wells generally involve higher injection pressure and a small confined underground reservoir with low permeability. However, significant induced seismicity has been documented for 2-3 hazardous waste wells, which are noted in the following chapter (see Table 1). The earthquakes are usually caused by the presence of a fault or fracture near the injection zone. The pressure of injection weakens the fault and a slip occurs, causing an earthquake. Measuring the stress of the earth's crust, locating faults and fractures, and determining the hydrologic properties of the injection reservoir are essential to preventing injection-induced earthquakes (Nicholson 1990).

The best geological information comes from well records made during drilling but can also be obtained from records of adjacent boreholes or geophysical surveys. But even with the best collection methods, there are limitations. Data comes from an individual point (or segment) in the well. As a result, you only "see" small fragments or a "snapshot" of the well which may not or accurately reflect actual rock properties. This can be minimized by taking multiple soil samples for analysis.

Waste Characteristics

Another important factor is the interaction between the injected wastes and the fluids and minerals in the receiving and confining formations. Incompatible wastes will cause chemical reactions which could "plug" the well or the receiving formation. Chemical reactions can create solids (precipitates) which prevent further injection. Sometimes wastes can continue to be pumped, increasing the pressure, which can cause fracturing of the rock or cracks in the well.

Once solids have formed, it's hard to "unplug" the well. Sometimes operators use dynamite to loosen the blockage and open the well. Dynamite is dropped down the well and exploded at the blockage. After the explosion, pressures are measured and more wastes injected. If the pipe seems clear, injection continues. Questions remain, however: Did the operator really know what the explosives did? Where did the charge go off? Was the blockage really cleared away or was the well itself damaged? Most likely the answer to these questions is no. There can't be much control over explosives detonated 4,000-5,000 feet underground.

Incompatible wastes can also destroy confining formations. Corrosive chemicals, primarily acids, can eat away at the rock formations that protect the water-bearing zones, causing two major problems. First, the permeability of the receiving zone increases, allowing wastes to move into unprotected areas. Second, corrosive chemicals expand the receiving formation "cavity" by destroying the walls of the injection zone. The size of the cavity grows, causing instability in the overlying rock formations. In Polk County, Florida, acidic industrial wastes created a cavity 100 feet high and 23feet wide. The collapse of the overlying rock formation into an underground pit of hazardous waste would be disastrous (Gordon 1985).

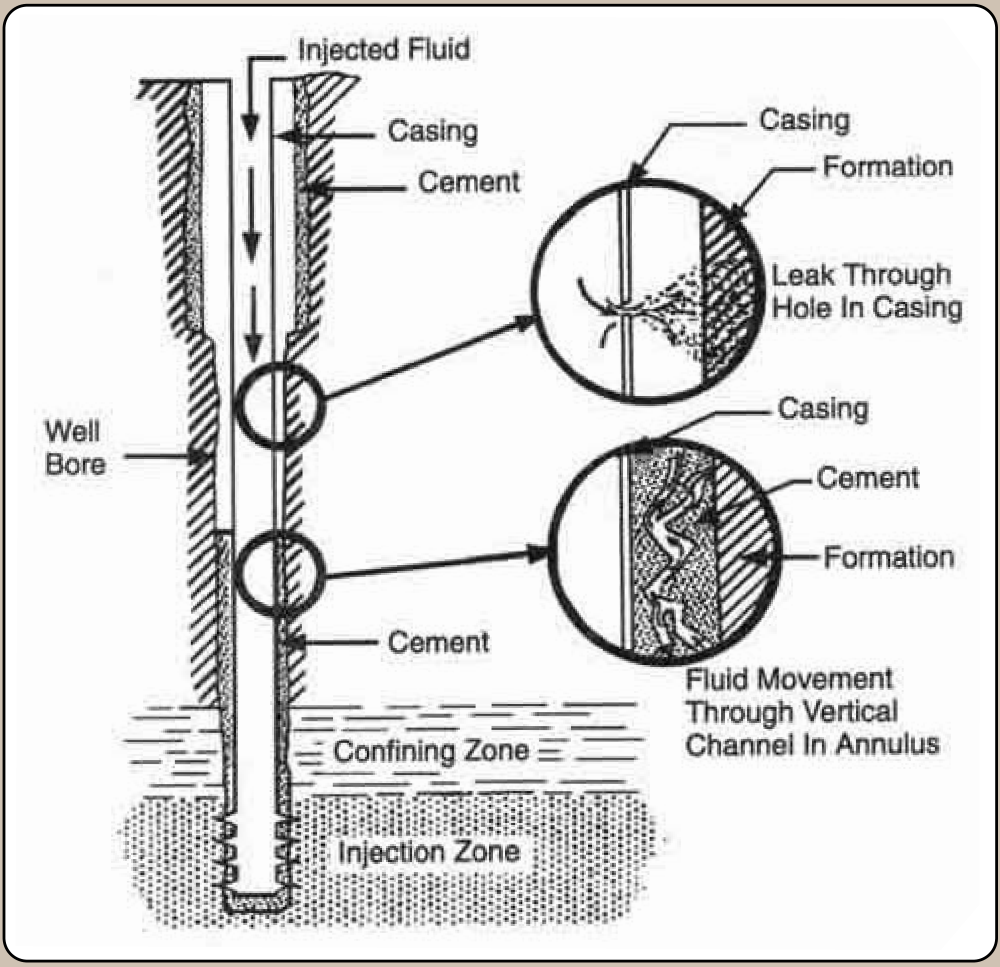
Furthermore, research at Texas A & M University has shown that concentrated organic liquids, acids or bases can significantly increase the permeability of clay used in the liner of landfills. Yet almost nothing is known about the effect of injected wastes on the permeability of clay or shale found in typical confining layers. Dr. David Anderson, a member of the original Texas A & M research team, notes, "It would be logical to assume that these confining layers could be rendered more permeable upon exposure to certain wastes" (Anderson 1984).

Examples of specific failures that may occur:

- Improper siting, design, and/or construction resulting in tube failures and leaks (regulations address these issues, but these types of problems have occurred, e.g. Elk City, OK)
- Poor application of cement causing wastes to enter well shaft
- Leaking casing or tubing, which could result in waste migration and groundwater contamination

- Failures in pressure monitoring or faulty gauges leading to excessive pressure buildup and subsequent failure of injection equipment, fracturing of the receiving formation, or possibly induced seismicity (earthquakes)
- Wastes under pressure can escape through nearby abandoned or improperly plugged wells (oil, gas, water wells, or other injection wells)
- Leaking or faulty packer, allowing wastes to enter annulus and corrode well casing; a recent UIC study identified this as the most common failure (USEPA 2001)
- Corrosion of casing or tubing, allowing fluids to escape or possible well blowout
- Chemical reactions among waste constituents and/or the wastes and the formation, causing corrosion, seepage, plugging of injection zone, etc. (Regulations attempt to address this, though these reactions are difficult to predict)
- Difficulty cleaning up once an accident/leakage has occurred
- Improper closure and abandonment may lead to leaks and other problems
- Poor management/operation leading to mistakes and violation of well permits (e.g. excessive pressure, injection of unauthorized wastes, etc.)

Figure5: *Mechanical integrity failures of injection wells*



Chapter 6
Case Histories

The following are examples of different communities who fought deep wells and/or were impacted by their failure. Table 1 provides a more complete listing of well failures and permit violations, dating back to the 1970s. For more information, see the references at the end of this guidebook.

Miami-Dade, Florida

Deep well injection in southern Florida is a unique situation in that this area is the part of the country disposing of municipal wastewater into deep wells. Due to the local conditions, simply dumping wastewater into surface bodies of water has led to problems such as nutrient overloading, damage to fish and other aquatic animals and so on. Surface discharge can also contaminate underground water sources as both sources mix in Florida's hydrological cycle (USEPA 2002). Deep well injection is believed by some to be the least problematic solution to this wastewater disposal problem (Bloetscher 2005). However, there have been a number of noted well failures in Florida, as shown in Table 1. In Miami-Dade, treated wastewater (with elevated levels of ammonia, chlorides; and fecal coliform) was found in the Upper Floridian aquifer, which is used for drinking water. Studies done for the EPA and the Sierra Club both found that the local geology does not prove to be a sufficient containing zone for the wastes, as it is somewhat permeable (Starr 2001, McNeill 2000). In addition, the Sierra Club study indicated that 10 of 17 wells were constructed improperly, having not been cased deep enough to inject below the confining zone. Overall, it seemed that there was much uncertainty about the geology of the area and the extent of the contamination, suggesting injection of wastes was not appropriate given the available information (McNeill 2000). Injection at the Dade county plant continues, but now under more stringent pretreatment standards set up by the EPA in 2005 (USEPA 2005a).

Romulus, Michigan

For more than 15 years, the citizens of Romulus, MI have fought against a deep well injection facility in their already environmentally burdened community. For a good number of years, they were winning by preventing the well operators from being granted the required permits for operation. Much was accomplished through the efforts of the citizens group R.E.C.A.P., or Romulus Environmentalists Care about People. The group, which at one point had over 600 members, battled the wells by writing letters, attending city council meetings, filing lawsuits and attending public hearings (Sylvester 2004). Despite opponents' doubts about the dependability of the operating company, Environmental Disposal Systems (EDS),

Figure 6: *Romulus, Michigan resident protesting deep injection wells. Photo from www.ecocenter.org*

they received EPA permits in September 2005 and subsequently began operation.

However, after being in operation for only about ten months, the injection wells and their operating company were already failing. In October 2006, inspections during the wells' mechanical integrity tests revealed the presence of leaks in the piping of one of the two wells, which led EPA to shut them down. Subsequent investigations revealed violation upon violation of the conditions of the permit, including failure to provide monitoring records, missed testing of safety systems, failure to complete proof of financial responsibility, and even injecting waste without an operator present (USEPA 2007a).

EDS no longer owns the wells due to bankruptcy and EPA has decided to terminate the permits held by the company. Any new operator will have to apply for ownership and UIC permits again and pay damage costs. R.P. Lilly, who has been a leader of R.E.C.A.P. throughout the entire process is not "popping the champagne bottles yet", but hopes that the liability costs will prevent a new company from buying and reopening the wells (Lilly 2007).

Vickery, Ohio

Ohio Liquid Disposal, a subsidiary of Waste Management which is now known as Vickery Environmental Inc., began as a waste oil disposal site. In the mid-1970s, however, it received permits for and began injecting commercial waste into six injection wells. The types of wastes historically and currently injected include pickle liquor from iron and steel production, recycling operations process water, scrubber water from incinerators, storm water from other contaminated sites, and landfill leachate (USEPA 2006c). These wastes include dangerous chemicals such as dioxins (Scorecard 2005, Fuchs 1983). In the late 1970s and early 1980s, all six wells experienced tube failures and annulus contamination. All of the wells leaked wastes into rock above the confining zone, with leakage estimated at least 45 million gallons. Several wells were found to have holes in part of the casing; others were severely corroded. The cause of the holes was unknown, but may have been damaged during cleaning or repair work on the well, while the corrosion was likely caused by the wastes (URM 1984).

In 1984 and 1985 Waste Management, Inc. was fined over $12.5 million for repeated mismanagement charges related to the leaking wells and illegally dumping one million gallons of PCBs (polychlorinated biphenyls) and dioxins into lagoons and other storage containers onsite (New York Times 1984). The company no longer stores wastes in open pits or lagoons, but does use aboveground storage tanks. Unfortunately, these tanks have leaked dangerous gasses (see Chapter 8). As a result of the court rulings against Waste Management, a citizens group was formed to meet with company management to discuss concerns. This group still meets with the company and according to one member, the current management has acted on some concerns expressed by the group. Other than the storage tank issues, in general there have been few problems at the Vickery facility since the company spent over $20 million to clean and rework it (Schwochow 2007, New York Times 1984, 1985). Several of the wells were plugged and the remaining were rebuilt; the site continues to inject into the four remaining wells.

Winona, Texas

In the early 1980s, Gibraltar Chemical Resources obtained a permit to operate two commercial deep injection wells near Winona, Texas, a small rural town of about 457 people. The company concurrently operated a hazardous waste fuel blending operation, a solvent recovery and recycling operation, and two transfer stations. In the following 17 years, the site became a menace to the largely minority population of the community. Animals and people of all ages suffered from a variety of adverse health effects. EPA investigations confirmed that adverse affects such as nausea, dizziness, and respiratory problems coincided with chemical releases at the plant (USEPA 2002a). The site generated noxious odors; experienced many explosions, fires, chemical releases and spills; and violated air and water pollution laws, including the Texas Clean Air Act (Poeschl 1996). In 1993, the plant was shut down for a period of time when the EPA found that one of the wells was operating without 800 feet of required concrete casing (McGuire 1997).

In 1992, residents banded together to form M.O.S.E.S., or Mothers Organized to Stop Environmental Sins, to spread awareness and fight back against the company. Tactics included picketing at the company grounds and leading media campaigns to raise awareness of the company's violations. The group as well as individual residents also filed several lawsuits against the company including a citizen suit and a Title VI civil rights complaint with the USEPA. In response, American Ecology Environmental Services Corp. (the facility's new name when American Ecology, Inc. bought Gibraltar in 1994) filed a SLAPP suit under the RICO (Racketeer Influenced and Corrupt Organizations) Act against Phyllis Glazer, head of M.O.S.E.S, her husband and mother for alleged racketeering, defamation and related claims. The case was later dropped (Multinational Monitor 1998).

American Ecology Corporation announced the closure of the Winona plant on Thursday March 20, 1997, citing financial problems due to legal battles as the reason for their closure (McGuire 1997). The company reached agreements with the involved parties to cease receiving waste and only continue using the injection wells for disposing of storm water runoff from the contaminated Winona site.

Table 1: Deep Well Failures

Location	Waste	Mishaps
Bucks (Stauffer Chem. Inc), *Alabama*	Sodium Chloride (NaCl, salt) and sodium hydroxide (NaOH) brine; traces of phosphates and organic compounds; by-products of agricultural chemicals	Casing failure leakages (HWTC 1985, Henry 1963).
Fairfield (U.S. Steel Corp.), *Alabama*	Waste pickle liquor, hydrochloric acid	Casing failures; formation clogged with solids; hydrofracturing occurred, annulus leaked.

Baldwin Hills, *California*		Reservoir failure reported to have been precipitated by earth movement caused by injection (US Congress 1973).
Rio Bravo, *California*	Pesticides and hazardous solvents, Class I toxics	Leakage from casings - faulty mechanics (Trihey 1985).
Santa Maria (Greka Integrated, Inc), *California*	Oil Refinery waste in a Class II well; benzene	In 2006, Greka was fined $127,500 for violating the SDWA by illegally disposing of industrial oil refinery wastes in a Class II well, rather than the required Class I well (USEA 2006d). In June of 2007, the company was fined $1 million for disposing of benzenec contaminated water in wells not permitted for such disposal and for "making false statements" to the EPA (USEPA 2007b).
Tuolumne River, *California*	Brine effluents (Class II)	Leakage from abandoned gas well (US Congress 1973)
Adams and Wade Counties, *Colorado*	Salt water disposal wastes (Class II)	Polluted water wells (Reports 1973)
Denver (Rocky Mountain Arsenal), *Colorado*	Pesticides from petrochemical plant	Triggered series of earthquakes (Anderson1984)
Belle Glade (sugar mill), *Florida*	Hot acids and highly organic wastes	Waste migrated to deep and shallow monitoring wells; all wastes found to be exiting through 8 foot holes in well casing, causing contamination of fresh water aquifer (Anderson 1984, Gordon 1985).

Dade County (3,500 shallow drainage wells), *Florida*	Cooling water return, swimming pool effluents, slaughterhouse waste, battery solid waste, metal plating waste, laundromat waste	Polluted fresh water Biscayne aquifer (US Congress 1973)
Dade County (South District Wastewater Treatment Plant), *Florida*	Municipal wastewater constituents: elevated levels of ammonia, chlorides; fecal coliform	Upward migration of injected wastewater, contaminating USDW; suspected mechanical failure of at least one of 17 wells (USEPA 2002)
Fort Lauderdale (Hollingsworth Solderless Terminal), *Florida*	Trichloroethylene sludge, copper, oil and grease	Contamination via a disposal well directly into aquifer (FDER 1983)
Fort Meyers , *Florida*	Phenolic waste	Contaminated fresh water aquifer (Henry 1983).
Live Oak and Gainesville, *Florida*		Municipal wastes injected into sink holes connected to aquifer for water supply (US Congress 1973).
Melbourne, *Florida*	Raw sewage, treated municipal wastewater	Accidental injection of untreated sewage; migration of effluent 1,200-1,800 feet away; possibly caused by leaks in concrete caps or leaks in casing (Florida Times-Union 1989).
Mulberry, *Florida*	Acidic waste	Dissolution of carbonate rock in the injection zone and leakage through confining bed (Anderson 1984, Gordon 1985).
Palm Beach County, *Florida*	Organic waste	Contaminated shallow aquifer above well (US Congress 1973) Confirmed fluid migration into USDW from municipal deep well (USEPA 2002).

Pensacola Nylon Plant, *Florida*	Nitric acid, salts and numerous organics	Pressure increase of 30 psi and waste migration over 1 mile in all directions – probably formation of large underground cavity (Anderson 1984).
Pinellas County (City of St. Petersburg facilities), *Florida*	Highly likely that saline waters were pushed upward by injectate; elevated ammonia	Probable and confirmed migration of fluids upward into USDW; significant change in water quality (USEPA 2002).
Polk County, *Florida*	Acidic industrial waste	Created cavity 100 feet high, 23 feet wide, around well bore (Gordon 1985).
Camilla, *Georgia*	Creosote disposal well	Contaminated fresh water aquifer (US Congress 1973).
Grandview, *Idaho*	Toxic chemicals	Contamination of groundwater leading to Snake River (USEPA 1977, Maranto 1985)
Marshall (Velsicol Chemical Corp.), *Illinois*	Chlordane-related compounds, process effluent; discharge untreated	Contamination of USDW beneath the plant area – contaminants found in Mill Creek, its tributaries and Wabash River; leakage in well casing found (USEPA 1984, USEPA 2001).
Furley (Vulcan Chemical), *Kansas*	Organic solvents, pesticides and PCBs	Chemicals found in on-site monitoring wells in 3 aquifers and in offsite private drinking water wells (Dienst 1985)
Lake Charles Willow Springs Site (Browning-Ferris Companies, Inc.), *Louisiana*	Commercial waste	Radioactive and chemical contamination of groundwater and upper aquifer (Senat 1984).

Plaquemine (Rollings Environmental Services Inc.), *Louisiana*	Hazardous and non-hazardous industrial waste and oil field aqueous waste	Allowed discharge of toxic and hazardous substances into roadside ditch (HWTC 1985)
Sulphur (Browning-Ferris Companies, Inc.), *Louisiana*	Liquid wastes from industrial waste generators	Case leaking found by UIC, contaminated groundwater (Senat 1984).
Yermilion Parrish (Quintena Petroleum Corp.), *Louisiana*	Hazardous waste from oilfield waste	Allowed discharge of toxic and hazardous substances into road ditch (LWRSC 1984)
Newaygo County, *Michigan*	LPG injection gas (Class III)	Polluted fresh water aquifer (US Congress 1973)
Midland (Dow Chemical Company), *Michigan*	60% of nation's hazardous waste - dioxins, PCB's, benzene, aniline, agent orange, 2,4,5-T, silver, Class I rinse-water.	Groundwater contamination (Wilson 1984, MDNR 1967-1979).
Romulus, *Michigan*	Commercial wastes	Leak in surface piping of one of two wells; numerous violations of UIC permit including injecting without an operator present (USEPA 2007a).
Fort Peck Indian Reservation in Daniels County (Summernight Oil Company LLC and Miocene Oil and Gas Ltd.), *Montana*	Brine (Class II)	Summernight was fined for violations of SDWA including failing to conduct required well tests and Miocene was fined for injecting without a permit; both incidents could have threatened groundwater (USEPA 2007c).
Wilmington (Hercules, Inc.), *North Carolina*	Dimethyl tetra phthalate, pH 4.0	Leakage into upper aquifer, vertical leakage of waste through confining layers (Gordon 1985, HWTC 1985, USEPA 1977).

Adams County, *Nebraska*	Phenolic Waste	Polluted shallow aquifer (US Congress 1973)
Copper mine, *Nevada*	Injecting acids into ore deposits (Class III)	Contamination of shallow aquifer (US Congress 1973)
Aurora (cheese plant), *New York*	Liquid wastes	Leakage appeared one mile away (US Congress 1973)
Buffalo, *New York*	Cyanide	Disposal well blow-out, contaminating water supply (US Congress 1973)
Medena County, *Ohio*	Brine wastes (Class II)	Contaminated fresh water aquifer leakage through abandoned unplugged well (US Congress 1973).
Vickery (6 wells - Chemical Waste Management), *Ohio*	Dioxin, PCBs, heavy metals; other commercial wastes	All original wells had tube failings and leaks in high pressure injection wells; fined over $12.5 million for leaks and illegal aboveground disposal of PCBs and dioxins (New York Times 1984, 1985, URM 1984).
Elk City (Southern Management, Inc.), *Oklahoma*	Acetone, methylethylketone, methylisobutylketone, benzene,xylenes, toluene, metals (lead, barium)	Mixed Class I and II wells suffered several blow-outs due to tubing leaks and operating without a packer (falsified UIC documents); contaminated 6 miles of land, possibly a drinking water source and nearby creek (USEPA 1992, Etter 1992). On-site storage containers also contaminated nearby land.

Okmulgee, Rogers, Muskogee, Nowata Counties, *Oklahoma*	Brine wastes (Class II)	Polluted shallow aquifer (US Congress 1973, Hensch 1985)
Tulsa (Chemical Resource Inc.), *Oklahoma*	Cyanide, chlorinated hydrocarbons and sulfides	Unacceptable groundwater monitoring; contamination of groundwater (Gordon 1985, HWTC 1985, Dunbar 1985)
Erie (Hammermill Paper Company), *Pennsylvania*	Suphite liquors, pH 5.3	Corrosion to well casing caused blow-out, which contaminated ground surface for several days at 140 gpm and caused backflow into Lake Erie; 4.5 miles away an unplugged and abandoned gas well began discharging volumes of waste for 2 years (Anderson 1984, HWTC 1985).
McKean County, *Pennsylvania*	Crude oil and brine (Class II)	Polluted freshwater aquifer through abandoned well (US Congress 1973)
Presque Isle State Park (Presque Isle Wells), *Pennsylvania*	Carcinogens, phenanthrene, fluoranthrene, pthallic acid, diethyl ether	Contaminated groundwater from poor quality water coming from an abandoned gas well (Grazier 1980, USDOI 1980, USEPA 1984)
Lawrence County, *South Dakota*	Mining waste	Polluted fresh water aquifer (US Congress 1973)
Mt. Pleasant (Stauffer Chemical Company, later Zeneca Holding, Inc.), *Tennessee*	Organophosphate, hydrochloric acid, brine, sulphur dioxide; contaminated wastewater	When owned by Stauffer: 7-inch casing ruptured between 2,000-3,000 feet (HWTC 1985, USEPA 1984a). After Zeneca took over in 1978, they continued to inject into an aquifer until 1999, when ordered by the

		EPA to stop injection and pay $3.5 million in fines for violations of SDWA, RCRA, CAA, CWA and UIC regulations (USDOJ 1998).
Oak Ridge, *Tennessee*	Radioactive wastes	Radiation found in nearby monitoring wells (USEPA 1984a).
Beaumont (Velsical Chemical Corp.), *Texas*	Herbicide wastes, dioxin, pH 4+	5 million gallons of acidic herbicides leaked into fresh water supply; corrosion of both inner and outer casings and surrounding layers of cement; contamination of groundwater resulted (Gordon 1985, Henry 1983).
Corpus Christie, *Texas*	Petrochemical wastes	Wastes leaked into overlying aquifer (Anderson 1984)
DeBerry area, Panola County (Basic Energy Services, Inc.), *Texas*	Oil wastes; benzene, barium, chloride and petroleum hydrocarbons (Class II)	Leaking casing; contamination of groundwater (Middleton 2006, TCEQ 2005).
Deer Park (EMPAX, Inc.), *Texas*	Pesticides, caustics, spent acids, waste oil, solvent wastes from various industrial sources.	Contamination of groundwater; unauthorized increase in maximum injection pressure causing tubing leak (Anderson 1984, HWTC 1985).
Malone Service Company, *Texas*	Aluminum chloride	Widespread contamination in Swan Lake (TDWR 1982, 1983, Seibel 1982).
Odessa (Browning-Ferris Industries), *Texas*	Two incompatible waste streams – no buffering	Major well failure: surface injection exceeded limits; undetermined leak; well plugged (Gordon 1985).

Orange County (4 wells - EI dupont de Nemours Co., Inc.), *Texas*		Major well failure (Gordon 1985, USEPA 1977)
Ranger, Eastland County (Sonics International, Inc.), *Texas*	Corrosive chemical waste-acids, base organics	Deteriorated tubing, packer and well casing; blow-outs and tube leakage caused groundwater contamination (Anderson 1984, TDWR 1982, 1983).
Wilbarger, Hockley and Hutchinson County, *Texas*	Brine/gas (Class II)	Polluted fresh water aquifer (US Congress 1973)
Winona (Gibraltar Chemical Company, later renamed American Ecology Environmental Services, Inc.), *Texas*	Hazardous wastes, stored above ground and injected into deep wells	Over 14 years of operation, racked up over 740 errant emissions and 400 notices of violations; accidental releases/spills of chemicals abundant; residents suffered health problems (Mullen 2002, Domino 1999/2000).
Utah	Solution mining of pot-ash (Class III)	Polluting streams and groundwater (US Congress 1973)
Kanawa and Roane County, *West Virginia*	Brine effluents (Class II)	Polluted freshwater aquifer through abandoned and unplugged wells (US Congress 1973).
Acid solution mining, *Wyoming*	Acid injection into ore deposits (Class III)	Polluted freshwater aquifer (US Congress 1973).

Chapter 7

Regulatory Requirements

In the early history of deep well injection, wells were regulated by states, which had varying standards for protection of groundwater. When the number of wells began increasing in the 1970s, EPA became concerned about protecting groundwater and drinking water. They were able to regulate some injection under earlier legislation, but they did not establish clear standards until the early 1980s (Clark 2005).

Two federal laws now regulate use and operation of deep wells. The Safe Drinking Water Act (SDWA) of 1974 established requirements to protect the nation's drinking water and the Resource Conservation and Recovery Act (RCRA), originally enacted in 1976, regulates disposal by injection under a permit program.

The SDWA set up the Underground Injection Control (UIC) Program to establish federalstate controls to ensure that underground injection practices do not endanger drinking water sources. Under this program, EPA was directed to establish minimum requirements for state regulation of injection wells; states were delegated as the primary enforcement authority for achieving these minimum requirements; and EPA was required to step in when a state chose not to (or failed to) implement a program (USEPA 2001). In addition, EPA was given authority to prohibit new injection wells over sole source aquifers. Currently, there are 33 states and three territories with primacy, while the EPA shares primacy in seven, and implements programs for all well classes in ten states (USEPA 2007d).

UIC regulations were supposed to go into effect in 1975, but it wasn't until February 1982 (prompted by a lawsuit filed by the National Wildlife Federation) that EPA finally released its guidelines and the description of how the UIC program would work (EPA 2001). EPA recognized that it was going to take some time for the states to gear up and adopt their own requirements. So, the agency decided to regulate wells under "interim status" requirements of RCRA until a UIC program was in place in that state. In addition, wells in existence prior to the time that the program was established by the state or EPA were given "authorization by rule" under UIC. This is different from the interim status standing of the RCRA program in that UIC governs what is below ground and RCRA governs what is above ground. All facilities were required to eventually obtain all applicable permits. The UIC regulations established the five classes of wells described in Chapter two.

In the past, hazardous wastes could be pumped into Class I or Class IV wells. The difference in the two types of wells is the point of discharge. Class I wells discharge waste below a drinking water source, while Class IV wells dispose of wastes into or above a drinking water source. Class IV wells were particularly threatening because no standards applied to them. EPA has now banned Class IV wells due to the health risks involved with them (USEPA 2006).

In 1984, the Hazardous and Solid Waste Amendments (HSWA) were enacted under the RCRA. These amendments ban all land disposal of hazardous waste that has not been treated to certain specifications. Under this ban, hazardous waste could not be injected into deep wells. However, in 1996, Congress passed the Land Disposal Flexibility Act, which offers operators of Class I wells exemptions to the land disposal ban if they can demonstrate "no migration" of wastes through a petition. This petition must demonstrate through modeling that wastes will not migrate from the injection zone for at least 10,000 years, or that decomposition or other means will render wastes non-hazardous before they migrate (USEPA 2001). Currently, 47 of 51 Class I hazardous waste facilities have been exempted from the land ban through this process (USEPA 2006a). Though it was thought by some that the land ban would reduce the amount of waste injected into wells, this was not the case. Based on data between 1988 and 1995, waste quantities injected decreased only slightly (NET 1998).

On November 22, 2005, the EPA enacted a new rule revising requirements for deep well injection in certain counties in Florida. After many incidents of wastewater migration from deep wells, the EPA decided that if the water is given "high-level disinfection" beyond current secondary treatment requirements, well operators can inject waste even if they have or may cause movement of wastewater into a USDW (USEPA 2005a). It is likely that wastewater migration will continue, given that of the 93 facilities operating in South Florida at the time of a 2002 EPA study, 18 had movement of fluid out of the injection zone, three had migration into a USDW, six showed probable movement into a USDW and nine had movement into the zone just below the USDW, but above the confining layer (USEPA 2002). However, unlike other UIC wells, Florida law requires all wells to have at least one monitoring well to detect fluid migration, with periodic testing of groundwater in the first aquifer above the injection zone and the lowermost USDW (Keith 2005).

Other than the various amendments and rules mentioned above, the UIC regulations for Class I wells remain roughly the same as when they were originally enacted. They establish minimum requirements for siting, construction, operating, monitoring and reporting, and information to be considered by the director. The UIC regulations also address financial responsibility, post-closure care and corrective action responsibility to a degree, but these provisions are considered too weak by some (USGAO 2003).

Siting Requirements

Siting requirements were formulated to ensure that upon failure of any of the other components of the wells, the geology of the area around the well would further protect wastes from migrating out of the intended area. A summary of the siting requirements for hazardous and non-hazardous injection wells is provided in Table 2.

The area of review (AoR) is the zone surrounding the injection well where waste is thought to be able to migrate due to injection pressure. AoR studies are required prior to construction in order to identify potential pathways of waste migration out of the injection zone, into drinking water sources. Operators must identify and repair or plug any wells within the area of review (USEPA 2001). Some states have made the required area of review for all wells larger than that required by the UIC program. Texas has a 2.5-mile AoR, Louisiana has a 2-mile AoR, and Florida and Kansas both require a 1-mile AoR (USEPA 2001).

Geological tests are intended to determine whether the rock in the injection zone is porous enough to accept wastes and whether the rock in the confining zone is impermeable and will prevent fluids from moving vertically. The confining zone is often made up of shales, which are less likely to fracture than other types of rock (USEPA 2001). Hazardous well operators must provide information showing that there are no fractures of faults that may "allow movement of fluids between formations". These regulations attempt to prevent Class I wells from being sited in areas where earthquakes occur. Furthermore, hazardous well operators must demonstrate that wastes will not migrate for 10,000 years or be rendered non-hazardous before migration, as discussed in the description of the Hazardous and Solid Waste Amendments.

Construction Requirements

Construction requirements were designed by EPA to assure that wells are adequately constructed, that the wastes are properly injected (with a minimum of leakage), and that well failure due to corrosion is minimized. Specific EPA guidelines are described in the following paragraphs. A summary of the construction requirements for hazardous and non-hazardous injection wells is provided in Table 3.

All Class I wells must be designed to inject wastes into a formation under the lowermost formation containing, within one quarter mile of the well bore, an underground source of drinking water. The operator must case and cement the well bore to block fluid movement into or between drinking water. The well must be designed to inject waste through tubing with a packer set immediately above the injection zone, or through tubing with an approved fluid seal, unless the fluid is non-corrosive. All wells must consider factors specific to the well (i.e. depth of well, hole size, etc.) to carry out appropriate casing and cementing and construction of the packer and tubing. Lastly, during drilling and construction of new wells, one must conduct tests, prepare logs, and submit the results to the UIC director (e.g. deviation check, resistivity, caliper logs, etc) (USEPA 2001).

Hazardous wells have a number of additional construction requirements. For example, all well materials must be compatible with the injected wastes and the construction of the casing and

Table 2: Summary of Siting Requirements

Hazardous Wells	Non-Hazardous Wells
Must complete 2-mile Area of Review Study.	Must complete ¼ mile area of review study (unless state requires a larger study area).
Must have demonstrated no-migration through petition.	Must be cited in geologically stable-area.
Must be cited in geologically stable-area.	
Additional geological studies suggested, but not explicitly required.	

Adopted from USEPA 2001

Table 3: Summary of Construction Requirements

Hazardous Wells	Non-Hazardous Wells
Well has appropriate casing and cementing to prevent movement of fluids into drinking water source.	Well has appropriate casing and cementing to prevent movement of fluids into drinking water source.
Tubing and packer based on individual well characteristics.	Tubing and packer based on individual well characteristics.
UIC program director must approve casing, cement, tubing and packer design before construction begins.	

Adopted from USEPA 2001

Table 4: Summary of Operating Requirements

Hazardous Wells	Non-Hazardous Wells
Maintain pressure of injection so as not to create new fractures or worsen existing fractures in rock.	Maintain pressure of injection so as not to create new fractures or worsen existing fractures in rock.
Continuously monitor injection pressure, flow rate and volume	Continuously monitor injection pressure, flow rate and volume
Install alarms that automatically "shut-in" the well (stop injection) if specified injection limits are exceeded.	

Adopted from USEPA 2001

cement must be designed for the life expectancy of the well, including the post-closure period. The UIC program director must approve casing, cement, tubing and packer before construction begins (USEPA 2007e).

Hazardous wells have a number of additional construction requirements. For example, all well materials must be compatible with the injected wastes and the construction of the casing and cement must be designed for the life expectancy of the well, including the post-closure period. The UIC program director must approve casing, cement, tubing and packer before construction begins (USEPA 2007e).

Operating Requirements

All Class I wells must assure that injection pressure at the wellhead does not cause new fractures or widen existing fractures in the injection or confining zones or cause the movement of injection or formation fluids into drinking water. However, it is difficult to know if fracturing is occurring. A summary of the operating requirements for hazardous and non-hazardous injection wells is provided in Table 4.

In addition to this minimum requirement, there can be no injection between the outermost casing and the well bore, as this practice could endanger drinking water. The annulus must be filled with an approved fluid and pressure maintained (EPA has guidelines on fluids).

Hazardous wells must also install continuous monitoring systems with alarms that automatically sound and stop injection whenever some operating limit (i.e. flow rate, volume, temperature of fluids, or pressure) exceeds allowed ranges. If this occurs, the director must authorize the operator to resume injection. Hazardous wells also have more detailed operating requirements for monitoring and maintaining mechanical integrity (USEPA 2001, USEPA 2007e).

Monitoring and Testing Requirements

There are a number of minimum monitoring requirements for all Class I wells. First of all, injected fluids must be analyzed "with sufficient frequency" to check their characteristics (chemical and physical properties). All wells must use continuous recording devices to monitor for injection pressure, flow rate and volume, and the annular pressure. A summary of monitoring and testing requirements of hazardous and non-hazardous injection wells is shown Table 5.

All wells must demonstrate mechanical integrity; hazardous wells must do so more frequently. Mechanical integrity (MI) consists of internal and external integrity. A well is considered to have internal MI if the tubing, packer and casing do not show significant leaking. A well has external MI if there is no flow of fluid on the outside of the casing; failure occurs if fluid moves up out of the well, due to improper cementing.

In addition, an operator may use other monitoring wells in the area of review, but must provide

Table 5: Summary of Monitoring and Testing Requirements

Hazardous Wells	Non-Hazardous Wells
Provide and follow approved waste analysis plan.	Conduct internal MIT every year and external MIT every five years.
Conduct internal MIT every year and external MIT every five years.	Supplemental monitoring wells
Supplemental monitoring wells are authorized or may be required by director.	

Adopted from USEPA 2001, USEPA 2007e

information regarding type, number, location of wells, what is being measured and frequency of monitoring. Monitoring of drinking water sources in the area of review is not explicitly required, but state directors may require some form of USDW monitoring (USEPA 2001).

Furthermore, hazardous wells must provide detailed waste analysis plans which include procedures for analysis of waste, test methods and so on. The plan must also include demonstrations that wastes will not react negatively with rock formations (changing their permeability or thickness) and that the wastes will not react with each other in a way which will compromise the well's functioning. Additional monitoring of USDWs may be required by the director (USEPA 2007e).

Reporting and Record Keeping Requirements

All well operators report results of monitoring and testing to their state or federal EPA UIC director at specified intervals. They must provide physical and chemical properties of injected wastes; various injection pressure values, flow rate, volume and annular pressure values; results of recent MIT tests; any work done on the well; and any additional monitoring information (USEPA 2001). A summary of the reporting and recordkeeping requirements for hazardous and non-hazardous injection wells is provided in Table 6.

Class I hazardous wells have additional reporting requirements including quarterly reports on maximum injection pressure, description of events that triggered the alarm system and so on (USEPA 2007e).

Closure Requirements

For Classes I, II, and III, wells that are to be abandoned must be plugged with cement (or for Class III wells, another director approved material) in a way that will not allow movement of wastes into a USDW. Hazardous Class I wells must complete pressure fall-off tests and mechanical integrity tests and report these results. The director requires cleanup and monitoring of USDWS as necessary.

Table 6: Summary of Reporting and Record Keeping Requirements

Hazardous Wells	Non-Hazardous Wells
Provide quarterly reports on injection and injected fluids and monitoring in area of review; results of waste analysis program; and geochemical compatibility.	Provide quarterly reports on injection and injected fluids and monitoring results.
Report internal/external mechanical integrity test results at required intervals.	Report internal/external mechanical integrity test results at required intervals.
Report any changes to the facility, loss of mechanical integrity, progress in compliance, or non-compliance with permit conditions.	Report any changes to the facility, loss of mechanical integrity, progress in compliance, or non-compliance with permit conditions.

Adopted from USEPA 2001, USEPA 2007e

Table 7: Summary of Closure Requirements

Hazardous Wells	Non-Hazardous Wells
Flush well with non-reactive fluid; test each cement plug.	Flush well with non-reactive fluid; test each cement plug.
Complete pressure fall-off test and mechanical integrity test.	Submit plugging and abandonment report.
Submit plugging and abandonment report.	
Complete outstanding clean-up actions; continue groundwater monitoring until injection zone pressure subsides enough to eliminate any potential of affecting a USDW.	
Inform authorities of the well location and zone of influence.	

Adopted from EPA 2001

Postclosure follow-up is required only for hazardous wells, and not necessarily for that long; most wells are not monitored after closure (USEPA 2001). Table 7 includes requirements specifically for Class I wells.

Closure costs can vary, depending on factors such as the location and depth of the well. A 2003 Government Accountability Office (USGAO) report found that one well in Michigan had a closure cost of about \$25,000, while another well in Ohio cost about \$125,000 to plug and abandon (USGAO 2003).

Information to be Considered by the Director

All class I wells must acquire a construction permit as well as an UIC permit. If operating a hazardous well, an operator must also apply for an RCRA permit for aboveground storage of hazardous waste (USGAO 2003). A draft permit is initially drawn up and there must be at least 30 days after it is drawn up and before the permit is issued for which the public can provide comment.

Before a permit is issued, the owner or operator of a proposed well must submit the following to the UIC director (USEPA 2007e):

- A map showing the injection well(s) location and the area of review; of adjacent wells, geologic features (e.g. faults, mines, etc.), topographic data, and related subsurface features (e.g. roads, etc.). Although this information is only required for a small area (1/4 – 2 or more miles, depending on the state), citizens should obtain information on a much larger area because the regulator has the discretion to consider more information.
- A description of all wells in the area of review that penetrate the injection zone. Only those

wells on public record or known to the permit applicant are required, but all wells which could be affected should be identified and submitted.

- Maps and cross-sections showing the limits of all underground drinking water in the area of review, their relationship to the injection zone, and the direction of groundwater flow.
- Maps and cross-sections of the area's geologic structure and setting.
- Operating data such as the rate and volume of injection, injection pressures, and analyses of the physical, chemical, and biological properties of injected fluids.
- Proposed operating data.
- Average maximum daily rate and volume of fluid to be injected and average maximum injection pressure.
- Proposed stimulation program and injection procedure.
- Drawings of the construction details both above and below ground; and construction procedures.
- Contingency plans to cope with shut-ins or failures, in order to prevent migration of fluids into a drinking water source.
- Plans for meeting monitoring requirements.
- Proposed corrective action for wells in the area of review that were not properly closed.
- Demonstration of financial ability (through bonds, trust funds, insurance) to properly plug and abandon the well.

Before granting approval of a Class I hazardous well, EPA must also review:

- All available logging and testing data.
- A demonstration of mechanical integrity.
- Anticipated maximum pressure and flow rate and actual injection procedure.
- The results of formation testing and the compatibility of injected waste with the fluids in the injection zone and minerals in both the injection zone and the confining zone.
- The status of corrective action on defective wells in the area of review.
- For any well injecting wastes onsite, where the waste is generated, the director must certify that the generator of the waste has a program to reduce the amount and toxicity of waste, as economically practicable.

Inadequacies and Concerns with the Legislation

While Class I regulations in particular are more stringent and are thought to be quite redundant in safety features, these regulations assume a best case scenario. Many of the failures that have resulted since the enactment of UIC regulations have had to do with human error. In an evaluation of risks of deep well injection, W.R. Rish found that "the presence, degree of training, and diligence of operation is important in preventing system failure and loss of waste isolation" (Rish 2005). In Romulus, MI, most of the violations against the deep well injection owners had to do with their own incompetence in operating the injection disposal facility. At one point, after being cited for violations, the owner of Environmental Disposal Services simply disappeared, yet to be found again (USEPA 2007a). In Elk City, Oklahoma, owners falsified reporting documents, continuing to inject into a well that illegally lacked a packer (USEPA 1992). Though problems may still arise, deep injection wells can be effectively operated to reduce risk to nearby communities and the environment, but this necessitates involvement of a responsible operating company that maintains open communications with the public.

In 2003, the Government Accountability Office issued a report investigating EPA's injection well regulations. In particular, they wanted to determine the effectiveness of both state and EPA-directed UIC programs in dealing with community concerns, environmental justice issues and the financial requirements for injection well operating companies. The GAO concluded that EPA did not sufficiently allow enough time for public comment, and recommended they increase community participation. However, the study found that the three states that they investigated which held primacy (Texas, Ohio and Louisiana) did allow for effective public participation. In addition, the GAO contended that the financial assurance requirements of the UIC regulations did not guarantee that an owner would have the resources to close a well, in the event of a bankruptcy. The GAO suggested EPA review and make necessary changes to financial requirements. The EPA reviewed the suggestions and ultimately decided they did not agree with the conclusions or recommendations, but the GAO stand by their assertions (USGAO 2003).

Other problematic areas of the legislation include the monitoring requirements. Though the UIC program requires monitoring of injection pressure and other mechanical problems, the regulations do not require any monitoring of the movement of fluids through the injection zone or in nearby areas to detect groundwater pollution. Though the latter is recommended for hazardous wells, it is not required and thus, many states with primacy do not require it (Wilson 2003). Typically, if pollution is suspected, the program director will then require certain action. However, this means that pollution could be occurring while remaining undetected. Furthermore, a well will not necessarily be shut down if tests indicate mechanical failure, as the confining rock is considered an additional safeguard against waste migration (USEPA 2001).

Though UIC regulations require plugging of abandoned boreholes, the EPA has calculated that there may be more than 300,000 abandoned wells and 100,000 producing wells just in the areas of review for Class I wells (USEPA 2001). These wells provide paths for migration of waste that could endanger drinking water. Unfortunately, these wells sometimes go undetected.

Another relevant issue with the UIC regulations is the fact that they are based on procedures rather than performance. They state what an operator must do, but do not ultimately stipulate an outcome that must be achieved (Wilson 2003). As can be seen with the GAO report, current regulations cannot guarantee adequate financing to properly close a well. Despite this information, EPA decided not to update regulations based upon this problem (USGAO 2003). Furthermore, the permitting process relies on modeling and predictions. Class I hazardous well operators use models to demonstrate that fluids will not migrate into a USDW for 10,000 years, yet this is impossible to prove with certainty. For example, models tend to lose accuracy in more complex scenarios such as the mixture of several types of waste and complex hydrogeology. No tests have ever been done to compare the actual fluid movement in wells to the predicted fluid transport (Wilson 2003). Those selecting and using such models must be well-trained in models and hydrogeology in order to use them appropriately (CPSMA 1990). Generally, it is unclear how practical many of these regulations are; given that the actual outcomes of their implementation have not been documented.

Though it is generally thought that underground injection itself has minimal impact on the health of surrounding community members, if leaks and groundwater contamination occur, there can be serious consequences. Underground water sources are incredibly important; over 90% of water supplies in the U.S. depend at least partially on underground water sources (USEPA 2002b). Contamination of these water supplies could lead to health problems, though few studies have been done for such scenarios. However, EPA conducted one study that indicated elevated cancer and non-cancer risks for benzene, arsenic and carbon tetrachloride, given the scenario of an unplugged well and high use of nearby drinking water wells (USEPA 2001).

There also remain risks from other activities that coincide with injection. There is a risk of exposure to contaminants through the process of handling and storing the waste before it is injected into the well. Many of the health effects suffered by residents of Winona, Texas, for example, may have been from leaks and releases from above ground storage and treatment of chemicals. See the following chapter for more information on transport and storage.

Finally, information about specific deep injection facilities is not easily accessible to the public. EPA should create a large, easily accessible database for deep injection wells. Currently, information on well locations; new well permits; facilities with violations and failures; and general characteristics of wells, including what types of wastes are accepted, is difficult to track down, and its accessibility is dependent on the state. If EPA compiled this information for all wells in the country in one place, people would easily be able to identify wells in an area and identify any risks they may pose. Every other type of waste disposal has a database such as this, so it is only appropriate that deep well injection have the same (NET 1998). While some information on types and amounts of wastes injected can be found in the EPA Toxics Release Inventory (TRI) and biennial reporting system (BRS) databases online, the information is incomplete, sometimes contradictory, and somewhat difficult to interpret (NET 1998).

Chapter 8

Transport and Storage of Hazardous Waste

No matter what methods are used to dispose of hazardous wastes, the wastes must be transported and stored for some period prior to disposal. At a deep well site, chemicals are often "stored" in large chemical lagoons, ponds or storage tanks until they are injected. Though less hazardous waste is stored in ponds or lagoons due to the land disposal ban, chemicals are usually kept in storage tanks for at least some time before disposal. Furthermore, there are a number of commercial hazardous waste injection sites that accept wastes that are transported from other parts of the country. Storage methods, waste transport, and transfer of wastes from transport vehicles and storage containers pose threats to the surrounding community and environment. Major concerns are described below.

Transport Accidents

As much as we would like to believe otherwise, accidents happen. It is impossible to completely avoid accidents resulting from the transport of wastes by trains or trucks. These types of accidents affect many people: the drivers of the vehicles using the road; the people who live near the accident site and their properties that may be contaminated; and the police, firefighters, ambulance drivers, medical personnel and other emergency response people who treat the victims or attempt to clean up the spill. On April 11, 1996 in Alberton, Montana, a freight train carrying hazardous materials derailed. Several cars ruptured, releasing 130,000 pounds of poisonous chlorine gas, 17,000 gallons of corrosive liquid potassium cresylate and 85 dry gallons of sodium chlorate. One thousand people from the area were evacuated and about 350 were treated for chlorine inhalation; 123 were injured as a result. A drifter who had been on the train was also killed from acute chlorine toxicity (NTSB 1998).

On-site Accidents

Containers can spill, break open, or possibly explode when they are unloaded or transferred. Connections between transfer lines and storage tanks can rupture. When they do, air pollution and soil and groundwater contamination occurs. If there's an explosion, there could be a chain reaction with other wastes making matters worse. The people affected by this type of accident are the on-site workers, nearby residents or those passing by, and emergency personnel.

On July 14, 2001, in Riverview Michigan, one such accident occurred when a railroad tank car was attempting to unload at the ATOFINA Chemicals, Inc. plant. A transfer pipe fractured and separated, releasing a poisonous and flammable gas called methyl mercaptan. Shortly afterwards, the gas ignited, engulfing the tank car in flames and sending a fireball 200 feet into the air. The fire burned through hoses in an adjacent tank car and caused the additional release of poisonous chlorine gas. Three plant employees were killed, several others were injured, and 2,000 area residents had to be evacuated for ten hours (NTSB 2001).

Pits, Ponds and Lagoons

Large storage areas pose several threats. First, the mixing of wastes that are not compatible can cause explosive reactions, as it did in Shelby Township, MI. In Shelby, two men were emptying a tank of wastes into a lagoon causing chemicals in the lagoon to give off a toxic gas that killed both men. The effectiveness of the lagoon liner (if one exists) is another concern. All liners eventually leak (USEPA 1988a and 1988b in Lee 1998; Allen 2001). These types of incidents affect the community, the workers, the drinking water supply, fish and wildlife. In fact, WCI Steel, Inc. of Warren Ohio was recently found to be endangering wildlife after 34 dead birds and bats were found near surface ponds containing oily wastes. The company was ordered by the EPA to halt disposal in some of the ponds and install netting and other deterrent systems in order to protect wildlife (USEPA 2007f). Clearly, storage areas can pose significant risks, which vary depending upon the size of the lagoon, the specific kinds of chemicals and the dispersion of chemicals evaporating into the air.

The Placement of Waste at the Storage Site

Chemical wastes that are explosive, ignitable or reactive should be kept well away from each other. For example, if combustible and explosive wastes are stored near each other, a small fire on-site could have disastrous results, as it did in Riverview, Michigan.

Furthermore, the storage of reactive wastes in containers that begin to leak can release of plume of toxic gas. Several times in the past few years, at the commercial hazardous waste facility in Vickery, Ohio, chemicals have reacted in storage containers, releasing "red clouds" of gas. The chemical released was nitrogen dioxide, a common pollutant formed from the burning of fossil fuels, which can damage lungs upon inhalation of large quantities (ACS 2007). At Vickery, preparatory laboratory tests of the stored chemicals did not indicate that the chemicals would react. After the accidents and further study, they became aware that it was a "delayed reaction" effect. The wastes are now directly injected without prior storage (Schwochow 2007, USEPA 2006b).

Leaking Containers

If barrels or containers leak and this leak goes undetected (or neglected by the company), the wastes could damage the environment, drinking water, air, and endanger people's health and property. In the late 1990s, the owner of a paint manufacturing company was convicted of illegally storing hazardous waste at his facility in eight underground storage tanks. The owner did nothing when he discovered that at least one or more containers were leaking, which were not removed until years later by the EPA. The plant was located near a daycare center, but luckily it appears the leaking tanks did not injure anyone nearby. However, the EPA had to clean up contaminated soil from the area (USEPA 1999).

The Operator's Financial Stability and Implications for Accidents

If there were an accident on or off-site, could the company afford cleanup and medical costs, and long-term health damages or compensation? The accident in Alberton, Montana cost about $3.9 million. Consider the following questions:

- How will the operator manage situations such as the real life examples above?
- Are emergency personnel (firefighters, hospitals, etc.) prepared? If not, who will train them and who will bear the costs?

- Will taxpayers be stuck with the costs of cleanup, medical care, devalued property, and maintenance of the site if the company leaves or goes bankrupt?
- Is there an emergency response plan to cover most emergency situations? Does the emergency plan include evacuation procedures?

Figure 7: *Hazardous waste storage facility*
Photo from www.co.portage.wi.us

Chapter 9

Alternatives to Deep Well Injection

The continued use of deep wells may threaten the environment, water supplies, and possibly people's health. So what are the alternatives? The following chapter explains alternatives to consider.

Toxic Use Reduction

This is one of the most important alternatives to any type of disposal. It simply means reducing the quantity of toxic chemicals used and/or the volume of waste generated by production. In other words, it entails reducing the amount of wastes at the source where it is created, instead of attempting to clean up waste after it's produced. This method includes using less hazardous intermediate products (substitution), reformulating products so that they contain fewer toxic chemicals, and modernizing production equipment to minimize waste. Reducing the amount of waste produced in the first place is often much simpler than attempting to treat or dispose of waste.

While some industrial operations partake in source reduction as well as deep injection, facilities with deep injection wells have initiated far fewer (about half as many) source reduction activities than facilities without wells. Furthermore, between 1990 and 1998, the amounts of wastes injected underground decreased much more slowly than releases to air or, water, land, despite the push of the 1990 national policy emphasizing source reduction (NET 1998). It is clear that deep well injection provides a disincentive for reducing wastes at the source, which hinders waste management progress as a whole.

Many of the source reduction methods mentioned here have been pioneered by the Toxics Use Reduction Institute (TURI) at the University of Massachusetts, Lowell. This organization educates and helps industry, companies and communities develop ways to reduce the use of toxic chemicals. They engage in research and offer training, laboratory services and grants to promote such alternatives (TURI 2007).

Resource Recovery

This involves using constituents of waste for other purposes, for example separating and reusing waste constituents and using waste for energy generation. This is often practiced by metal products manufacturers who recover metals for reuse.

Waste Treatment

This method involves biological, chemical or physical treatment of wastes in attempts to degrade and detoxify wastes. It is also sometimes called neutralization (CDHS 1989).

Chapter 10

Arguments and Responses

This chapter is intended to provide readers with examples of arguments that proponents of deep wells might make and possible counter arguments or responses that one could provide.

Argument 1

Very few incidences of groundwater contamination have occurred in the history of deep wells, with most occurring before the UIC program; current legislation protects groundwater.

- While UIC regulations focus on the protection of underground drinking water sources, there are some problems with this legislation. One of the major inadequacies lies in that there are no requirements for monitoring or testing water quality of groundwater sources near a deep well.
- Some water contamination has occurred since UIC regulations were adopted, including several examples in Florida (see Chapter 6).
- Models and other guarantees of "no-migration" are only predictions; it is impossible to predict the movement of fluids underground

Argument 2

Industry meets all state/federal requirements, so everything is okay.

- The regulations have inadequacies (see Chapter 9; Argument 1).
- No true studies have been done to determine how effective the state/federal regulations are (Wilson 2003).
- Under the federal regulations, public comment periods for permit applications are too short to allow people to properly evaluate and respond to a proposed well (USGAO 2003).
- There are very few restrictions on the types of wastes that can be injected, and even if some types of waste are banned, exemptions can easily be sought.
- There are no specific requirements to do anything if a leak is found. Everything is at the discretion of the UIC director.

Argument 3

Industry cannot live with the liability for failed wells.

- Those that receive the benefits (profits) should bear the costs of poor management and pollution.
- Deep well injection remains one of the cheapest waste disposal methods; if industry is going to use this method, they must be willing to bear the

cost of a possible failure.

- High penalties for failure encourage better management of deep wells by operators and encourage waste reduction and the development of other waste disposal techniques.

Argument 4
The wastes injected into wells are dilute, so they are harmless.

- Small quantities of chemicals can still be toxic. The dose does not make the poison.
- If it is harmless, there must be better ways to deal with it, including recycling and treatment.

Argument 5
Wells are continuously monitored, so everything is under control.

- Self monitoring is suspect (think of the fox guarding the chicken coop)
- Interpretation of monitoring gauges is subjective. Someone with a different perspective (other than industry) would likely be sensitive to changes industry will ignore.
- Some monitoring is optional, e.g. monitoring of USDWs.
- Monitoring methods are insensitive to small leaks.

Argument 6
It's a proven technology; it's been used for years in the oil and gas industries.

- There is a big difference between injecting hazardous wastes or other industrial wastes and injecting what was originally taken out of the earth.
- Even though it's been used for years, we still don't know the long-term effects (a hundred or more years from now) of injecting wastes underground.

Argument 7
The wastes are confined to small areas and they are not migrating.

- How does anybody know? Monitoring ground water or migration of wastes is not required.
- This statement is likely based on modeling, which, as discussed in Chapter 9, is not perfect. Given the many uncertainties about site characteristics and waste compatibility, at best, the model is only "guessing".
- Pressure the state agency to "prove" wastes are not migrating.

Argument 8
The rock's capacity to absorb is infinite.

- This statement contradicts the previous assertion that wastes are not migrating (most arguments in previous example can apply to this).
- There are actually many underground drinking water sources and many areas where the geology is not suitable for deep wells, so in fact it is not "infinite." Research on the capacity of saline aquifers for storage of CO_2, for example, have varied from very low to very high estimations of available storage space that would hold anywhere from one hundred to thousands of years of CO_2 emissions (Bruant 2002).

Argument 9
No one has died and deep well injection is said to pose a low risk to human health, so why worry?

- How can we really prove this? There have been very few health studies conducted near deep well sites.
- People have gotten sick (see Winona, Texas story in Chapter 6). Even if it isn't from the deep injection itself, there are proven health risks involved in the storage and transport of hazardous wastes.
- Many health problems take years to develop following exposure, making it hard to definitively link a cause and a health problem. Cancer, for example, usually takes 20-30 years to develop.

Chapter 11

Conclusions

While the EPA and industry generally endorse deep well injection as a safe and economical waste disposal technology, there are a variety of uncertainties and concerns that remain. The effectiveness of the regulatory system, the deficiency in research regarding the technology's performance and effects on human health, and the unpredictability of the long-term fate of underground wastes are just a few of these concerns. With geologic sequestration of CO_2 and other new projects utilizing underground injection gaining popularity, it is clear that discussion of the technology should no longer be on the back burner. More research is needed and caution should be exercised when utilizing deep well injection. More importantly, toxic use reduction should be the primary waste management method, in order to decrease dependence on deep well injection and other potentially risky waste disposal methods.

For more help in building strong arguments and to discuss ways to engage and involve your community to address a deep well injection project, please contact CHEJ.

Glossary

Annulus: The space between the inner casing and the middle layer of an injection well. The annulus is filled with protective, non-corrosive fluid which is pressurized and monitored to detect leakage.

Aquifer: Underground rock that holds or contains water.

Basin: A structural rock formation that dips downward in a broad, wide shape.

Bedding: A layer of rock formation.

Borehole: A hole drilled into the earth using a drilling rig or hand auger. Deep boreholes can become wells after completion and "development."

Brine: Water that is saturated with salt (sodium chloride).

Casing: A barrier installed in an injection well to prevent collapse of the borehole and to keep the injected fluid in the tubing. Casings are generally made of steel and usually more than one are used.

Confining Bed: A layer of rock or soil that is relatively impermeable and serves to confine water and prevent its movement; also called a confining zone.

Decharacterized Waste: Rendering a hazardous waste non-hazardous by any means, including treatment, dilution, etc.

Dome: Structural rock formations caused by pressures forced upwards. The beds dip in all direction from a central area like an inverted, but distorted cup.

Fault Line: A space or crack in a rock formation caused by movement.

Fissure: A narrow opening or crack of some length and depth usually the result of pressure movements.

Fold: A bend, flexure or wrinkle in rock produced when the rock was in a plastic state.

Fracture: A break, rupture or tear in a mineral formation.

Geology: The science of rock formations.

Hazardous Waste: As defined by the EPA, a hazardous waste is one which illustrates a characteristic of ignitability, corrosivity (very acidic or alkaline), reactivity (unstable; react with other wastes w/ possibility of explosion), or toxicity.

Hydrogeology: A specific type of hydrology, defined as science of water movement through rock and soil.

Hydrology: The science of the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere.

Hydrocarbon: An organic compound containing only carbon and hydrogen and often occurring in petroleum, natural gas, and coal.

Joint: A break in rock mass where there has been no relative movement of rock on either side of the break.

Joint Pattern: A combination of intersecting joints often at approximately right angles.

Mechanical Integrity (MI): A term used to describe the proper operation of an injection well. By regulation, a well with MI demonstrates that (1) there is no significant leak in the casing, tubing or packer and (2) there is no significant fluid movement into an underground source of drinking water through vertical movement channels adjacent to the injection well bore.

Mechanical Integrity Tests: Tests required by regulation (UIC) to show that a well is operating properly.

Packer: Used at the bottom of the annulus to plug the space between the casing and the injection tubing.

Producing Formation: An underground formation of rock which contains oil or gas, which is then extracted for use.

Receiving Formation: This is the area underground into which wastes are injected. Also called the injection or receiving zone.

Strategic Lawsuit Against Public Participation (SLAPP) Suit: These types of lawsuits are typically filed by corporations, real estate developers, government officials, etc. against individuals and groups who oppose them on issues of public interest. [1]

Stratigraphy: The layers of rock in the earth's crust.

Topography: The shape, slope, and other features of the earth's surface.

Tubing: The pipe used to inject waste through a deep well into the receiving formation.

UIC – Underground Injection Control: The UIC program was set up as part of the Safe Drinking Water Act, to protect underground sources of drinking water. Under the UIC, EPA set up minimum regulations for underground injection wells; states formulate their own regulations at or better than these standards to take over primacy for wells in their state.

Underground Source of Drinking Water (USDW): Defined by the EPA as, "An aquifer or a portion of an aquifer that (1) supplies a public water system, or (2) contains a sufficient quantity of ground water to supply a public water system and currently supplies drinking water for human consumption or contains fewer than 10,000 mg/l total dissolved solids, and is not an exempted aquifer (USEPA 2006e).

Note: Primary sources for this glossary were Merriam-Webster online (merriam-webster.com accessed July 2007) and USEPA 2001.

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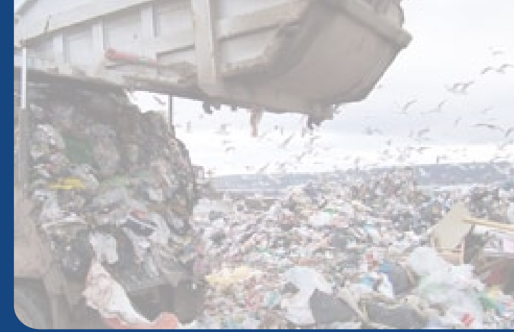

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