Deep Well Injection of Industrial Wastes: Government Controls and Legal Constraints

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Preface

A substantial literature has been developed regarding the physical and, to a lesser extent, economic aspects of industrial waste injection. Little attention, however, has been given to the legal and institutional issues associated with this method of waste disposal. This book attempts to fill that void by describing and analyzing the legal and institutional framework within which waste injection must be accomplished.

The review and evaluation necessary for preparation of this book was complicated by the occurrence of a number of changes within certain elements of the legal and institutional framework while the study was in process. The most significant modification has been the development of a federal control program. Prior to 1970, governmental control of injection activities was almost exclusively a state responsibility. Since the federal program is still in a developmental stage, the level of analysis cannot be as comprehensive as is the case with established state control programs.

The state control programs themselves are subject to relatively frequent change, with the result that an analysis remains current for a limited time only. Several changes that were noted during the course of the study have been incorporated, but other changes in state programs occurring since the initial compilation of data may have escaped detection. Other changes certainly will be made in the near future. Because of the tendency toward frequent change, the primary significance of the summary of statutes and regulations contained in this work is to indicate the range of options in injection well control programs, rather than to serve as a reference for the specific current requirements of a particular state.

The review of existing laws and institutional arrangements upon which this book is based was conducted as a part of a research project funded by the National Science Foundation's program of Research Applied to National Needs (Grant Number GI-34815) and conducted at the Virginia Water Resources Research Center. This NSF-RANN project encompassed two other elements that are not examined in this book. One was an analysis of the determinants of physical feasibility and an assessment of the injection potential of the southeastern United States. This aspect of the research was under the direction of Dr. James E. Hackett. The other additional component of the total project was an economic analysis that included an assessment of the economic potential for injection in the southeastern United States, under the direction of Dr. Burl F. Long. Neither of these study elements is included in this book, which is focused closely on legal and institutional components, but each made an important contribution to the total study.

Acknowledgment also is given to the numerous other contributions to the work. The research would not have been possible without the NSF-RANN funding, and particular appreciation is expressed to Dr. Edward H. Bryan for the assistance he provided as NSF program manager. The assistance and cooperation of many state and federal agencies were indispensable. Appreciation also is expressed to the private firms that provided information and assistance, especially Subsurface Disposal Corporation of Houston, Texas. A number of law students at Washington and Lee University assisted with the legal research, with Jonathan Lynn and Robert Morrison making particularly significant contributions. Tejinder Sibia and Victoria Kok of the Virginia Polytechnic Institute and State University provided valuable bibliographical assistance. Victoria Esarey typed the final manuscript and Richard C. Underwood directed the process of transforming that manuscript into this book. Acknowledgement also is given to the participants in a special workshop held in Williamsburg, Virginia during October of 1974. Like the original research, the workshop was funded by NSF-RANN (Grant Number GI-43675). Although they were not directly involved in the preparation of this manuscript, the workshop participants made a significant contribution through their critical review of a preliminary draft of the total study and their general discussion of injection well management issues. Many of the comments and insights voiced by those workshop participants are reflected in this manuscript.

I
Deep Well Injection: An Overview

Basic Concepts

In the quest for efficient and environmentally satisfactory methods of disposing of the waste by-products of an industrialized society, all the component parts of the earth—including its air, land, and water—have been utilized as a depository. Attempts to dispose of wastes beneath the surface of the earth have long-standing historical precedent. But the true potential of the subsurface to act in this capacity has been intensively explored only recently. Deep well injection of liquid wastes is one technique for utilizing this potential.

Deep well waste disposal is a procedure involving the injection of liquid wastes into subsurface geologic formations by means of wells, and therefore is the inverse operation to pumping ground water from wells. This disposal technique is based on the concept that liquid wastes can be injected into, and contained by, confined geologic strata not having other actual or potential uses of a more beneficial nature, thereby providing long-term isolation of the waste material from man's usable environment. The validity of this concept depends on two basic factors: (1) the presence of suitable receptor zones, and (2) the existence of adequate confinement.

One basic factor determining a formation's suitability as a waste receptor is its capacity to accept the injected waste under reasonable injection pressures without adverse response. Capacity to accept an injected waste is a function of the amount of void space within the formation material (its porosity) and its ability to transmit fluid (its permeability). Therefore capacity varies with the type of formation. Since only a relatively insignificant percentage of underground space exists in the form of large cavernous openings, injection operations typically utilize inter-granular pore space in high porosity materials, or space made up of fractures, joints, and solution channels where certain other materials such as limestone are involved. Another factor of importance is that most of this subsurface space is already occupied by natural water, either fresh or mineralized to some extent. Thus injection does not usually involve the filling of unoccupied space, but rather consists of a compression or displacement of existing fluids. Since the compressibility of water is small, creation of significant volumes of storage space through this mechanism requires disposal strata of large capacity.

Adverse response to injection into a given formation may be either chemical or physical in nature. Possible chemical responses of the disposal formation or its native fluids include reaction with the injected wastes so the formation's capacity to receive the waste is destroyed or impaired. Physical response conceivably could involve stability problems resulting either from the chemical effect of the waste on the formation or from associated pressure increases. Either type of response may adversely affect the feasibility of using a particular formation as a waste receptor.

Another element of the suitability of a receptor zone is the absence of valuable resources that would be destroyed by injection. The principal resource of concern in this regard is ground water. Since many subsurface formations contain mineralized water of unsuitable quality for human consumption and most other uses, this factor may not pose a significant constraint. However, it must be remembered that mineralized water, particularly that of relatively low mineral content, may become a valuable resource in some locations in the future as a result of increases in water demand and advances in desalination technology.

The second basic factor required for validation of the injection concept is the existence of adequate confinement conditions. Thus there must be present a natural barrier to the migration of the injected water upward from the disposal zone into strata containing valuable resources or having more beneficial uses. Such barriers will generally exist in the form of strata of dense, unfractured rock or other impermeable materials such as clay or shale. Although the necessity of having a potential disposal zone overlain by an impermeable formation limits the number of suitable injection sites, such physical occurrences are not uncommon in areas underlain by a sedimentary sequence of deposits.[1]

Deep well injection is primarily a process of long-term waste storage rather than treatment. One of the primary characteristics of the wastes usually injected is their lack of susceptibility to conventional treatment processes. However, in certain cases there is evidence of some degree of subsurface treatment. One of the most obvious situations involves the injection of acidic wastes into carbonate rock. Prolonged contact of these materials would be expected to result in at least partial neutralization of the waste. Measurements of borehole size after a period of injection of acid into such rock has shown an increase in hole diameter,[2] thereby indicating chemical reaction. Decomposition of organic wastes also has been noted in certain cases. For example, studies of organic waste injected at Wilmington, North Carolina indicate bacterial decomposition of low efficiency. The major zone of decomposition was limited to the periphery of the mass of injected waste where dilution had occurred. Greater concentrations of the waste inhibited microbial activity. The studies concluded that complete decomposition of the waste would require a much slower movement of the waste front, and therefore a much lower injection rate than the 200 gal. per min. rate utilized at the site.[3]

As traditionally used, the terms "deep well disposal" and "subsurface injection" do not encompass all subsurface waste disposal operations.

Those that can be excluded include disposal of solids such as is accomplished by landfill operations and by emplacement in excavated chambers, a possible means of disposing of high-level radioactive wastes. Disposal of intermediate-level radioactive wastes by means of cement slurry injection also can be excluded, since the waste and cement mixture does not retain its liquid nature after solidification of the cement. Cement slurry injection also differs in that it utilizes impermeable strata, which are artificially fractured to give the waste access, rather than permeable strata, as are used in conventional liquid industrial waste injection.

In addition, the concept of deep well disposal traditionally has excluded operations which place liquids in the zone of potable ground water. This category includes drainage wells, recharge wells, septic tanks, and land treatment operations such as spreading. The term "deep well disposal" is generally used to denote injection into geologic strata located at depths below the occurrence of potable ground water or other extractable natural resources. In some locations, strata suitable for use as a disposal zone occur near the earth's surface; at others they exist only at considerable depths, or do not exist at all. It is possible for a suitable disposal stratum to overlie others containing valuable resources, provided that it is isolated from both overlying and underlying strata by means of impermeable formations which will effectively confine the waste. Thus the concept of "deep" is relative and cannot be subjected to absolute quantitative limits.

Beneficial and Adverse Consequences

Since public policy concerning injection should reflect all the beneficial and adverse effects of injection relative to alternative methods of waste disposal, it is necessary to identify these effects. The nature of the beneficial and adverse consequences poses serious problems of measurement, but they can be enumerated at the conceptual level.

Beneficial Effects

One of the most direct benefits often associated with waste injection is its lower cost. Due to the wide range of variables affecting the cost of the individual injection well[4] and the variation in available alternatives to meet specific waste disposal problems, generalizations concerning cost comparisons are of little value. Use of injection can result in substantial savings in cases involving wastes that are very costly to treat for disposal into the surface environment, since subsurface confinement greatly reduces the need for treatment. However, proper design and construction of injection wells is an expensive operation, and in some cases the initial capital costs may exceed those of alternative facilities. Thus the principal economic advantage often results from lower operating costs arising from the simplified handling and treatment of wastes prior to disposal. Part of this savings is likely to be in the form of reduced energy consumption, since many conventional waste treatment processes are energy-intensive. Any savings in energy consumption takes on special significance in view of increasing costs.

In addition to direct cost savings, injection also offers potential environmental benefits. One of the most obvious advantages is improved surface water quality relative to conventional methods of liquid waste disposal.

Improvement of surface water quality results in such benefits as reduced treatment costs for other users, greater recreational use, and improved aesthetics. Elimination of a large number of discharges, or perhaps a few discharges of considerable magnitude, would produce very significant benefits. But benefits attributable to the elimination of a single discharge often would be subtle, making precise measurement difficult or impossible. Nevertheless, benefits in some form normally will be produced when a discharge to surface waters is prevented.

In addition to improving surface water quality, deep well injection of wastes also can produce desirable environmental results by improving land utilization, primarily through reduction in the need for waste treatment facilities. Commitment of land to surface waste treatment and storage facilities is a use usually without aesthetic amenities and with a potential for creation of nuisance-like conditions. Since injection usually requires a certain amount of pretreatment, complete elimination of surface facilities usually is not possible. Often, however, injection allows such facilities to be reduced in scope and extent. Reduction in land requirements may be especially significant in urban areas where land is scarce. The greatest potential benefit from reduced land requirements exists in the case of waste lagoons. These often occupy considerable land area and result in almost continuous environmental problems, such as leakage, damage to wildlife, and aesthetic pollution.

Reduction in waste treatment facilities by use of injection wells may also create environmental benefits by decreasing energy consumption. Waste treatment operations consuming large amounts of energy have their own environmental costs, since most forms of energy production have an adverse impact. For example, generation of electricity through use of conventional steam plants requires the mining and combustion of coal, with associated consequences. Similarly, electricity generation by nuclear power plants involves some release of radiation to the environment. These effects are decreased whenever energy consumption is reduced. So waste injection, with its lower energy requirements, has less of an adverse environmental impact than do many waste treatment operations, particularly where advanced or complete treatment is required before discharge into surface waters.

The advantages of deep well waste disposal arise in a general way from the fact that this technique makes possible the utilization of an essentially ignored resource—the space existing within the matrix of subsurface formations. What constitutes a resource is not determined solely by its physical characteristics. In the most fundamental sense, man determines or defines what is a resource at any particular time. This determination is a function of the physical and technological parameters, the social and economic institutions and laws which determine the manner in which the relationships between man and resources occur, and the needs, desires, and demands existing at the time. The concept of a resource in this sense, then, is not one which remains constant. For example, the existence of underground storage capacity may have changed little, if any, over centuries. Only recently, however, has the technology existed to make disposal of wastes in underground space a feasible alternative. Thus the value of this storage capacity as a resource has changed as technology and the demands for more adequate waste treatment and disposal methods have changed. It may continue to change as a number of these factors (other than the physical characteristics) also change.

Adverse Effects

Unlike most other forms of waste disposal, subsurface injection is designed to eliminate, as nearly as possible, *any* adverse environmental impact. In the situation where wastes are not treated completely before being discharged into surface waters, degradation of a basic part of man's usable environment is a necessary consequence. Maintenance of water quality above a predetermined level serves to prevent major adverse impacts, but even minor quality degradations are likely to have some detrimental effect. Since injection into subsurface mineralized waters utilizes a portion of the environment not generally having other existing or anticipated uses, there is no predictable impact.

Still, the possibility exists that environmental degradation may occur as a result of unexpected occurrences or developments. These hazards exist primarily because of imperfect knowledge concerning the physical system involved, its response to injection, and the problem of estimating future demand for other potential subsurface resources. For example, injected wastes may not remain confined in the disposal stratum but may escape because of the existence of an undiscovered break in the confining formation. Likewise, changes in society's needs and/or technological advances may result in the creation of a new subsurface resource in conflict with waste injection. Therefore the adverse environmental consequences of deep well disposal cannot be anticipated and evaluated with any certainty.

Disposal wells substitute some potential for a generally undeterminable amount of damage for the relatively certain occurrence of predictable losses such as are associated with other common types of waste disposal. This important fact conditions acceptance of the technique. If it were possible to determine the probability of different types of related damages, and to estimate expected loss or damage more precisely, this information would be useful in the regulatory decision making process. In the absence of such a function, approaches to handling the associated risk have included (a) complete rejection of subsurface injection, and (b) permitting it only as a temporary last resort where other methods of disposal are not feasible. These approaches place an almost infinitely high risk factor on injection, or, alternately, place an infinite value on other subsurface resources. Few resources, if any, can be accorded an infinite value. Better information on the probability of damages in a geologic sense would allow better estimates of the probable economic damage function.

Adverse effects that could conceivably result from the operation of an injection well may be grouped into four general areas: (1) contamination of natural resources; (2) pre-emption of subsurface storage space; (3) effects of subsurface pressure alterations, and (4) chemical compatibility problems.

Contamination of Natural Resources

The contamination of natural resources is a serious potential problem because of the nature of many injected materials. Many injected wastes are dangerous, long-lived substances whose pollutional effects in the subsurface environment would be detrimental and long-lasting. If such wastes were to contaminate ground water, the toxicity of the waste would be of prime concern. Another important factor, which together with the refractory nature of many of the wastes would result in a long-term effect, is the slow rate of ground water movement. Pollution of ground water thus has a greater degree of permanence than pollution of a surface stream. If injected wastes contaminate subsurface minerals, actual physical destruction is probably not as important a factor as the imparting of objectionable qualities which may make the minerals involved unsuitable for use.

Protecting natural resources that may exist in the disposal strata is complicated by the fact that the definition of what constitutes a resource is not fixed, and varies with changes in technology and the demands of society. Therefore it is conceivable—even likely—that certain natural materials having no present economic value may become useful in the future. For example, saline water currently is used to a very limited extent and therefore is viewed as an acceptable receptor for waste discharge. But increasing demands on a constant supply of potable water, combined with further advances in desalination technology, are likely to give such water added economic significance. Of special interest in this regard is relatively low-salinity brackish water, which can be desalted more economically than water with greater mineral concentrations.

Even if wastes are not injected directly into zones where natural resources occur, contamination can result from horizontal waste migration. Although vertical confinement is generally considered a requirement for an acceptable injection site, little attention normally is given to horizontal movement. The nature of this movement is due primarily to the injection rate, the physical characteristics and dimensions of the injection zone, and the hydrodynamics of the site. Horizontal migration can lead to contamination where natural resources occur at other locations within the disposal stratum, where avenues for vertical migration exist at other locations in the disposal stratum, or where the disposal stratum outcrops.

If waste injection is restricted to strata not containing natural resources at any location which will be affected, contamination may occur through escape of the waste from the disposal zone. Confinement is dependent on the integrity of an overlying impermeable formation. Vertical movement can take place along such natural geologic features as faults; by means of abandoned, unsealed wells or other excavations, or via the injection well itself—due to casing failure or inadequate cementing of the casing through the confining stratum.

The dangers inherent in waste injection in areas of abandoned wells are illustrated by problems experienced in the Port Huron, Michigan area. Numerous oil and gas wells were drilled in the area in the late 1800's and early 1900's before state regulatory controls existed. The location of many of these wells is no longer known, and no information exists concerning plugging operations on abandonment.

A number of waste injection wells have since been installed in Sarnia, Ontario, located across the St. Clair River from Port Huron. Injection apparently began as early as 1958. A number of cases of old wells leaking oil, gas, and brine to the surface were reported in the Port Huron area in 1967, apparently because of increased formation pressures resulting from disposal operations. Other leaks have been reported since. Seepage did not contain injected materials until 1970, when an analysis of seepage from a well, prior to its being plugged, indicated the presence of the waste material phenol.

One approach to alleviating the problem involved an attempt to plug the leaking wells. The state of Michigan appropriated funds for this purpose. Only limited success was reported.

Another approach involved negotiation with representatives of the government of the Province of Ontario to achieve control over the injection itself. The situation was first brought to the attention of the Ontario Department of Energy and Resources Management in 1967. The Province's original position was that disposal operations would continue until the State of Michigan could conclusively prove that injection was the cause of the leaking wells—though the Province was instrumental in gaining reduction in volumes of wastes injected. After a chemical analysis of seepage in 1970 demonstrated that injected fluids were migrating to Port Huron, the Province required a gradual phasing out of waste injection.[5]

Pre-emption of Subsurface Storage Space

The increasing use of underground storage of retrievable substances creates the potential for conflict with subsurface waste disposal operations. Since a given geologic formation has a finite capacity for accepting injected materials, its use as a disposal zone can preclude use for other types of storage. In addition, introduction of waste materials creates a contaminated subsurface environment that imparts objectionable characteristics to the stored material which might interfere with its ultimate use.

One of the principal substances being stored within geologic strata is fresh water. This technique is often an efficient and economical alternative to storage in surface reservoirs, for which suitable sites are becoming scarce. Water stored for later withdrawal is usually placed in fresh water aquifers, thus posing no direct conflict with deep well disposal operations which traditionally utilize saline aquifers. However, there is interest in the possibility of storing fresh water in saline aquifers, and some experimental projects have produced promising results.[6] This type of operation, however, may in some instances be in direct conflict with subsurface waste disposal.

Natural gas is another substance that has been stored in geologic reservoirs.[7] This practice has been employed where suitable reservoirs exist near demand centers so storage can be used to offset peak seasonal usage. Underground storage in some instances is considerably less costly than conventional storage in tanks. Since losses must be kept to a minimum, gas storage reservoirs must possess certain specific characteristics which do not exist in abundance. Depleted gas fields are likely to be prime candidates for this type of operation. Because waste disposal and gas storage are incompatible, use for one type of operation will likely preclude the other and therefore require consideration in the economic analysis of the value of uses precluded.

Effects of Subsurface Pressure Alterations

In many cases, deep well disposal operations result in modification of normal subsurface pressures. Nearly three-fourths of existing wells operate at pressures greater than gravity flow. Another possible source of high pressures is chemical or biological activity such as that resulting from waste decomposition or reaction with native reservoir materials. Pressure increases also may be caused by increased temperatures where radioactive wastes are disposed of in the subsurface.

Perhaps the most exotic potential effect of subsurface pressure increases is the stimulation of seismic activity. The causal relationship between injection and earthquakes has been of interest since a strong correlation was noted between injection into the Rocky Mountain Arsenal Well near Denver, Colorado and numerous earthquakes in the area. Seismic activity has also been noted in connection with other activities affecting subsurface pressures, such as the filling of surface reservoirs. Although other mechanisms have been discussed, the significant factor appears to be a reduction in the friction existing at faults—friction which resists residual stresses that may be present. If the reduction in friction is sufficient to allow movement, the result may be a damaging shock or earthquake. Thus any area where large faults are present, even if they have been inactive for long periods, must be subject to special scrutiny if disposal wells utilizing high injection pressures are proposed.

Another potential problem arising from high subsurface pressures is the fracturing of formations. It is conceivable that use of excessive injection pressures could, in some cases, result in fractures extending to the ground surface, leading to possible personal injury or direct damage to the surface environment. A more likely possibility is the fracturing of the confining stratum, thereby allowing injected waste to escape from the intended disposal zone into other strata where it may produce damage. In some types of injection and mineral extraction operations, high pressures are induced to produce intentional fracturing as a means of reducing resistance to flow within the injection or recovery zone. This practice must be employed carefully when used with industrial waste injection wells to avoid loss of waste confinement.

A further detrimental consequence of the increase in subsurface pressures is the migration of resident fluids, which may be mineralized or have other objectionable qualities. Since the effects of increased pressure travel at a faster rate and have a wider area of influence than the actual movement of the waste itself, significant pollution problems can result from movements of these natural substances in response to injection. For example, natural substances moving in response to pressure increases were the major source of the problems occurring in the previously discussed situation in the area of Port Huron, Michigan as a result of injection around Sarnia, Ontario. Seepage of oil, natural gas, and salt water from abandoned oil wells occurred for a considerable period of time before seepage of the injected waste was detected.

Chemical Compatibility Problems

Compatibility of the injected waste with the formation's rock and fluid can be an important operational problem and also can constitute an environmental hazard under some conditions. One of the most obvious compatibility problems is found when the waste reacts with injection zone materials to form a precipitate that reduces or destroys the permeability of the formation. This problem is of direct concern to the operator, but it can become a hazard where contingency plans do not exist for waste handling in the event of well malfunction. Such plans must provide for well shut-down and an alternative means of waste disposal while the well is out of service. Thus the possibility of compatibility and other operational problems creates a necessity for standby waste disposal or storage facilities so temporary discharges to the usable environment can be avoided.

Another type of compatibility problem posing a potential environmental hazard involves the dissolution of reservoir rock by the injected waste. This is most likely to occur where acidic wastes are injected into carbonate formations. A possible result of such dissolution, on a larger scale, is the subsidence or collapse of the land surface. The probability of such an occurrence appears low where injection takes place at considerable depth. A more likely effect is the localized failure of formations, which could have such detrimental results as destruction of confining strata or damage to the well.

Current Utilization of Waste Injection

Industrial waste injection had its origins in the practice of returning oil field brines resulting from petroleum extraction to subsurface formations. Discharge of salt water to surface waters and use of surface evaporation pits were once widespread, but the problems resulting from these practices ultimately led to their virtual elimination in favor of injection into aquifers already containing saline water. It has been estimated that 74,000 injection wells for oil field brine disposal existed in 1970.[8]

Injection of industrial wastes other than brines has a relatively brief history. A 1964 inventory disclosed the existence of only 30 industrial wastewater injection wells.[9] That number had grown to 110 in a 1967-68 survey[10] and to 246 in 1972.[11] The most recently published data shows a combined total of 333 municipal and industrial waste injection wells either constructed or authorized at the beginning of 1974.[12]

The accompanying listing shows a breakdown of authorized injection wells in 1972 and 1974 by individual states.

Differences in the number of wells between the two listings for a particular state may be due not only to increased usage of industrial injection wells during the period between the surveys, but also to other factors. One important factor is that municipal disposal wells were not included in the 1972 data but were included in the 1974 study. Although injection of municipal wastes is not widespread, this change is significant in certain states such as Florida, where most of the increase in usage can be attributed to this source. Other differences in accounting may also be significant. Both surveys presumably have excluded certain types of disposal wells, such as salt-water injection facilities, but differences in classification of individual wells may result in variation in totals. This factor may have been significant in the case of Kansas, where the total number of wells dropped from 27 in 1972 to 16 in 1974. A decrease in total is not conceivable without changes in classifications, since the lists are intended to be cumulative and include wells which may have been abandoned. North Carolina is another example of an apparent change in usage resulting from an alteration in counting methods. The four wells listed in 1974 are all part of one now-abandoned injection operation which is shown as one well in the 1972 data.

Authorized Injection Wells, 1972 and 1974

State	1972	1974
Alabama	5	5
Arkansas	—	1
California	4	5
Colorado	2	2
Florida	5	9
Hawaii	—	4
Illinois	5	7
Indiana	12	13
Iowa	1	1
Kansas	27	16
Kentucky	3	3
Louisiana	40	77
Michigan	27	32
Mississippi	—	1
Nevada	1	1
New Mexico	1	1
New York	4	4
North Carolina	1	4
Ohio	8	9
Oklahoma	9	14
Pennsylvania	8	9
Tennessee	4	4
Texas	71	104
West Virginia	7	6
Wyoming	1	1
Total	246	333

Surveys of the distribution of injection wells by industry type indicate that the majority of existing wells are operated by chemical, petrochemical, and pharmaceutical companies. Other significant users are petroleum refineries and metal products companies, with a diversity of other industries making relatively minor use.[13] The extent of usage by individual companies ranges from one well in a large number of cases to over 30 wells in one case involving a large chemical company with several plants located throughout the United States.

Physical characteristics of existing injection wells are summarized in the following tables[14] based on the 1972 data:

Physical Characteristics of Injection Wells, 1972

Total Well Depth: *meters*	*feet*	Percent of Wells
0 - 300	0 - 984	8
300 - 600	984 - 1,968	16
600 - 1,200	1,968 - 3,936	29
1,200 - 1,800	3,936 - 5,904	34
1,800 - 3,700	5,904 - 12,136	12
Over 3,700	Over 12,136	1

Injection Rate: *liters per second*	*gallons per minute*	Percent of Wells
0 - 3	0 - 48	36
3 - 6	48 - 95	13
6 - 13	95 - 206	20
13 - 25	206 - 396	17
25 - 50	396 - 792	7
Over 50	Over 792	7

Injection Pressure: *kilograms per square centimeter*	*pounds per square inch*	Percent of Wells
Gravity flow		27
Gravity - 10	0 - 142	22
10 - 20	142 - 284	14
20 - 40	284 - 569	16
40 - 100	569 - 1,422	18
Over 100	Over 1,422	3

Rock Type	Percent of Wells
Sand	36
Sandstone	25
Limestone and Dolomite	35
Other	4

The 1974 data indicates that 278 of the authorized wells had been constructed, and that 178 of these were actually being used for waste injection. An additional 45 wells had been used for waste disposal in the past but were not operational at the time of the survey. Of these, 22 were listed as having been plugged and therefore permanently abandoned. A number of wells had been authorized but not drilled (44) or drilled but never utilized (55).[15]

Policy and Management Issues

Although utilization of subsurface injection has increased in recent years as a result of intensified efforts to reduce the discharge of pollutants to surface waters, concern over possible adverse consequences has also grown, making this disposal technique one of the most controversial. Since waste disposal operations have become a primary concern of government, public officials must function within this controversial atmosphere in formulating policy and operational guidelines defining the role of injection as a wastewater management alternative.

Extensive governmental involvement in injection well management has resulted from the inherent potential of such operations to produce adverse external effects. These externalities do not necessarily require governmental action. In the case of waste disposal, however, direct governmental regulation has developed as the traditional approach, due at least in part to the failure of alternative mechanisms such as private bargaining to effectively restrict the discharge of pollutants.

Public policy and control procedures applicable to waste disposal operations must adequately protect public safety and environmental quality, but within these limits should facilitate the selection of the most cost-effective alternatives. The public should not be required to pay a higher price for conventional environmental protection measures if less costly alternatives exist. Thus a basic policy and management issue concerning subsurface waste injection is what degree of control provides adequate safeguards without unnecessarily frustrating the economic resource created by injection technology.

In addition to governmental controls, injection well management also encompasses institutional constraints in the form of the private rights of individual citizens. Private controls over waste injection exist primarily in the form of property rights and the body of civil law that defines rights and responsibilities where the activities of one party injure or infringe upon the rights of another. These privately enforced controls exist somewhat independently of governmental restrictions and may be significant determinants of the feasibility of injection.

Part I Footnotes

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[10]Robert E. Ives and Gerald E. Eddy, "Subsurface Disposal of Industrial Wastes," Interstate Oil Compact Commission, Oklahoma City, Okla., 1968.

[11]Don L. Warner, *Survey of Industrial Waste Injection Wells,* (3 Vols.) U.S. Geological Survey, Menlo Park, Calif., June, 1972.

[12]*Compilation of Industrial and Municipal Injection Wells in the United States* (2 Vols.), EPA-520/9-74-020, U.S. Environmental Protection Agency, Washington, D. C., Oct., 1974 (hereinafter cited as *Compilation of Injection Wells).*

[13]*Ground Water Pollution from Subsurface Excavations,* EPA-430/9-73-012, U.S. Environmental Protection Agency, Washington, D. C., 1973, p. 37 (hereinafter cited as "Pollution from Excavations").

[14]Taken from "Pollution from Excavations," pp. 38-40 *(supra,* note 13).

[15]*Compilation of Injection Wells,* Vol. I, pp. 7-8 *(supra,* note 12).

II
Governmental Controls Over Waste Injection

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Development of Governmental Controls

The history of injection well regulatory activity parallels the growth of injection practice, with the first controls applicable to oil field brine disposal and administered by state agencies responsible for regulation of the petroleum industry. For example, the Kansas Legislature in 1934 adopted an act giving the Kansas State Corporation Commission control over the subsurface disposal of oil field brine. Regulatory authority over such wastes was expanded in 1945 to include the Kansas State Department of Health, and in 1952, the State Board of Health adopted rules and regulations requiring permits for the use of industrial waste disposal wells other than oil field wells.[1]

Texas is generally credited with enacting the first legislation giving specific consideration to injection of wastes other than oil field brines. The Injection Well Act[2] adopted in 1961 retained the permitting authority of the Texas Railroad Commission with regard to oil field brine disposal wells and required a permit from the Texas Board of Water Engineers for all other types of waste (authority to issue permits for injection of other wastes is now vested in the Texas Water Quality Board[3]).

Considerable activity to establish regulatory programs was initiated in the late 1960's, still primarily at the state level. In 1967, legislation applicable to all types of waste injection was adopted in Ohio as a part of oil and gas law.[4] In 1969, the Michigan Mineral Well Law[5] applicable to waste injection wells was enacted, as was an addition to West Virginia pollution control law covering waste injection.[6] An injection well policy was established in New York in the same year,[7] and the Ohio River Valley Water Sanitation Commission published a recommended policy[8] for its member states.

Expansion of regulatory controls has accelerated in the early 1970's. Several new laws, regulations, and policy statements have been enacted and a number of existing ones have been revised. Some of these recent developments are significant from a historical perspective. In 1970, Colorado adopted a comprehensive set of disposal well rules and regulations.[9] Missouri in 1971 became the first state to prohibit waste disposal wells by means of legislation.[10] In 1973, North Carolina joined Missouri with legislation prohibiting disposal wells,[11] apparently as a result of serious operational problems associated with the state's first injection installation.[12]

The 1970's have also seen considerable developmental activity in the area of federal controls over injection. The federal entry into injection well control is marked by the 1970 adoption of an injection well policy statement[13] by the Federal Water Quality Administration (FWQA), an action not specifically mandated by legislation. This policy statement was revised in 1973 by the Environmental Protection Agency (EPA), successor of FWQA.

A significant milestone in the historical development of federal controls over injection consists of the adoption of the Federal Water Pollution Control Act Amendments of 1972 (FWPCA).[14] The most direct reference to injection is contained in the requirement that states desiring to implement provisions of the act authorizing state administration of a waste discharge permit program in lieu of federal administration must have adequate authority to issue disposal well permits.[15] Pursuant to a directive in FWPCA,[16] EPA in 1973 published a report[17] describing processes, procedures, and methods for the control of pollution from deep well injection and other sources.

Although a principal feature of FWPCA is the establishment of a federal waste discharge permit program, the National Pollutant Discharge Elimination System (NPDES),[18] provisions of law for the program do not specifically encompass injection wells. The basic provision of NPDES is that the discharge of any pollutant without a permit from the EPA Administrator is unlawful, but "discharge of any pollutant" is defined in the act to mean "(A) any addition of any pollutant to navigable waters from any point source, (B) any addition of any pollutant to the waters of the contiguous zone or the ocean from any point source other than a vessel or other floating craft."[19] This definition would appear on its face to exclude subsurface waste discharge from its scope, but the vague and ambiguous definition of "navigable waters" contained in the act requires further consideration. The definition states that "navigable waters" means "the waters of the United States, including the territorial seas,"[20] and therefore lacks the necessary specificity to serve a useful purpose.

Although no explicit inclusion of disposal wells exists in legislative provisions for NPDES, the apparent broadness of the scope of the act led EPA to promulgate rules and regulations for implementation which extended federal jurisdiction to disposal wells in certain situations.

> If an applicant for a permit is disposing or proposes to dispose of pollutants into wells as part of a program to meet the proposed terms and conditions of a permit, the Regional Administrator (of EPA) shall specify additional terms and conditions in the permit which shall (i) prohibit the disposal, or (ii) control the disposal in order to prevent the pollution of ground and surface water resources and to protect the public health and welfare.[21]

This provision was intended to encompass the situation where both injection and surface discharge facilities were operated by a firm. Applicability would also have extended to an injection well used as a replacement for a previously existing surface discharge. In a memorandum concerning the applicability of NPDES to injection wells, the EPA Acting Deputy General Counsel in 1973 indicated that the only situations outside the scope of the permit requirement consisted of existing and new installations which had no surface discharge and relied on wells for all disposal operations.[22]

The position taken by EPA regarding extension of jurisdiction to injection wells related to surface discharge facilities was given some support by precedent in the form of a 1971 federal court decision, *United States* v. *Armco Steel Corp.*[23] The suit was brought by the United States to enjoin the discharge of certain toxic wastes to the Houston Ship Channel in Texas in violation of provisions of the Refuse Act,[24] the principal legal basis for direct federal control over waste discharge prior to enactment of FWPCA. The proposed solution to the discharge problem was an injection well disposal system which was authorized and ordered by the state regulatory agency. After this state authorization, the United States amended its complaint to additionally enjoin use of the injection well system and enforcement of the state order for its use, primarily because of the existence of abandoned oil and gas wells in the area which might have allowed the injected waste to escape from confinement.

Because of the existence of legislation in the form of the Refuse Act,[24] the authority of the United States to regulate the waste discharge to the ship channel was upheld by the court without question. The United States based jurisdiction over the injection well proposal on two theories. Following are exerpts from the court's discussion of these theories and the jurisdictional question in general:

> Plaintiff urges this Court's ancillary jurisdiction over the injection well system on two theories. One is the equity principle that a Court of equity will render complete rather than partial relief, that it will adjudicate by the whole rather than by halves [citation omitted]. This, however, is not an ordinary equity suit wherein a question of law might arise the resolution of which is essential to a conclusion of the suit. This is not the ordinary situation wherein an equity court might exercise ancillary powers to avoid the waste and cost incident to a multiplicity of suits . . . . Federal courts are courts of specified and limited jurisdiction—however supreme they may be within the sphere of their legitimate powers. Federal jurisdiction statutes are to be strictly, not expansively, construed. The statutory basis for this suit arises strictly from constitutional federal authority over the nation's navigable rivers and waterways. The phenomenon of subsurface disposal for industrial wastes might well give rise to Congressional legislative control under the

federal commerce power or other designated federal Constitutional powers. In the present posture of legislation on the subject, both as to territorial and subject matter jurisdiction, it is now primarily the responsibility of the several states.

But the Plantiff also urges the theory of pendent jurisdiction. This is the theory by which a federal court in a substantial federal controversy might also under certain circumstances take cognizance of a similar, parallel or related state claim [citation omitted].

> "Pendent jurisdiction, in the sense of judicial power, exists whenever there is a claim 'arising under the Constitution, the Laws of the United States, and Treaties made, or which shall be made under their Authority . . . . , [citation omitted]' and the relationship between that claim and the state claim permits the conclusion that the entire action before the court comprises but one constitutional 'case' . . . ." [citation omitted].

Application of the doctrine of pendent jurisdiction, however, is a matter of judicial discretion rather than of a litigant's right. It has always been concerned with the graver questions of jurisdiction as well as those of judicial economy, convenience, and fairness to litigants [citation omitted]. It cannot be overlooked that the jurisdictional question here involves in a most basic and direct sense the fundamental allocation of constitutional powers.

A court of equity is a court of conscience but not of omniscience—be it assumed or suggested from without. It is one thing, upon a recognizable statutory basis, to enjoin the continued obstructive pollution of a navigable waterway at the instance, long quiescent, of the Executive power. It is another matter to purport to affirmatively direct the industry in question as to what it must do.[25]

Although the language of the court in the case never deals conclusively with the question of jurisdiction, it is obvious that limitations are recognized. Nevertheless, the suit for injunction was not dismissed completely; rather, a compromise solution was imposed. After noting that it was not within the province of the court to affirmatively direct any one method of waste disposal, the court granted an injunction prohibiting certain discharges to the ship channel and also conditionally enjoined the injection well proposal. The condition imposed as a necessary requirement for using the injection technique was that a number of abandoned wells within a two and one-half mile radius be plugged. This requirement was based on the recommendations of EPA. The court also noted that it was impressed with testimony that other feasible methods of waste disposal were available for use, thereby creating alternatives to the steel corporation if the conditions for use of subsurface injection were unacceptable.

The question of EPA's regulatory jurisdiction over injection wells under FWPCA was officially answered in early 1975 by the U.S. District Court for the Southern District of Texas in *United States* v. *GAF*,[26] a suit brought by EPA challenging the authority of an industry to engage in deep well injection without EPA approval. The court decided the jurisdictional question in the negative and dismissed EPA's attempt to obtain an injunction against the use of the injection wells in question.

The court based its decision on two independent reasons, the first of which consisted of its interpretation that FWPCA does not apply to waste discharges into subsurface waters. EPA's position was based on several provisions of the act which the agency interpreted as granting implied jurisdiction. Two definitions were relied upon by EPA. It was noted that the definition for point source of pollution specifically encompassed wells. The exclusion of certain injections made in connection with oil and gas production was also seen as support since the exclusion was viewed as unnecessary if all subsurface waste discharges were already excluded. Another attempt to establish implied jurisdiction was based on joint consideration of two provisions, one subjecting the federal permit program to the same terms, conditions, and requirements as apply to a State permit program and the other establishing the authority for issuance of injection well permits as a necessary condition for state assumption of NPDES administration. However, the court noted that a proposed amendment that specifically would have extended federal control to ground water had been rejected. Thus it viewed EPA's interpretation that ground water was encompassed by provisions of FWPCA as attempts to build a "jurisdictional back-door"[27] that were opposed by "irrebuttable language and unambiguous action found in the legislative history."[28]

The court's second reason for its decision is perhaps less fundamental and of a more temporary nature. It was held that even if FWPCA encompassed the use of injection wells, the defendant's operations were not in violation of its provisions since the effluent limitations provided for in the Act had not been established. The court noted that the failure of the EPA to establish these limitations in a timely manner had the effect of "allowing, for the time being, the defendant to discharge the wastes in question without the effective federal regulation Congress sought to achieve with the FWPCA."[29]

Although the district court's decision in this case if upheld on appeal effectively would have ended EPA efforts to regulate injection wells under the provisions of FWPCA, the decision had no lasting effect since jurisdiction had clearly been conferred by passage of the Safe Drinking Water Act (SDWA)[30] approved in December, 1974, prior to the final decision in *GAF.* The basic authority concerning injection wells conferred by the SDWA consists of the provision that the EPA administrator develop regulations for state injection control programs that contain minimum requirements to prevent injection which endangers underground drinking water sources. This legislation is presently the primary legal basis for the federal regulatory program with respect to waste injection and is further discussed in the next section concerning existing federal controls.

The Existing Federal Control Program

Injection Well Policy

The current statement of federal policy concerning waste injection wells is embodied in the Environmental Protection Agency's "Administrator's Decision Statement No. 5."[31] The essence of EPA policy is that it ". . . will oppose emplacement of materials by subsurface injection without strict controls and a clear demonstration that such emplacement will not interfere with present or potential use of the subsurface environment, contaminate ground water resources or otherwise damage the environment."[32] The policy statement views subsurface injection as a ". . . temporary means of waste disposal until new technology becomes available enabling more assured environmental protection."[33]

The stated objectives of EPA injection well policy are to:

1. Protect the subsurface from pollution or other environmental hazards attributable to improper injection or ill-sited injection wells.

2. Ensure that engineering and geological safeguards adequate to protect the integrity of the subsurface environment are adhered to in the preliminary investigation, design, construction, operation, monitoring and abandonment phases of injection well projects.

3. Encourage development of alternative means of disposal which afford greater environmental protection.[34]

EPA policy is based on three principal findings. The first is that increasing difficulty of meeting surface water quality standards and the comparative economics of injection wells and conventional treatment methods are creating pressures for more extensive use of the injection technique. The second is recognition that improper injection could result in serious pollution of water supplies or other environmental hazards. The final factor is the uncertainty associated with the effects of injection and the fact that solutions to possible pollution or other environmental damages may be complex, costly, and long-term.[35]

The policy statement contains seven specific criteria to be used for the evaluation of injection proposals. In order for a proposal to be viewed as acceptable, it must be determined that:

> (a) All reasonable alternative measures have been explored and found less satisfactory in terms of environmental protection;
> (b) Adequate preinjection tests have been made for predicting the fate of materials injected;
> (c) There is conclusive technical evidence to demonstrate that such injection will not interfere with present or potential use of water resources nor result in other environmental hazards;
> (d) The subsurface injection system has been designed and constructed to provide maximal environmental protection;
> (e) Provisions have been made for monitoring both the injection operation and the resulting effects on the environment;
> (f) Contingency plans that will obviate any environmental degradation have been prepared to cope with all well shut-ins or any well failures;
> (g) Provision will be made for plugging injection wells when abandoned and for monitoring plugs to ensure their adequacy in providing continuous environmental protection.[36]

Although federal injection well policy has been developed without a specific legislative mandate, the legislative history of the SDWA indicates Congressional endorsement of EPA policy. The committee report accompanying the final version of the act expressed an intent to ratify this policy and indicated that it was to be used as the basis for establishing minimum requirements for state regulatory programs pursuant to the act.[37]

Impact of FWPCA

As indicated previously, the courts have held that the direct regulatory provisions of FWPCA do not apply to injection wells, but the act does extend federal involvement through less direct means. The principal provision of FWPCA concerning injection well control consists of the requirements imposed for state assumption of administrative authority with respect to NPDES. Any state desiring to administer its own program must submit it to the Administrator for approval. Approval of a state program requires that the state have adequate authority to carry out a number of prescribed activities in connection with its administration, one of which is the issuance of permits which ". . . control the disposal of pollutants into wells . . . ."[38] Thus the regulation of disposal wells is made an integral part of the conditions upon which approval of the total state permit program is based.

Approval of a state permit program requires conformity with guidelines developed by the Administrator pursuant to authority contained in FWPCA[39] as well as compliance with specific provisions of the Act itself. These guidelines, entitled "State Program Elements Necessary for Participation in the National Pollutant Discharge Elimination System,"[40] contain somewhat more specific provisions with regard to the control of the disposal of pollutants into wells. The basic requirement is that "[a]ny such disposal shall be sufficiently controlled to protect the public health and welfare and to prevent pollution of ground and surface water resources.[41] State controls must encompass all injection wells:

> A State agency participating in the NPDES shall have procedures to prohibit or control through the issuance of permits all other proposed disposals of pollutants into wells. Following approval of the Administrator of a State program . . . the Director [of the State pollution control agency] shall permit no uncontrolled disposals of pollutants into wells within the State.[42]

The guidelines do not contain specific provisions for evaluation of disposal well proposals; rather, it is specified that such permits be issued in accordance with the procedures and requirements set forth for the issuance of permits in general. Stipulation is made for distribution to the state agency of any policies, technical information, or requirements specified by the Administrator. Any such material is also to be used by the Regional Administrator in his review of disposal well permits proposed to be issued by the state agency.[43] The 1972 Amendments provide for general EPA review of state permit decisions with the exception of specific categories of discharges established by the Administrator.[44]

Guidelines Issued Pursuant to FWPCA

There is a specific requirement in the Act that information to be issued to the state agencies shall include ". . . processes, procedures, and methods to control pollution resulting from . . . (D) the disposal of pollutants in wells or in subsurface excavations . . . ."[45] The basic list of control methods published by EPA[46] pursuant to this directive consists of 10 items, each of which will be briefly reviewed.

"Evaluation of hydrogeologic framework and restriction on unsuitable locations and aquifers for waste water injection." This control measure contains a discussion of the physical factors upon which the feasibility of waste injection depends. The following quotation contains some of the pertinent geologic considerations:

Sedimentary rocks, especially those deposited in a marine environment, are most likely to have the geologic characteristics suitable for waste-injection wells. These characteristics are: (1) an injection zone with sufficient permeability, porosity, thickness, and areal extent to act as a liquid-storage reservoir at safe injection pressures; and (2) an injection zone that is vertically below the level of fresh water circulation and is confined vertically by rocks that are, for practical purposes, impermeable to waste liquids.

Vertical confinement of injected wastes is important not only for the protection of usable water resources, but also for the protection of developed and undeveloped deposits of hydrocarbons and other minerals. The effect of lateral movement of waste on such natural resources also must be considered.

Unfractured beds of shale, clay, slate, anhydrite, gypsum, marl, and bentonite have been found to provide good seals against the upward flow of fluids. Limestone and dolomite may be satisfactory confining strata but these rocks commonly contain fractures or solution channels and their adequacy must be determined carefully in each case.

The minimum salinity of natural water in the injection zone probably will be specified by regulatory agencies in most states, but will be at least 1,000 mg of dissolved solids per liter of water except under unusual circumstances . . . . The minimum salinity in arid regions may be set at a level higher than 30,000 mg./1 of dissolved solids to provide a margin of safety and because water with this dissolved-solids content is used in certain areas to supply desalination plants which produce fresh water . . . .

It has been found that a confining stratum only a meter thick may provide a good seal to retain oil and gas. Such thin confining beds generally would not be satisfactory for containing injected waste because they would be very susceptible to hydraulic fracturing, and even a small fault could completely offset them vertically. Fortunately, in many places hundreds or thousands of feet of impermeable strata enclose potential injection zones and virtually ensure their segregation.

In addition to stratigraphy, structure, and rock properties, which are factors routinely considered in subsurface studies, aquifer hydrodynamics may be significant in the evaluation of waste-injection well sites. The presence of a natural hydrodynamic gradient in the injection zone will cause the injected waste to be distributed asymmetrically about the well bore and transported through the aquifer even after injection has ceased.

Hydrodynamic dispersion (the mixing of displacing and displaced fluids during movement through porous media) may cause much wider distribution of waste in the injection zone than otherwise would be anticipated. Dispersion is known to occur in essentially homogeneous isotropic sandstone, and it could lead to particularly rapid lateral distribution of waste in heterogeneous sandstone and fractured or cavernous strata. Sorption of waste constituents by aquifer minerals retards the spread of waste from the injection site . . . .

Other considerations in the determination of site suitability are: (1) the presence of abnormally high natural fluid pressure and temperature in the potential injection zone that may make injection difficult or uneconomical; (2) the local incidence of earthquakes that can cause movement along faults and damage to the subsurface well facilities; (3) the presence in the area of other wells, or, improperly plugged wells that penetrate the injection zone and provide a means for escape of injected waste to ground water aquifers or to the surface; (4) the mineralogy of the injection zone and chemistry of the resident water, which may determine the injectability of a specific waste; and (5) the possibility that in tectonically unstable areas, fluid injection may contribute to the occurrence of earthquakes.[47]

A summary of the factors considered essential to a hydrogeologic evaluation of an injection well site is contained in the following listing:[48]

Regional Geologic and Hydrologic Framework

Structural geology
Stratigraphic geology
Groundwater geology
Mineral resources
Seismicity
Hydrodynamics

Local Geology and Geohydrology

Structural geology
Geologic description of sedimentary rock units

1. Lithology
2. Detailed description of potential injection horizons and confining beds
   a. Thickness and vertical and lateral distribution
   b. Porosity (type and distribution as well as amount)
   c. Permeability (same as b)
   d. Chemical characteristics of reservoir fluids
3. Groundwater aquifers at the site and in the vicinity
   a. Thickness
   b. General character
   c. Amount of use and potential for use
4. Mineral resources and their occurrence at the well site and in the immediate area
   a. Oil and gas (including past, present and possible future development)
   b. Coal (as in a)
   c. Brines (as in a)
   d. Other (as in a)

"Evaluation of fluids for injection including estimation of nature and extent of chemical reactions between injected fluids and aquifer fluids and minerals, of heat generation and its effects in the case of radioactive wastes and restrictions on those deemed unsuitable." Two general determinants of suitability are discussed. The first is based on the concept that waste injection constitutes the use of limited storage space, thereby indicating

that only concentrated, very objectionable, relatively untreatable waste should be considered for injection. The second aspect of waste suitability is its compatibility with formation fluids and minerals. The principal concern is with destruction of formation porosity through formation of reactions which form precipitates or otherwise result in plugging. The following factors[49] are listed for consideration in evaluating the suitability of untreated industrial wastes for well injection:

Volume

Physical Characteristics

1. Specific gravity
2. Temperature
3. Suspended solids content
4. Gas content

Chemical Characteristics

1. Chemical constituents
2. pH
3. Chemical stability
4. Reactivity
   a. with system components
   b. with formation waters
   c. with formation minerals
5. Toxicity

Biological Characteristics

"Requirement of proper design and construction of injection wells including hardware and sealants." This control measure notes that requirements for construction of injection well facilities must encompass drilling, logging and testing, and completion, with completion for injection purposes to be accomplished only after logging and testing confirms the well's suitability. Specific completion requirements are as follows:

> Design of a casing program depends primarily on well depth, character of the rock sequence, fluid pressures, type of well completion, and the corrosiveness of the fluids that will contact the casing. Where fresh ground water supplies are present, a casing string (surface casing) is usually installed to below the depth of the deepest ground water aquifer immediately after drilling through the aquifer . . . . One or more smaller-diameter casing strings are then set, with the bottom of the last string just above, into or through the injection horizon, depending on whether the well is to be completed as an open hole or is to be cased and perforated.
>
> The annulus between the hole wall and the casing is filled with cement to protect the casing from external corrosion, to increase casing strength, to prevent mixing of the waters contained in the aquifers behind the casing, and to forestall travel of the injected waste into aquifers other than the disposal horizon. Neat Portland cement (no sand or gravel) is the basic material for cementing. Many additives have been developed to impart some particular quality to the cement. Additives can, for example, be

selected to give increased resistance to acid, sulfates, pressure, temperature, and shrinkage.

Temperature logs, cement logs, and other well-logging techniques can be required as a verification of the adequacy of the cementing. Cement can be pressure-tested if the adequacy of a seal is in question.

Waste should be injected through separate interior tubing rather than being in contact with the well casing. This is particularly important when corrosive wastes are being injected. The injection tubing can be made from, or lined with, a material that is not affected by the particular waste involved. A packer can be set near the bottom of the tubing to prevent corrosive waste from contacting the casing. Additional corrosion protection can be provided by filling the annular space between the casing and the tubing with oil or water containing an added corrosion inhibitor.

It is frequently desired to increase the acceptance rate of injection wells by chemical or mechanical treatment of the injection zone. Careful attention should be given to stimulation techniques such as hydraulic fracturing, perforating, and acidizing to ensure that only the desired intervals are treated and that no damage to the casing, cement, or confining beds occurs.[50]

"Requirement of thorough hydrogeologic evaluation during construction and testing of wells." Information to be obtained for a hydrogeologic evaluation includes porosity, permeability, fluid pressures, water samples, identification of geologic formations intersected, thickness and character of disposal horizon, mineral content and temperature of formation, and the amount of flow into various horizons.[51]

"Determination of aquifer characteristics and estimation of aquifer response to injection, and direction and rate of movement of injected fluid and aquifer fluids." The primary considerations here concern the rate of pressure build-up and the lateral extent of waste water movement. Estimates of the rate of pressure build-up are seen as important because ". . . . the maximum pressure at which liquids can be injected may be the factor limiting the safe injection rate and operating life of an injection well."[52] Estimates of the lateral extent of waste water movement are seen as important ". . . . so that the location of the underground space occupied by the waste water can be made a matter of record to be used in regulation and management of the subsurface."[53]

"Restriction on operating programs for injection wells." General requirements for injection well operation include the following:

Injection rates and pressures must be considered jointly, since the pressure will usually depend on the volume being injected. Pressures are limited to those values that will prevent damage to well facilities or to the confining formations. The maximum bottom-hole injection pressure is commonly specified on the basis of well depth. Regulatory agencies have specified maximum allowable bottom-hole pressure of from about 0.11 to 0.23 kilograms per square centimeter per meter of well depth, depending on geologic conditions, but operating pressures are seldom allowed to exceed about 0.18 ksc per meter of depth.

Experience with injection systems has shown that an operating schedule involving rapid or extreme variations in injection rates, pressures, or waste quality can damage the facilities. Consequently, provisions should be made for shut-off in the event of hazardous flow rates, pressure, or waste quality fluctuations.[54]

"Surface equipment and programs for emergency procedures in the event of malfunction, including rapid shutoff and standby facilities and programs for long-term decontamination." Surface equipment described includes holding tanks, flow lines, filters, other treatment equipment, pumps, monitoring devices, and standby facilities. It is stated that provision should be made in all cases for alternative waste management facilities and procedures in the event of injection system failure, with standby wells and holding tanks mentioned as possible alternative facilities. Emergency procedures suggested include special provisions for handling dangerous wastes during failures or remedial operations, notification of nearby users of ground water or other resources, and aquifer rehabilitation programs.[55]

"Abandonment procedures for all wells." No discussion of abandonment procedures or injection wells is given.

"Monitoring programs for injection wells." The following general guidelines are given for monitoring to be performed on injection systems:

Well-head pressure and waste injection rate should be continuously measured. If injection tubing is used, the casing-tubing annulus should be pressure monitored. Other types of monitoring include measurement of the physical, chemical, and biological character of injected fluids on a periodic or continuous basis, and periodic checking of the casing and tubing for corrosion, scaling, or other defects.[56]

"Monitoring programs for aquifers." Provisions for monitoring injection zones and aquifers above or below such zones are as follows:

The possible purposes in monitoring the injection zone or adjacent aquifers are to determine fluid pressures and the rate and direction of movement of the waste water and aquifer fluids.

As discussed by Warner [citation omitted], monitoring with wells to determine the rate and extent of movement of waste water within the injection zone may be of limited value because of the difficulty of intercepting the waste water front and of interpreting information that is obtained.

For these reasons, and because of the cost, few such monitor wells have been constructed.

A more feasible approach is to monitor the fluid pressure in the injection zone or adjacent aquifers. A larger number of monitor wells have been constructed for this purpose. Goolsby [citation omitted] discusses an example of an injection system where a monitor well was useful for both detection of waste travel and measurement of reservoir fluid pressure.

The most common type of monitor well used in conjunction with waste water injection systems is that constructed in the fresh water aquifers near the injection well. If these wells are pumping wells, they provide a means for detecting (eventually) leakage from the injection well or injection horizon; pollutants entering the supply aquifer will tend to move toward a discharging well. Changes in the quality of water in springs, water supply wells, streams, and lakes may also be monitored to detect effects from waste disposal wells.[57]

Comprehensive environmental evaluation requires the establishment of an extensive data base. In order to make such an evaluation possible and to implement its injection well policy, EPA has compiled a detailed listing[58] of information to be provided by the injector. These requirements are appended to the guidelines developed pursuant to FWPCA and include the following:

(a) An accurate plat showing location and surface elevation of proposed injection well site, surface features, property boundaries, and surface and mineral ownership at an approved scale.

(b) Maps indicating location of water wells and all other wells, mines or artificial penetrations, including but not limited to oil and gas wells and exploratory or test wells, showing depths, elevations and the deepest formation penetrated within twice the calculated zone of influence of the proposed project. Plugging and abandonment records for all oil and gas tests, and water wells should accompany the map.

(c) Maps indicating vertical and lateral limits of potable water supplies which would include both short- and long-term variations in surface water supplies and subsurface aquifers containing water with less than 10,000 mg/1 total dissolved solids. Available amounts and present and potential uses of these waters, as well as projections of public water supply requirements, must be considered.

(d) Descriptions of mineral resources present or believed to be present in area of project and the effect of this project on present or potential mineral resources in the area.

(e) Maps and cross sections at approved scales illustrating detailed geologic structure and a stratigraphic section (including formations, lithology, and physical characteristics) for the local area, and generalized maps and cross sections illustrating the regional geologic setting of the project.

(f) Description of chemical, physical, and biological properties and characteristics of the fluids to be injected.

(g) Potentiometric maps at approved scales and isopleth intervals of the proposed injection horizon and of those aquifers immediately above and below the injection horizon, with copies of all drill-stem test charts, extrapolations, and data used in compiling such maps.

(h) Description of the location and nature of present or potentially usable minerals from the zone of influence.

(i) Volume, rate, and injection pressure of the fluid.

(j) The following geological and physical characteristics of the injection interval and the overlying and underlying impermeable barriers should be determined and submitted:

(1) Thickness;
(2) areal extent;
(3) lithology;
(4) grain mineralogy;
(5) type and mineralogy of matrix;
(6) clay content;
(7) clay mineralogy;
(8) effective porosity (including an explanation of how determined);
(9) permeability (including an explanation of how determined);
(10) coefficient of aquifer storage;
(11) amount and extent of natural fracturing;
(12) location, extent, and effects of known or suspected faulting indicating whether faults are sealed, or fractured avenues for fluid movement;
(13) extent and effects of natural solution channels;
(14) degree of fluid saturation;
(15) formation fluid chemistry (including local and regional variations);
(16) temperature of formation (including an explanation of how determined);
(17) formation and fluid pressure (including original and modifications resulting from fluid withdrawal or injection);
(18) fracturing gradients;
(19) diffusion and dispersion characteristics of the waste and the formation fluid including effect of gravity segregation;
(20) compatibility of injected waste with the physical, chemical and biological characteristics of the reservoir; and
(21) injectivity profiles.

(k) The following engineering data should be supplied:
(1) Diameter of hole and total depth of well;
(2) type, size, weight, and strength, of all surface, intermediate, and injection casing strings;
(3) specifications and proposed installation of tubing and packers;

(4) proposed cementing procedures and type of cement;
(5) proposed coring program;
(6) proposed formation testing program;
(7) proposed logging program;
(8) proposed artificial fracturing or stimulation program;
(9) proposed injection procedure;
(10) plans of the surface and subsurface construction details of the system including engineering drawings and specifications of the system (including but not limited to pumps, well head construction, and casing depth);
(11) plans for monitoring including a multi-point fluid pressure monitoring system constructed to monitor pressures above as well as within the injection zones; and description of annular fluid;
(12) expected changes in pressure, rate of native fluid displacement by injected fluid, directions of dispersion and zone affected by the project;
(13) contingency plans to cope with all shut-ins or well failures in a manner that will obviate any environmental degradation.

(1) Preparation of a report thoroughly investigating the effects of the proposed subsurface injection well should be a prerequisite for evaluation of a project. Such a statement should include a thorough assessment of: 1) the alternative disposal schemes in terms of maximum environmental protection; 2) projection of fluid pressure response with time both in the injection zones and overlying formations, with particular attention to acquifers which may be used for fresh water supplies in the future; and 3) problems associated with possible chemical interactions between injected wastes, formation fluids, and mineralogical constituents.

These information requirements and provisions for injection well control programs were developed prior to enactment of the SDWA. Since this legislation provides for development of minimum requirements for state regulatory programs, these existing controls will have to be coordinated with the new regulations. The legislative history of SDWA expresses an intent that the program developed under the act be administratively compatible with, and nonduplicative of, the permit provisions of FWPCA.[59] Thus, it would appear that some degree of consolidation of program guidelines developed under the two acts will be necessary.

Impact of SDWA

The SDWA is the most comprehensive federal legislation enacted to date with regard to subsurface waste injection. A major concern reflected in the Act is protection of underground sources of drinking water. The principal regulatory measure is contained in the provision that the Administrator of EPA develop regulations for state injection control programs which contain minimum requirements to prevent waste injection which endangers underground sources of drinking water.[60] The Act provides that injection endangers drinking water if it may result in the failure of any public water system to comply with water quality standards to be developed by EPA pursuant to SDWA or otherwise adversely affect the health of persons.[61] The Act's legislative history indicates that this provision is to be construed liberally so as to protect potential drinking water sources as well as currently used sources. It is indicated that Congress intended the Administrator to provide protection for all subsurface water having less than 10,000 ppm dissolved solids.[62]

The Act provides for state assumption of enforcement responsibility upon the approval by the Administrator of EPA.[63] A state must comply with various procedural requirements in order to acquire and maintain enforcement responsibility, but the primary condition is adoption and implementation of an injection control program consistent with regulations developed by EPA under SDWA. If a given state does not apply for enforcement responsibility or if the state program is disapproved, the Administrator is authorized to prescribe a program for such state.

Where EPA has enforcement authority in a given state, the Administrator is to enforce compliance with the injection control program by means of civil actions in U.S. district court. EPA is also authorized to bring such actions to compel compliance where a state has obtained enforcement authority, but exercise of such authority cannot be accomplished prior to exhaustion of specified procedural requirements designed to give the state an opportunity to act.[64] The enforcement authority of a state can be terminated after a public hearing by rule of the Administrator where requirements for approval are no longer being met.[65]

The SDWA gives the EPA Administrator considerable discretion in developing injection well regulations, but certain specific requirements are enumerated. The Act provides that the regulations:

> (A) shall prohibit, effective three years after the date of the enactment of this title, any underground injection in such State which is not authorized by a permit issued by the State (except that the regulations may permit a State to authorize underground injection by rule);
>
> (B) shall require (i) in the case of a program which provides for authorization of underground injection by permit, that the applicant for the permit to inject must satisfy the State that the underground injection will not endanger drinking water sources, and (ii) in the case of a program which provides for such an authorization by rule, that no rule may be promulgated which authorizes any underground injection which endangers drinking water sources;
>
> (C) shall include inspection, monitoring, recordkeeping, and reporting requirements; and

(D) shall apply (i) as prescribed by section 1447 (b), to underground injections by Federal agencies, and (ii) to underground injections by any other person whether or not occurring on property owned or leased by the United States.[66]

The Act places the following restrictions on the regulations as they apply to injection associated with oil and gas production:

Regulations of the Administrator under this section for state underground injection control programs may not prescribe requirements which interfere with or impede—

(A) the underground injection of brine or other fluids which are brought to the surface in connection with oil or natural gas production, or

(B) any underground injection for the secondary or tertiary recovery of oil or natural gas,

unless such requirements are essential to assure that underground sources of drinking water will not be endangered by such injection.[67]

These special provisions reflect the fact that the goal of ground water protection is somewhat in conflict with maximizing energy production. While injection related to energy development is to be given special consideration, the act does not exclude such operations from regulation as did FWPCA. The legislative history indicates an intent that such operations be regulated where essential to assure protection of underground drinking water sources but not be subjected to requirements that would stop or substantially delay production of oil or gas.[68]

The SDWA contains special provisions[69] applicable during the three-year interim period while injection control programs are being developed. Although federal jurisdiction generally will not be established during this period, the act provides for designation of special management areas within which new injection wells cannot be operated without an EPA permit. Such areas can be designated by the Administrator upon the petition of any person if he finds that the area has one aquifer which is the sole or principal source of drinking water and which, if contaminated, would create a significant hazard to public health. Permits for new injection wells in such designated areas can be issued only if the Administrator finds that operation of the well will not cause contamination of the aquifer so as to create a significant hazard to public health, and the issuance of permits may be conditioned on such control measures necessary to prevent hazardous contamination.

Another aspect of such designation consists of restrictions on federal funding of projects within the area. The Act provides that after designation ". . . no commitment for Federal financial assistance (through a grant, contract, loan guarantee, or otherwise) may be entered into for any project which the Administrator determines may contaminate such aquifer through a recharge zone so as to create a significant hazard to public health . . . ."[70] This provision is therefore a potentially significant constraint on the development of certain geographical areas.

In recognition of the possible difficulties of some states in processing all injection well permit applications before the three-year deadline established by the SDWA, the Act provides for state issuance of temporary permits for an additional year under the following conditions:

> (A) the Administrator finds that the State has demonstrated that it is unable and could not reasonably have been able to process all permit applications within the time available;
>
> (B) the Administrator determines the adverse effect on the environment of such temporary permits is not unwarranted;
>
> (C) such temporary permits will be issued only with respect to injection wells in operation on the date on which such State's permit program approved under this part first takes effect and for which there was inadequate time to process its permit application; and
>
> (D) the Administrator determines the temporary permits require the use of adequate safeguards established by rules adopted by him.[71]

Temporary permits applicable to particular injection wells and the injection of particular fluids can be issued to be effective during the additional year which pose some danger to drinking water sources, but permit conditions are even more restrictive. Authorization for issuance of such permits requires application to EPA by the Governor of the state involved after public hearing and provided:

> (A) that technology (or other means) to permit safe injection of the fluid in accordance with the applicable underground injection control program is not generally available (taking costs into consideration);
>
> (B) that injection of the fluid would be less harmful to the health than the use of other available means of disposing of waste or producing the desired product; and
>
> (C) that available technology or other means have been employed (and will be employed) to reduce the volume and toxicity of the fluid and to minimize the potentially adverse effect of the injection on the public health.[72]

Regulations Developed Pursuant to SDWA

One of the potentially controversial aspects of the underground injection control (UIC) regulations developed pursuant to SDWA concerns their scope. This potential problem exists because of the failure of SDWA to clearly specify the types of activities to be regulated. The term generally used in the Act to describe the activities encompassed is "underground injection," which is simply defined as "the subsurface emplacement of fluids by well injection."[73] This lack of specificity leaves the scope of the Act somewhat open to question.

In order to establish more workable guidelines, the currently proposed UIC regulations[74] further define the term "well injection" to mean ". . . subsurface emplacement through a bored, drilled, or driven well, or through a dug well where the depth is greater than the largest surface dimension, whenever a principal function of the well is the subsurface emplacement of fluids."[75] Within this general definition, three specific classifications of wells are identified and subjected to individualized controls. Included are "waste disposal wells and engineering wells," "injection wells related to oil or gas production," and "other underground injections."

The category of "other underground injections" offers the greatest potential for controversy. At present it appears to be limited to agricultural and urban drainage wells,[76] but the regulations indicate that this category is likely to be expanded in the future to include other excavations such as lagoons that result in introduction of wastes to the underground. The current scope of this category therefore is much more restricted than that of the UIC regulations as originally proposed.[77] The original proposal would have extended control to a wide range of activities not coming within the traditional meaning of the term "well injection," including disposal and other activities involving excavations with surface dimensions greater than their depth.[78]

The authority for EPA to encompass these other activities within the UIC regulations is somewhat questionable. By consistent use of the term "underground injection" to describe the activity to be regulated, SDWA does not clearly reflect an intent to encompass other potential sources of ground water contamination not involving injection wells. EPA is taking a very broad view of what constitutes "injection" and what is a "well," but SDWA itself contains little evidence that these terms are to be expanded from their conventional meanings. The EPA position is being based in large part on the following statement from SDWA's legislative history:

> The definition of "underground injection" is intended to be broad enough to cover any contaminant which may be put below ground level and which flows or moves, whether the contaminant is in semi-solid, liquid, sludge, or any other form or state.
>
> This definition is not limited to the injection of wastes or to injection for disposal purposes; it is intended also to cover, among other contaminants, the injection of brines and the injection of contaminants for extraction or

> other purposes. While the Committee does not intend this definition to apply to septic tanks or other individual residential waste disposal systems, it does intend that the definition apply to a multiple dwelling, community or regional system of injection of waste.[79]

The currently proposed UIC regulations quote the first paragraph and first sentence of the second paragraph of the above quotation in support of the position that ". . . . the nature of the fluid emplaced and the depth of the emplacement are not limiting factors in determining which 'well injection' practices are to be covered by the underground injection control regulations."[80] An obvious intent of this provision in the legislative history is to insure inclusion of substances injected during oil field operations. However, there is no positive statement in these provisions which suggests that the UIC regulations are intended to encompass methods of emplacement other than conventional injection by means of wells.

It is possible that the last sentence in the above quotation concerning waste disposal systems serving more than one residential unit could be interpreted to mean that all septic systems serving multiple units were to be included. However, it is significant to note that the statement concerning septic systems serving more than one residential unit does not necessarily apply to all multiple connection septic systems but applies to a ". . . . multiple dwelling, community, or regional *system of injection of waste* [emphasis added]." Conventional injection wells have been used to dispose of sewage and can be distinguished from the typical facility for underground sewage disposal. Therefore the scope of this provision may not be broad enough to encompass traditional systems of underground sewage disposal even where multiple residential units are served.

With regard to waste lagoons, a provision in SDWA which suggests that its authors did not intend inclusion consists of the directive for the EPA Administrator to carry out various studies, including the following:

> (5) The Administrator shall carry out a study of methods of underground injection which do not result in the degradation of underground drinking water sources . . . .
>
> (8) The Administrator shall carry out a study of the nature and extent of the impact on underground water which supplies or can reasonably be expected to supply public water systems of . . . . (C) ponds, pools, lagoons, pits, or other surface disposal or contaminants in underground water recharge areas.[81]

While there is no explicit statement in these provisions to the effect that injection does not include the other waste handling operations enumerated, the fact that separate provisions are utilized implies that the different categories enumerated were viewed as distinct.

It appears that the strongest support for inclusion of these other waste handling operations within the scope of "injection" is the expressed intent of SDWA to protect underground sources of drinking water. Waste disposal operations and other activities not encompassed by the conventional definition of injection in aggregate pose a greater hazard to ground water than do conventional injection wells and therefore need to be regulated. Thus a liberal interpretation would likely uphold the proposed scope of the UIC regulations as a valid exercise of authority while a stricter interpretation based on the precise language of the statute possibly would result in a determination that EPA is attempting to construct another "jurisdictional backdoor" as was determined in the courts when EPA attempted to extend the provisions of FWPCA to activities not encompassed by the statute.

With regard to the substance of the proposed regulations, separate controls are provided for each of the three categories of underground disposal identified previously. The first of these categories—waste disposal wells and engineering wells—includes industrial and municipal waste disposal wells, subsidence control wells, barrier wells, recharge wells, mining wells, storage wells, and geothermal wells. The regulations require that such wells be regulated by means of individual permits for each installation. A temporary exception to the permit requirement exists in the case of injection wells existing when a particular state program is approved by EPA. For a period of up to five years after program approval, such wells may be regulated by rule, provided underground drinking water sources are not endangered.[82]

During this five-year period, each existing well must be reviewed to assure compliance with the following requirements, which also apply to new injection wells:

> The Director shall review data on each existing underground injection and on each proposed new underground injection to assure that:
>
> (a) All underground drinking water sources of 3,000 mg/1 total dissolved solids or less are protected by casing cemented to the surface; except that the State may require some lesser degree of protection by casing in those areas where, pursuant to public hearing, compelling evidence has demonstrated that the lesser degree of protection will prevent endangerment of underground drinking water sources;
>
> (b) The long string is cemented with sufficient cement to fill the annular space to a height above the injection zone adequate to assure that upward migration of fluid cannot occur;
>
> (c) Injection is maintained through tubing with a suitable packer set immediately above the injection zone;

(d) There are no leaks in the system;

(e) Surface injection pressure is limited to preclude the possibility of fracturing the formulation;

(f) All well completion and plugging reports for wells penetrating the proposed injection zone within a two-mile radius of the proposed well injection should be thoroughly reviewed to insure that all wells are properly completed and/or plugged that in the judgment of the Director present a potential threat to underground drinking water sources; and

(g) Annular injection is not practiced.[83]

Application for a UIC permit requires submission of the following data by the applicant:

(a) Ownership and Location Data—The application shall identify the owner and operator of the proposed underground injection facility, and the location of the facility.

(b) An accurate map showing location and surface elevation of the injection facility, property boundaries, and surface and mineral ownership.

(c) An accurate map showing the location of: water wells; surface bodies of water; oil, gas, exploratory or test wells (with depths of penetration); mines (surface and subsurface) and quarries; and other pertinent surface features including residences, roads, bedrock outcrops, and faults and fractures within a two-mile radius of the injection facility.

(d) A tabulation of all wells requested under (c) penetrating the proposed injection zone, showing operator; lease or owner; well number; surface casing size and weight, depth and cementing data; intermediate casing size and weight; depth and cementing data; long string size and weight, depth and cementing data; and plugging data.

(e) Maps and cross sections indicating the vertical and lateral limits of acquifers containing 3,000 and 10,000 mg/1 TDS water quality levels, and direction of movement of the water in every underground drinking water source which may be affected by the proposed injection.

(f) Maps and cross sections detailing geologic structure for the local area and generalized maps and cross sections illustrating the regional geologic setting.

(g) Description of chemical, physical, and biological properties and characteristics of the fluid to be injected.

(h) Volume, injection rate, and injection pressure of the fluid to be injected.

(i) The following geological and physical characteristics of the injection interval and the overlying and underlying confining beds:

(1) thickness;
(2) areal extent;
(3) lithology;
(4) location, extent and effects of known or suspected faulting, fracturing and natural solution channels;
(5) formation fluid chemistry, including total dissolved solids; and
(6) fracturing gradients.

(j) The following engineering data:
(1) diameter of hole and total depth of the well;
(2) type, size, weight, and strength of all casing strings;
(3) proposed cementing procedures and type of cement;
(4) proposed formation testing program;
(5) proposed stimulation program;
(6) proposed injection procedure;
(7) plans of the surface and subsurface construction details of the system including engineering drawings;
(8) plans for monitoring both well head and annular fluid pressure, fluids being injected in injection zone and other aquifers;
(9) expected changes in pressure, native fluid displacement and direction of movement of injected fluid; and
(10) contingency plans to cope with all shut-ins or well failures to prevent endangerment of underground drinking water sources.

(k) A written evaluation of alternative disposal practices in terms of maximum environmental protection.[84]

Required procedures for action on UIC permit applications include public notice whenever a preliminary determination in favor of permit issuance is reached.[85] In addition to general notice within the geographical area of the proposed injection, notification of other appropriate government agencies and/or foreign countries is required.[86] Notice must be given to the agency responsible for injection regulation in any other state whose waters may be affected by issuance of the permit in question. Any such state is authorized to submit written recommendations with regard to the application, and written explanation must be presented to any such state and EPA Regional Administrator for the affected area whenever such recommendations are not accepted.[87] Where significant public interest exists, a public hearing is required. Final approval of an application can be given only if consideration of all pertinent information leads to the finding that the proposed injection will not endanger underground drinking water sources.[88]

The UIC regulations require that permits must be subjected to a variety of conditions as set forth in the following quotation:

State procedures must insure that the terms and conditions of each issued UIC permit comply with the following:

(a) Adherence to any applicable more stringent limitations including those (i) necessary to meet treatment standards and/or schedules of compliance, established pursuant to State law or regulation, or (ii) necessary to meet other Federal law or regulations;

(b) Allowance of no underground injection of contaminants until after:
(1) The use of appropriate techniques for construction, operation and maintenance of the injection system; and
(2) Provisions for inspection, monitoring, record keeping and reporting of the underground injection operation;

(c) Allowance of no contaminant to enter an underground drinking water source if the presence of such contaminant may endanger such drinking water source;

(d) Adequate contingency plans to cope with malfunctions or failure of the underground injection system;

(e) Adequate procedures for detecting failure of the system in a timely fashion;

(f) Provisions for such measures as the Director finds necessary to assure the availability of adequate financial resources for dealing with underground injection systems which either are improperly abandoned or may otherwise cause contamination of underground drinking water sources;

(g) That all injections authorized by the UIC permit shall be consistent with the terms and conditions of the permit and that the injection of any contaminant at a greater rate or pressure than that authorized by the permit or a volume in excess of that authorized by the permit shall constitute a violation of the terms and conditions of the permit;

(h) That the permit may be modified, suspended, or revoked in whole or in part during its term for cause including, but not limited to, the following:
(1) The underground injection endangers underground drinking water sources;
(2) Violation of any material terms or conditions of the permit;
(3) Obtaining a permit by misrepresentation or failure to disclose fully all relevant facts; or
(4) A change in any condition that may indicate failure of the underground injection system;

(i) That the permittee shall allow the Director or his authorized representative, upon the presentation of appropriate credentials;
(1) To enter the permittee's premises in which a contaminant source or injection source or injection system is located and in which any records are required to be kept under terms and conditions of the permit;
(2) To have access to and copy records required to be kept under terms and conditions of the permit;
(3) To inspect the permittee's facilities, including any monitoring equipment or analytical devices; and

(4) To sample any fluids being injected, and if sampling of the injection zone and other aquifers is required by the permittee under the monitoring plan of the permit, to also have the right to sample those zones;

(j) That the permittee at all times shall maintain in good working order and operate efficiently facilities or systems of control installed by the permittee to achieve compliance with terms and conditions of the permit.

(k) That immediately following the permanent cessation of underground injection or where a well is not completed, the permittee shall notify the Director and follow the procedures prescribed by the Director for plugging and abandonment; and

(l) That the permittee shall submit copies of all workover orders to the Director.[89]

With regard to monitoring and record keeping, the regulations contain the following provisions:

Each permittee shall keep on forms prescribed by the Director complete and accurate records of:

(a) All monitoring required in the permit which will include, but not be limited to:
(1) Weekly readings of the surface injection pressure;
(2) Weekly readings of the tubing—long string annulus pressure;
(3) Weekly total volume of injected fluid; and
(4) Weekly average injection volume (bbls/day).

(b) All periodic well tests, including but not limited to:
(1) Water analyses;
(2) Bottom ho'e pressure readings of the injection zone;
(3) Well conditions; and

(c) All shut-in periods, times contingency measures used for handling the fluid to be injected.

(d) The permittee shall retain, for a period of five years, records of all information resulting from any monitoring activities required by the UIC permit or by regulation. This requirement shall continue in effect during the five-year period following abandonment of the well. The period of retention shall be extended when requested by the Director; and

(e) Records of monitoring activities and results shall include for all samples; (1) the date, place and time of sampling; (2) the dates analyses were performed; (3) who performed the analyses; (4) the analytical techniques/methods; and (5) the result of such analyses.[90]

The second category of injection wells subjected to special controls—those related to oil and gas production—encompasses wells used for disposal of brines and those used in secondary and tertiary recovery operations. As in the case of municipal and industrial injection wells, the UIC regulations require permitting on a case-by-case basis after an initial period during which existing wells can be regulated by rule. The UIC regulations contain comprehensive regulatory provisions for this type of injection well,[91] but they will not be considered further here since the scope of this study is limited to industrial injection wells.

The regulations provide for more flexibility in the control of the third category of wells,[92] which at present is limited to agricultural and urban drainage wells. Such wells may be regulated either by permit or rule. This type of disposal well is also outside the scope of the present study.

Constitutionality of Federal Controls Over Ground Water Quality

Extension of federal regulatory activity to encompass ground water quality is a substantial expansion in scope of federal water resources jurisdiction, and the constitutional validity of this activity has not been considered directly by the courts. Nevertheless, there is considerable legal precedent which suggests that this action is a constitutional exercise of federal authority.

The primary basis for federal regulatory programs with respect to water resources has been the commerce clause of the U.S. Constitution.[93] An alternative basis for action in the case of direct federal investment in water resources development is the general welfare clause,[94] but this source of authority appears to be limited to actions involving the raising and disposition of tax revenues. Therefore, the welfare clause would likely serve as a basis for the expenditure of federal funds for waste treatment facilities but probably would not justify the regulation of water polluting activities.

The most direct application of the commerce clause to water resources arises through governmental control over navigable waters. The commerce clause was first held to encompass navigation by the U.S. Supreme Court in the 1824 case of *Gibbons* v. *Ogden*[95] and has continued to serve as the basis for most governmental controls. The authority to regulate navigation has subsequently been expanded to include a wide range of controls over navigable waters themselves, and the definition of "navigable" has likewise undergone expansion to include several classes of water not falling within the strict physical meaning of the term. Waters that fall within the navigable classification include those that can be made navigable by reasonable improvements;[96] those that at some past period have been navigable;[97] and those that, although nonnavigable themselves, affect the navigable capacity of a navigable body of water.[98] The result of these expansions is that essentially all waters fall within the scope of federal controls, at least in the case of surface waters.

No direct attempt has been made to include ground water within the navigable classification, but it is possible that such an attempt would be upheld by the Supreme Court in view of previous extensions of the definition, particularly in the case of nonnavigable tributaries. An analogy might be drawn between this extension and the inclusion of ground water within the navigable classification since there is an intimate connection between surface and ground water. In fact, the greatest portion of stream flow may be attributable to ground water discharge during substantial periods of time. Thus the argument that ground water is subject to federal control because of its effect on the navigable capacity of surface waters appears plausible.

However, it is unlikely that such a tenuous approach would be necessary to sustain the validity of federal controls. The commerce clause is considerably broader than the navigation power alone, and protection of water quality, both surface and subsurface, appears to be justified on other grounds. The following language from the legislative history of SDWA suggests the possible justifications for federal jurisdiction arising from other aspects of the commerce clause:

> That the causes and effects of unhealthy drinking water are national in scope is evident from a variety of facts. Federal air and water pollution control legislation have increased the pressure to dispose of waste materials on or below land, frequently in ways, such as subsurface injection, which endanger drinking water quality. Moreover, the national economy may be expected to be harmed by unhealthy drinking water and the illnesses which may result therefrom. This is the case for several reasons. First, outbreaks of waterborne disease are likely to inhibit interstate travel and tourism in or through the areas in which the water is unsafe. Second, the economic productivity of those engaged in interstate commerce or activities affecting commerce is likely to be diminished to the extent that unsafe drinking water causes illness and absence from the place of employment. Third, agricultural employees who migrate across State lines may properly be reluctant to work in areas with only contaminated water supplies. Those who have contracted communicable disease may be barred from entering other States. Fourth, diseases caused by contaminated drinking water may be communicable beyond State lines. Fifth, contaminants which endanger the public health when present in drinking water are frequently generated by business engaged in or enterprises affecting interstate commerce. Sixth, the unavailability of a reliably safe drinking water supply may well be a primary limiting factor in the

economic growth of a town or region and ultimately in the growth of the Nation's economy.

Other factors also illustrate the need for national concern about unsafe drinking water. Underground drinking sources which carry contaminants may cross State boundaries. In general, water in the hydrologic cycle does not respect State borders. The Nation also has an important fiscal interest in minimizing drinking water-related disease, since such disease may well contribute significantly to the drain on the Federal health care financing system—Medicare, Medicaid, etc.—unless the quality of the Nation's drinking water supplies is protected.[99]

Prior decisions of the Supreme Court interpreting the extent of the Commerce Clause indicate that the suggested relationships of water pollution to interstate commerce would be accepted by the Court as a basis for upholding the constitutionality of federal controls to protect ground water quality. Several cases exist where only an indirect impact on interstate commerce has been viewed as sufficient grounds for upholding the validity of federal controls. For example, the Supreme Court in *Wichard* v. *Filburn*[100] upheld the validity of agricultural production controls even where the crops were not placed in interstate commerce but were consumed on the farm. The rationale for this holding was that the crop in question satisfied a need which otherwise would have been reflected by purchases on the open market, thereby competing in effect with similar crops in commerce. Another example of the extensive reach of the commerce clause is given by *United States* v. *Darby,*[101] a case upholding the validity of labor standards legislation applicable to employers engaged in interstate commerce on the grounds that interstate shipments of goods produced under substandard labor conditions constituted injurious competition. This case may serve as an analogy with the water pollution situation since inadequate waste treatment also constitutes unfair competition in connection with goods shipped in interstate commerce, even if the effects of the pollution are solely intrastate.

Existing State Regulatory Programs

Injection Well Policy

As would be expected in the case of a relatively new method of waste disposal whose feasibility varies with location, policy on deep well disposal is not uniform among the states but varies over a considerable spectrum of philosophical positions. Several states are unequivocally opposed and prohibit all deep well injection. Included in this category are Delaware,[102] Georgia,[103] Massachusetts,[104] Missouri,[105] Minnesota,[106] New Jersey,[107] North Carolina,[108] Rhode Island,[109] South Carolina,[110] Vermont,[111] Virginia,[112] and Wisconsin.[113] Industrial injection wells have not been constructed in any of these states with the exception of North Carolina, where one installation consisting of several wells was utilized for a short period of time prior to passage of prohibitory legislation.

A somewhat lesser degree of opposition has been expressed in a few other states. The Iowa Natural Resources Council indicates that it has been the general philosophy of all departments in the state to discourage disposal of any water into aquifers except that used for cooling purposes.[114] The Tennessee Department of Public Health has approved use of disposal wells but indicates reluctance to consider other use of such wells.[115]

A majority of the states gives some degree of acceptance to the injection well concept. Reference to a previous section of this report summarizing current injection well practice indicates that 25 states have allowed the construction of such wells, 13 of which have five or more wells. As noted above, North Carolina has prohibited further use, and Iowa and Tennessee are attempting to discourage future use. Within the 22 remaining states that have authorized injection, actual policy regarding acceptance varies considerably as reflected in the nature of regulatory controls and criteria for approval. Injection is considered a viable alternative to surface treatment in some cases but in others is viewed only as a last resort where surface treatment is not feasible or practical. States where this latter position has been adopted include Indiana,[116] Kansas,[117] Mississippi,[118] and New York.[119] In the State of Washington, disposal of pollutants into wells is authorized only under "extraordinary circumstances."[120]

Some of the remaining states where injection wells have not been installed have given indication that this disposal technique will at least be given consideration as a possible alternative. One indication of tentative acceptance of the concept is the adoption of controls which do not prohibit injection wells but subject them to regulatory procedures. The adoption of such controls does not necessarily mean that state approval for injection well proposals will be forthcoming but appears to indicate the absence of a completely negative philosophy. States in this category include Arizona,[121] Connecticut,[122] Idaho,[123] Maryland,[124] Montana,[125] Nebraska,[126] North Dakota,[127] Oregon,[128] and South Dakota.[129]

A total of 46 states have been categorized to this point with regard to their disposal well policy on the basis of explicit declarations of policy, their response to actual injection proposals, and the adoption of explicit regulatory controls. The remaining four states of Alaska, Maine, New Hampshire, and Utah cannot be classified on the basis of these factors. Disposal wells have not been proposed, and no specific policy or control measures exist. It appears that present policy and general controls over wastewater disposal do not prohibit injection, but further attempts to interpret policy would be highly speculative.

Regulatory Controls

Waste injection, like other methods of waste disposal, has been subjected to considerable regulation and control by the various state governments in recent years. In some cases, controls have taken the form of complete prohibition but more commonly have involved application of regulatory procedures wherein requirements for construction and operation are imposed as conditions to be met in order to obtain state authorization. The states that have decided to permit injection have taken a variety of approaches in the establishment and implementation of controls. This variation is reflected in the form of the controls, the administrative organization for their implementation, and in the actual conditions and requirements to which disposal well operators are subjected.

Form of the Controls

With regard to the form of the controls, legislation, administrative regulations, and statements of policy have been utilized. Some combination of statutory provisions and regulations is generally employed, with certain states having comprehensive statutory provisions and relatively minor supplemental regulations, while others have only general statutory controls and detailed administrative regulation. This latter approach appears to have been given the greatest acceptance. In some cases, the provisions of statutes and regulations taken together provide only very general control, with considerable discretionary decision making authority vested in an administrative agency; however, other states have adopted detailed formal controls, thereby reducing the extent of discretionary authority.

The legislative basis for state control programs also varies in form itself. A relatively small number of states has adopted specific statutes applicable to disposal well operations, including Texas,[130] Michigan,[131] and Idaho.[132] In a greater number of cases, legislation having broader application to natural resources or pollution control has been made applicable to disposal wells. North Carolina presently prohibits waste injection[133] but has previously employed a water well statute[134] to regulate disposal wells. A statutory provision in Hawaii requiring notice to a state agency for well drilling specifically includes injection and disposal wells.[135] In Ohio, a part of oil and gas law applies to the injection of all wastes,[136] even those from firms not related to the petroleum industry.

Several states regulate subsurface disposal through the use of a general pollution control statute applicable to all waste disposal operations. Disposal wells are specifically included within the terms of general pollution control law in the states of Arizona,[137] California,[138] Colorado,[139] Connecticut,[140] Illinois,[141] Maryland,[142] Mississippi,[143] Missouri,[144] Nebraska,[145] New Mexico,[146] North Carolina,[147] North Dakota,[148] Oregon,[149] South Dakota,[150] Vermont,[151] West Virginia,[152] and Wyoming.[153] Most of the states in this group simply subject disposal wells to the general terms of pollution control law without providing more specific statutory controls. California and West Virginia are exceptions and provide some degree of detailed control within the terms of such law. The provision cited in North Carolina law prohibits use of disposal wells. Although pollution control law in Missouri and Vermont encompasses disposal wells, they are prohibited by other means in these two states. In Missouri[154] a separate statutory prohibition exists while an administrative prohibition exists in Vermont.[155]

Most of the remaining states must rely upon general pollution control statutes making no explicit mention of disposal wells. In a number of states, use of injection wells has not been proposed, making consideration of the adequacy of these general laws unnecessary. In other cases where injection wells have been proposed and installed, active regulatory programs have been based on such laws.[156] Most pollution control laws can reasonably be interpreted to apply to disposal well operations without specific inclusion since they generally apply to discharges of wastes to surface and ground waters.[157] The applicability of such a statute could conceivably be contested in cases where "pollution" is defined in terms of adverse effects on other water uses[158] since injection usually takes place into subsurface saline waters having no other beneficial use. However, an argument based on the potential usefulness of such water or the possibility that injected waste may migrate and contaminate useful water in other strata would likely be sufficient support for the claim that waste injection constitutes an activity within the jurisdiction of the pollution control legislation.

Comprehensive administrative regulations applicable to injection have been adopted in the states of Colorado,[159] Hawaii,[160] Louisiana,[161] Michigan,[162] Nebraska,[163] and Oklahoma.[164] In Michigan, regulations supplement detailed statutory provisions. Regulations in Colorado and Nebraska contain all formalized control measures specifically applicable to disposal wells since explicit legislative provisions are limited to inclusion of disposal wells within the scope of pollution control law. Since Oklahoma law makes no specific reference to industrial injection wells, the regulations have been adopted pursuant to general authority with respect to water quality protection.

Less comprehensive regulations exist in a number of other cases. States with regulations containing limited control measures include California[165] and Pennsylvania.[166] Regulations in effect in Alaska,[167] Indiana,[168] Kansas,[169] and Montana[170] are essentially limited to requiring agency approval for injection well usage. Washington regulations set forth a permit requirement but state that disposal wells will be authorized only under "extraordinary circumstances."[171] Oregon regulations which disclose an intent to phase out present shallow disposal wells used primarily for discharge of sewage make no specific provisions for deep injection wells but preserve the option for future consideration of this technique.[172] Regulations in effect in Delaware[173] and Wisconsin[174] prohibit waste disposal wells.

Regulatory measures sometimes exist under a title other than "rules" or "regulations." Michigan, for example, has adopted guidelines for the preparation of a required environmental impact statement in connection with disposal wells.[175] Water quality standards of New York State establish requirements for disposal zones in terms of ground water quality.[176] Oklahoma rules and regulations are supplemented by an injection well questionnaire which serves a regulatory function through the requirement for detailed information.[177] "Subsurface Waste Disposal in Texas,"[178] a publication of the Texas Water Quality Board, contains much supplemental information concerning agency regulatory procedures in that state. In West Virginia, many of the regulatory provisions in effect exist in the form of instructions for filing disposal well permit applications.[179]

State philosophy and general regulatory procedures are presented in the form of policy statements in Alabama,[180] Florida,[181] Michigan,[182] New York,[183] and Virginia.[184] In Alabama and Florida, policy statements constitute the sole source of formal regulatory provisions. The Michigan statement of policy is supplemental to comprehensive statutory provisions and regulations. New York policy is the primary basis for the control program, with water quality standards imposing additional requirements. In Virginia, the policy statement expresses opposition to the disposal well concept.

State policy and regulatory guidelines exist in some cases without expression in a formally adopted document. Kentucky,[185] Mississippi,[186] and Pennsylvania[187] are examples of states where these somewhat informal controls exist.

Administrative Organization

As would be expected from consideration of the varying nature of the legal controls applicable to injection wells, administrative organization for the implementation of controls also varies among the states. Primary regulatory authority is usually vested in the agency with responsibilities for health, water quality, environmental protection, or natural resources. In several states, complete authority is vested in a single agency. Co-operative arrangements of an advisory nature sometimes exist between state agencies with regard to review of disposal well proposals. For example, the Alabama Water Improvement Commission has regulatory authority over waste disposal operations, but the Geological Survey of Alabama is under contract[188] to the Commission to provide expertise in reviewing subsurface waste disposal proposals.

Multi-agency approval is required for authorization of injection wells in some states. In Florida, authorization must be obtained from the appropriate regional water quality authority and the Department of Pollution Control.[189] Approval of industrial injection wells in Texas requires the action of two state agencies. Each application for an authorizing permit from the Texas Water Quality Board must be accompanied by a letter from the Texas Railroad Commission, the agency responsible for regulation of petroleum production, stating that the proposed installation will not injure or endanger any oil or gas formation.[190] In addition, copies of the application must be sent to the Texas Water Development Board, the State Department of Health, and the Texas Water Well Drillers Board, all of whom may make recommendations concerning the application.[191]

The consent of an even greater number of agencies is required for approval of industrial waste disposal wells in Ohio. The permit-granting agency, the Division of Oil and Gas, cannot issue a permit without the approval of the Director of Environmental Protection and the Chief of the Division of Geological Survey. The controlling statute specifies that the Division of Oil and Gas base its determination on whether the proposed injection would present an unreasonable risk to oil and gas resources; the approval of the Director of Environmental Protection on whether the proposed injection will cause pollution; and the approval of the Chief of the Division of Geological Survey on whether the proposed injection would present an unreasonable risk to valuable mineral resources. In addition, approval must also be obtained from the Chief of the Division of Mines where the proposed well is located in a coal-bearing township.[192]

Control Provisions

The two previous sections have dealt with the form which state injection well controls have taken and the administrative organization for their implementation. Consideration will now be given to the actual substance of the controls themselves. Since regulations and other administrative controls generally have the force and effect of law, specific control measures will be examined without regard to the particular form of the controls. For example, a comparative analysis of monitoring provisions does not reflect the fact that the requirements are in legislative form in one state while embodied in regulations in another.

State controls over deep well disposal collectively encompass requirements regarding preliminary feasibility studies; well design, construction, and operation; monitoring; and well abandonment. There is much variation among the states with regard to the comprehensiveness with which each of these elements is treated. A basic factor here is the amount of discretionary authority vested in the administrative agency involved. Considerable discretionary flexibility exists in all cases because of the degree of uniqueness associated with individual injection installations, but formal controls are much more detailed and specific in some cases than in others. States having formal controls which address at least some of these elements include Alabama, California, Colorado, Florida, Hawaii, Idaho, Illinois, Michigan, Nebraska, New York, Ohio, Oklahoma, Texas and West Virginia. The following discussions of each of the four types of requirements is based largely on the controls in these states.

Preliminary Feasibility Studies—Requirements for information to be collected relative to physical feasibility vary from comprehensive listings of specific data to be presented with permit applications to a complete lack of written guidelines in the area. States with very comprehensive requirements include Colorado,[193] Michigan,[194] Nebraska,[195] Oklahoma,[196] Texas,[197] and West Virginia.[198] The following quotation is a listing of Michigan's requirements which are similar to those in the other states listed:

> 1. Notice of Intent: Evidence that notice has been given to mineral owners within a two-mile radius of the proposed well(s). These owners may waive right of protest. If the expected zone of influence of the proposed project is larger, then the area should be expanded to include the expected affected parties.
>
> 2. A map indicating location of water wells and all other wells, mines, artificial penetrations (oil and gas wells, exploratory tests, etc.) showing depths and deepest formation penetrated, and their present condition within the expected area of influence of the proposed project. Exhaustive search shall

be made to locate such penetrations. Well and abandonment records of the wells should accompany the map.

3. Description of local topography, culture and human population in the area of the proposed disposal program and probable effects of the program on that culture and population.

4. A map indicating vertical and lateral limits of potable water supplies which would include surface water supplies and subsurface aquifers containing water with less than 10,000 ppm total solids, as well as available amounts and present and potential use of these waters.

5. Mineral resources present or believed to be present in the area of the project. The effect of this project on present or potential mineral resources in the area.

6. Maps and cross sections illustrating detailed geologic structure and stratigraphic sections (formation, lithologic, and physical characteristics) for the local area and generalized maps and cross sections illustrating the regional geologic setting of the project.

7. Description of the chemical, physical, and biological properties and characteristics of the waste to be injected or disposed of. Relative alteration of stability characteristics of the wastes when exposed to time, pressures, temperature or other media.

8. Potentiometric surface maps of the injection aquifers and those aquifers immediately above and below the injection aquifers and copies of all drill stem tests, extrapolations and data used in making maps.

9. Anticipated volume, rate and injection pressure.

10. The following geological and physical characteristics of the injection interval and the confining units should be determined and submitted by the owner.

(a) Effective thickness
(b) Areal extent
(c) Lithology: Grain mineralogy, type and mineralogy of matrix amount and type of cementing material, clay content and clay mineralogy
(d) Effective porosity (how determined)
(e) Permeability, vertical and horizontal (how determined, mechanical, radiation, electronic or other logs, core analysis, formation tests, etc.). Differentiation should be made between the relatively high permeable zones and the relatively low permeable zones and their comparative thicknesses
(f) Coefficient of storage of aquifer
(g) Amount and extent of natural fracturing
(h) Location, extent and effects of known or suspected faulting
(i) Extent and effects of natural solution channels
(j) Fluid saturation

(k) Formation fluid chemistry (local and regional variations)
(l) Temperature of formation (how determined)
(m) Formation and fluid pressures (original and modifications resulting from previous fluid withdrawals)
(n) Fracturing and fracture propagation gradients
(o) Osmotic characteristics of rock and fluids both comprising and contiguous to the reservoir
(p) Diffusion and dispersion characteristics of the waste and the formation fluid including effect of gravity segregation
(q) Compatibility of injected waste with the physical, chemical, and biological characteristics of the reservoir
(r) Injectivity profiles.

11. The following engineering data should be supplied:
(a) Size of hole and estimated depth of well
(b) Type, size, weight, strength, etc. of all surface, intermediate, and production casing
(c) Specifications and proposed installation of tubing and packers
(d) Proposed cementing procedures and type of cement
(e) Proposed coring program
(f) Proposed formation testing program
(g) Proposed logging program
(h) Proposed artificial fracturing or stimulation program
(i) Proposed completion procedure (open hole, perforated casing)
(j) Plans of the surface and subsurface construction details of the system including a diagrammatic sketch of the system (pump, well head construction, casing depth, etc.)
(k) Plans for monitoring injection pressures and formation pressures (injection well(s), observation well(s))
(l) Expected changes in pressure, rate, and direction of fluid displacement by injected wastes relative to time in area affected by the project.[199]

Other states with specific but somewhat less comprehensive information requirements include Florida,[200] Hawaii,[201] Idaho,[202] and Ohio.[203]

The purpose of requiring the submission of such data with permit applications is of course to provide an information base for evaluating the physical feasibility of the proposal. However, very few guidelines have been formalized with regard to the decision making process concerning approval of individual proposals. Guidelines for approval frequently are limited to general requirements that valuable ground water resources be protected. For example, requirements in effect in Colorado prohibit approval without one of the following conditions being met:

(1) that no waters of the State will be polluted thereby; or

(2) that if waters of the State may be polluted thereby, the pollution resulting therefrom will be limited to waters in a specified limited area from which there is no risk of significant migration and the proposed activity is justified by the public need.[204]

One exception to this lack of specific criteria for approval exists in the form of water quality limitations that certain states have adopted with respect to disposal zones. These requirements generally attempt to protect all fresh water and potentially useful brackish water by prohibiting waste discharge into all water whose quality exceeds certain levels as indicated by specific quality parameters, usually chloride or total dissolved solids content. Standards established by the New York Department of Environmental Conservation classify waters having a chloride content greater than 250 mg/1 or a total dissolved solids content of more than 1000 mg/1 as saline, but saline waters containing less than 1000 mg/1 chloride or less than 2000 mg/1 total solids are separately designated for protection.[205] Nebraska regulations require a disposal zone concentration of at least 5000 mg/1 total dissolved solids.[206] The Texas Water Quality Board considers to be potentially beneficial all water having a total dissolved mineral concentration between 3000 and 10,000 mg/1.[207] Illinois[208] and Mississippi[209] also protect all water having a total dissolved solids content of less than 10,000 mg/1. The unwritten guidelines used in Alabama prohibit waste discharges into all ground water less saline than sea water,[210] which contains approximately 35,000 mg/1 total solids.

Since complete evaluation of the feasibility of injection at a particular site includes testing conducted after the well is drilled, final authorization of use of a well for waste disposal purposes must come after such testing is complete. Regulations in effect in Michigan set forth this requirement.

> Confirmation of the use of a storage or disposal well, the drilling of which has been authorized by a permit, is conditioned on approval of the well by an order of the water resources commission after completion and testing. If it is determined by inspection, and appropriate evidence is filed after testing, that a well can be used for storage or disposal in a manner that will not cause surface or underground waste, the supervisor shall approve and thereafter regulate the use and operation of the well in accordance with these rules and the order of the water resources commission.
>
> Requirements for testing are prescribed in rules 61 and 62. If a well is determined after testing to be unsuitable for storage or disposal use, it shall be abandoned and plugged . . . .[211]

The evaluation of physical feasibility may pose problems for regulatory agencies without experience with waste injection. There are a number of states where injection wells have not been utilized, and new proposals are relatively rare in many of the states where disposal wells exist. Thus the accumulation of agency expertise and maintenance of specialized personnel are often difficult to accomplish. The result in a particular situation may be that the scope of a feasibility study and the interpretation of its findings may be determined largely by the applicant or his consultant rather than by the state. Without intending to imply that consultants and potential users of the injection well technique would as a general rule employ inadequate feasibility studies or attempt injection at infeasible sites, matters relating to such determinations should be under the control of the governmental authorities responsible for protecting the public interest.

This type of deficiency may be mitigated in several manners. One of the basic procedures involves inter-agency cooperation. Since the evaluation process is primarily geologic in nature, cooperative arrangements between pollution control and geological agencies are common. A manner in which a state can retain control over feasibility studies is to become directly involved as a participant. This approach has been utilized in Alabama where the State Geological Survey, acting as consultant to the pollution control agency, has carried out or supervised this phase of several injection well proposals. Even if this involvement is of limited duration, expertise gained from the experience should be very beneficial in developing regulatory procedures for later use.

One of the obvious restrictions on such ventures involves financing. The feasibility study is normally viewed as a private cost to be assigned to the injector, and public expenditures for such purposes are likely to meet with substantial opposition. The Alabama experiences apparently involved contributions from both state government and the private firms involved, and in one situation federal funds were made available for installation of monitoring facilities. It is recognized that direct state participation involves complicated questions of financing and requires the establishment of safeguards for the use of public funds, but the potential benefits from such arrangements merit their consideration.

Another method of assuring adequate and impartial evaluation of feasibility is through use of independent consultants. Recognition of the need for outside opinion is reflected in the revised regulations of the Colorado Department of Health. An applicant for a permit is required upon request to furnish an opinion of independent experts with regard to the accuracy and completeness of any information furnished on any aspect of the proposed disposal system or its effects.[212]

Requirements for Well Design, Construction, and Operation—Since the details of well design, construction and operation vary between individual wells, the extent to which control measures lend themselves to formalization as explicit provisions is limited. Thus in the majority of cases, regulatory procedures do not set forth detailed standards but rather require simply that all aspects of design, construction, and operation be subject to approval by the appropriate regulatory agency.

However, formal controls do include specific provisions in some cases. One of the most detailed sets of specifications for well design is contained in regulations adopted by the Nebraska Environmental Control Council from which the following is quoted:

> For approval of the actual operation of the system and issuance of the operating permit, the applicant shall file with the Department an application for public hearing which shall contain the following:
>
> (A) *Design of well within but not limited to the following specifications.*
> (1) At least two strings of casing shall be placed and centered in the well. The outer string shall extend at least 100 feet below the lowest limit of ground water subject to protection in the area. The inner string of casing shall extend at least into the upper portion of the injection zone. All casing shall consist of new seamless casing meeting or exceeding American Petroleum Institute specifications for casing.
>
> The casing strings shall be designed utilizing the following safety factors:

Collapse	1⅛
Tension	2
Internal Pressure	1⅛

> All casing shall be cemented from bottom to top utilizing cement conforming to American Peteroleum Institute specifications and shall be of a type recommended by a cementing specialist after analysis of the effluent and the effect of such effluent on said cement. All cement shall be placed by the displacement method under pressure for a minimum of 24 hours. The cementing operation shall be performed by a qualified and experienced well servicing company. A cement bond log shall be run upon completion of each cementing operation.
>
> (2) The well shall be logged upon completion of drilling by a qualified well servicing company by the appropriate mechanical, electrical or radioactive logs to indicate the general lithology, permeable bed thickness, porosity, and resistivity of interstitial water.
>
> (3) Samples of all rocks obtained by drilling and coring of the disposal well or other accessory holes and any results of tests performed upon these rocks shall be placed on file with the Conservation and Survey Division, University of Nebraska.
>
> (4) The well shall shall be constructed so that the effluent is transported to the injection zone through a string of injection tubing. Tubing shall be fabricated of corrosion resistant materials or shall be coated to provide corrosion resistance to the effluent injected. Injection tubing shall be fixed to the inner string of casing by a tubing packer located near the injection interval. The packer shall be of the permanent type and shall feature a back pressure valve and be adaptable to the use of a stinger for injection. The packer shall be fabricated of corrosion resistant material or shall be coated to provide corrosion resistance to the effluent injected. The annular space between the injection tubing and the inner casing string shall be filled with a liquid approved by the Department.

(5) The wellhead shall contain automatic safety valves which will provide shutdown in case of tubing-casing annulus pressure buildup, loss of wellhead pressure, or wellhead fire . . . .

(C) *Surface Equipment Design*

(1) A flow diagram showing the surface facilities shall be provided.

(2) Surface equipment, including pump, wellhead, transmission lines, holding tanks and treatment facilities, shall be designed and constructed so that the system can be safely shut down in the event of component failure.

(3) All components of the surface facilities that may come in contact with the effluent, including pumps, lines, tanks, filters, etc., shall be fabricated of corrosion resistant material or shall be coated to provide corrosion resistance to the effluent.

(4) A secondary facility shall be maintained in the event of a temporary well failure. Such facility may consist of a lined, impermeable retention pond or storage tanks, or a treatment process that will prepare the effluent to a suitable degree for temporary surface storage or disposal.[213]

With regard to disposal well operations, an example of detailed controls is given by the following provision from rules adopted by the Michigan Department of Natural Resources:

(1) Anomalous behavior of a storage or disposal well shall be reported promptly to the supervisor. In case of an anomalous behavior arising from or likely to arise from storage or disposal practices, the supervisor may order reduction or cessation of storage or disposal operations, may order additional testing by the operator, or may order the drilling of an observation well by the operator to provide additional data on the movement and behavior of injected fluids, indigenous formation fluids or stored fluids.

(2) Elimination and correction of leaks or losses of fluids or pressure in wells, reservoirs and surface installations shall be made immediately.

(3) An operation which may cause or create a condition endangering public health or welfare shall be avoided.

(4) Adequate equipment and installations at a disposal well for appropriate testing and monitoring of the operation shall be used.

(5) Wastes shall be treated before injection unless otherwise approved by the supervisor.

(6) Records or reports, forms, charts of operating pressures, rates of injection, types and volumes of fluids injected or withdrawn, and other pertinent information shall be maintained and submitted monthly to the supervisor or at other specified times.

(7) Wastes shall be treated and stored before injection in a manner to avoid surface or ground water pollution.

(8) A request for change of status shall be filed before any rework operations are commenced.

(9) Volumes, injection rates and pressures used shall not exceed those specified in the approval of the disposal or storage use.

(10) Only wastes specified in the statement required by rule 13 may be injected into a well.

(11) Not less than 1 observation well, located within 100 feet of the disposal well, shall be provided for each well used for the disposal or storage of radioactive materials. An observation well shall penetrate, as a minimum, the formational unit immediately overlying and confining the disposal formation. The well or wells shall be used for continuous control and monitoring on a scale commensurate with the level of the radioactivity.[214]

Other states having somewhat detailed regulatory provisions relative to well design, construction, and operation include Oklahoma and Texas. Oklahoma has the more comprehensive provisions. Requirements encompass casing, construction materials, pressure gradients, emergency facilities, qualifications of designers and operators of disposal wells, and pretreatment of wastes.[215] The following Oklahoma operating requirement is similar to one in effect in Michigan:[216]

Every six (6) months the disposal well shall be shut down for a period of 24 consecutive hours for the purpose of conducting a formation pressure test. Results of this test shall be given to the Board. If a problem or failure is indicated, a pressure test will be made at the earliest possible time and the results presented to the Board. Any remedial (or emergency) work shall be commenced immediately. The Board will be informed of the operator's work and a final report submitted within ten (10) days following completion of such work.[217]

Formal controls in effect in Texas are more generalized, but guidelines for setting casing depth are contained in the Disposal Well Act.[218] The approach taken by the Texas Water Quality Board in regulating disposal well design and construction is summarized in the following quotation from an agency publication:

The type of construction for injection wells is quite variable because of the different compositions and volumes of waste injected. The Board has not adopted standards on well construction, but prefers to consider each proposal on an individual basis. The construction of the well must be such that the potentially usable-quality water resources are adequately protected and the injected fluid is confined to the permitted disposal zone. A typical well would be completed as shown in Figure 4. The surface casing is set from the surface to a depth below strata containing potentially beneficial water, and then cemented back to the surface by the pump and plug method. The long string casing or protection casing is set from the surface to either the top or through the entire disposal zone. This casing is usually cemented to the surface by circulating cement from total depth, or by cementing the upper part by circulating through a multiple-stage cementing tool installed in the casing below the base of fresh water strata. The casing is pressure tested to assure that there are no leaks.

Two strings of cemented casing placed through the fresh water zone give added strength to the casing and extra protection to the fresh water resources. The protection casing is usually made of carbon steel, but may be of a special alloy that is not affected by the corrosive nature of the waste.

Injection of waste as shown in Figure 4 is confined to the tubing, set or sealed in a packer. The injection tubing is made of a material that will not be affected by the injected waste. Materials commonly used in the construction of the tubing are carbon steel, internally plastic coated steel, fiberglass, and stainless steel. Screens, if utilized, are usually made of stainless steel.

The materials used in the well construction must be new and meet either American Petroleum Institute, American Society for Testing and Materials, or comparable nationally recognized standards . . . .

Common methods of oil field construction and completion are utilized in the disposal wells. The specific method used in well design and construction depends more on past experience of the consulting engineer or geologist than on any trends or practice in an area. Stimulation of the disposal zone by acid and surging is common, and seems to be necessary in many instances. In fact, many wells are "acidized" each time the injection pressure increases significantly above the expected norm.[219]

Monitoring Requirements—Regulatory provisions with regard to monitoring, like those concerning other elements of state control procedures, exhibit a wide range of variation. The spectrum extends from complete absence of formal provisions to relatively detailed requirements concerning monitoring procedures, with the general provision for such monitoring as is required by the state regulatory agency falling somewhere in between. States with specific monitoring provisions include Florida, Michigan, Nebraska, Oklahoma, and Texas. The following requirements are from a technical memorandum of the Florida Department of Pollution Control containing a statement and explanation of injection well policy:

Adequate monitoring systems in disposal and fresh water aquifers are required and shall be adequate to insure knowledge of migration and behavior of injected liquid wastes. Periodic reporting of the following shall be required:

(1) Results of monitoring the volume, chemical quality, temperature, and other properties of the injected waste.

(2) Results of continuously monitoring hydraulic pressures at the wellhead, in the annulus, in the injection aquifer, in the lower-most fresh water aquifer, and at other places when required.

(3) Results of monitoring quality of water in the fresh water aquifers at springs and shallow observation wells and in the injection aquifer at deep observation wells near the injection well.[220]

In Colorado, information submitted with an application for an injection well must include ". . . plans for monitoring injection pressures and formation pressures, i.e., injection wells and observation wells."[221] In addition, two somewhat unique provisions are included. The regulatory agency, the State Health Department, ". . . may designate some third party to utilize the monitoring system data developed by or for the operation of the system."[222] Also, the controls provide that "[m]onitoring equipment shall be operated and precautionary steps shall be undertaken after termination or abandonment for as long as the Division [of administration of the state health deparment] may reasonably require which operation and steps shall be at the sole risk, cost, and expense of the person responsible for the disposal system."[223]

Requirements of the other states mentioned above are somewhat less extensive. Michigan requires monitoring of ". . . operating pressures, rates of injection, types and volumes of fluids injected or withdrawn, and other pertinent information . . . ."[224] Nebraska requires monitoring of effluent quality, injection rate and pressure, and pressure in the casing-tubing annulus.[225] Reporting requirements in Oklahoma include chemical and physical nature of waste material disposed of, amount of waste material, density of waste in pounds per cubic foot, disposal pump pressure, annular pressure between tubing and production casing, and pressure and fluid-quality reports from monitoring wells where required.[226] Although not contained in formal controls, monitoring requirements in effect in Texas have been described by the Water Quality Board as follows:

The Agency usually requires that a pressure gauge be installed on the wellhead for monitoring the pressure on the annulus between the injection tubing and the protection casing. Should a leak occur in the tubing or the packer seat, a pressure increase on the annulus during injection would be indicated by the gauge, and remedial action can be initiated to correct the malfunction. A gauge on the injection tubing is also required to monitor the surface injection pressure.[227]

Abandonment Requirements—States with explicit abandonment procedures include Michigan, Nebraska, Ohio, Oklahoma, and Texas. The following requirements in effect in Oklahoma appear to be the most comprehensive:

> The owner and/or operator of any industrial disposal well shall be jointly and individually liable and responsible for the proper plugging of said well.
>
> The owner and/or operator of any disposal well not in operation for a period of six (6) months must either apply for a new permit as specified in Item 10.6 above or immediately plug the well.
>
> Any well to be permanently abandoned shall be immediately plugged.
>
> The owner and/or operator of a disposal well shall notify Oklahoma Water Resources Board of his intention to plug. Written notification shall be received at least ten (10) days prior to the commencement of plugging operations.
>
> The staff of Oklahoma Water Resources Board shall be given the opportunity to be present at plugging operations. The plugging operator shall notify the Oklahoma Water Resources Board of the exact time during which all plugging operations will take place.
>
> Every well shall be plugged in such a manner as to permanently prevent the migration of any disposed substances out of the disposal zone, as well as the migration of oil, gas, or salt water into or out of any productive formations, by means of the well bore. Plugging shall also seal off all fresh ground water strata encountered in the well so as to prevent the entrance of salt water or the escape of fresh ground water by means of the well bore.
>
> Before any casing is removed from a well, all liquids shall be removed or displaced and the well filled with mud. As the casing is removed, the well shall be kept filled with mud.
>
> Any uncased hole below the shoe of any casing to be left in the well shall be filled with cement to a depth of at least fifty (50) feet above the shoe of the casing. If the well is completed with a screen or liner and the screen or liner is not removed, the well bore shall be filled with cement from the base of the screen or liner to a point at least fifty (50) feet above the screen or liner.
>
> Whenever production casing is severed and removed, the well bore shall be cemented from a point fifty (50) feet below to a point fifty (50) feet above the point of severance; provided that, if after such cement plug has been set, the same string of casing is again severed in the process of removal, further cementing thereof shall not be required.
>
> All fresh water zones encountered in the well shall be sealed off and protected by adequate casing extending from a point at least fifty (50) feet

below the base of the lowest fresh-water zone to within three (3) feet of the top of the well bore, and by completely filling the annular space behind such casing with cement. If the surface or other casing in the well meets these requirements, a cement plug may be set at least fifty (50) feet below the shoe of the casing to extend at least fifty (50) feet above the shoe of the casing. If the casing and cement behind the casing do not meet the requirements of this subsection, the well bore shall be filled with cement from a point fifty (50) feet below the base of the lowest fresh-water zone to a point fifty (50) feet above the shoe of the surface casing. The well bore shall, in all events, be filled with cement from a point three (3) feet below ground surface to a point thirty-three (33) feet below ground surface.

All intervals between cement plugs in the well bore shall be filled with mud.

Any "rat" or "mouse hole" used in the drilling of a well with rotary tools shall be filled with mud to a point eight (8) feet below ground level and with cement from such point to a point three (3) feet below ground level, and filled in with earth above the top of the cement.

The top of the plug of any plugged well shall show clearly, by permanent markings, whether inscribed in the cement, or on a steel plate embedded in the cement, the well number and date of plugging.

Within fifteen (15) days after a well has been plugged, the owner or operator shall file a plugging record, in duplicate, with the Oklahoma Water Resources Board. If there is not a complete and correct log of the well on file with the Board, then the owner at the time of plugging shall furnish and file a complete and correct log thereof, or the best information available. The well bond will be released only when the requirements of this rule have been met.[228]

Ohio law also contains detailed provisions with regard to abandonment. These provisions appear to have been designed primarily for oil and gas wells but theoretically apply to industrial disposal wells since they are encompassed in the definition of "well" contained in oil and gas law. Pertinent provisions follow:

No person shall plug and abandon a well without having a permit to do so issued by the chief of the division of oil and gas . . . .

When any well is to be abandoned, it must first be plugged by filling the hole with rock sediment of properly prepared clay to a point above the oil or gas sand or rock formation. There shall then be placed or driven on top of the sediment or clay one or more seasoned wooden plugs or a lead plug as the case may require and such plug or plugs shall be placed or driven in such a manner that the same shall be at the top of the oil, gas, or rock formation, and will prevent the escape of gas or oil and will prevent water or destructive matter entering the oil or gas, sand or rock formation. Such hole shall be filled at least one hundred feet above such plug or plugs or filled to the lowest casing seat with rock sediment or clay

> and such material used for such filling shall be properly prepared. After the first string of casing has been withdrawn from such well, a wooden plug or iron ball of sufficient size shall be placed upon the casing seat and at least fifty feet of rock sediment or properly prepared clay placed upon such wooden plug or iron ball . . . .
>
> In the abandonment and plugging of wells located in congested areas, where the plugging method, as outlined in such sections, cannot be applied or, if applied, would be ineffective in carrying out the protection which the law is meant to give, the chief may designate the method of plugging to be used. He may also require the installation of casing and vent pipe to provide additional safety to the surrounding area. The abandonment report shall show the manner in which the well was plugged.
>
> If any well has passed through a stratum bearing potable water, it shall, when it is abandoned, be plugged by bridging the hole a minimum of fifty feet below all potable water stratum and filling it to the surface with properly prepared clay or rock sediment. Where there are two or more fresh water strata, a bridge shall be set below the lowest fresh water stratum, and filling shall be continued to a point as specified in this section . . . .
>
> If any well has passed through a vein or seam of coal or mineral, it shall, when it is abandoned, be plugged by driving a seasoned wooden plug to a point fifty feet below the lowest seam of coal or mineral, and filling the hole with properly prepared clay or rock sediment to a point at least twenty feet above this seam of coal or mineral at which point another wooden plug shall be placed and the hole filled for a distance of thirty feet with properly prepared clay or rock sediment. If there is more than one seam of coal or mineral, the next seam above must be plugged off in like manner. When any well which has been drilled is to be abandoned and has passed through the excavations of any mine, the person owning such well shall leave the casing in it from a point thirty feet below the floor of such mine to a point at least fifteen feet above the roof of such mine or to the rock above the seam if roof conditions at such mine warrant the extension thereto. A seasoned wooden plug shall be driven to a point at least one hundred feet below the floor of such mine and the hole above such plug, together with the casing left in, which extends through the mine, shall be filled with properly prepared concrete; then a seasoned wooden plug shall be driven on top of such casing, and the hole filled with properly prepared concrete for a distance of not less than twenty feet.[229]

Abandonment provisions in the other states listed are similar in nature but slightly less detailed. In Michigan, it is required that "fluids and gases shall be confined to the strata in which they occur . . . ."[230] Plugging operations cannot be commenced prior to notice to the regulatory agency and issuance of plugging instructions which are to specify all necessary requirements.[231]

Nebraska regulations require that disposal wells to be abandoned

". . . shall have the injection tubing removed and the entire length of the well and injection zone filled with cement from the bottom to the top," with the cementing operation to be performed by an experienced well servicing company. Cement used must have "expansive properties," "conform to American Petroleum Institute specifications," and be "placed in the well under pressure." An affidavit setting forth the detailed data regarding plugging operations must be filed with the regulatory agency.[232]

Formal injection well controls in Texas make no specific reference to abandonment procedures, but the following requirements have been stated in a publication of the Texas Water Quality Board:

> Obviously, a standard method of well plugging cannot be adopted because of the different types of well construction utilized. Nevertheless, certain guidelines encompassing minimum criteria have been formulated. Basically, three cement plugs should be placed in each well previously used for disposal. First, a plug should be placed across the injection zone to seal it and prevent backflow. A second plug should be placed across the base of the surface casing to extend above and below the casing shoe approximately 50 feet. This plug affords protection from upward flow of fluid from any lower zone into the casing opposite the usable quality water zone. If the protection string casing has been cemented to the surface during installation, then this plug should be placed in the protection string casing at the same place as above to give added protection from upward movement of fluid in the event of casing collapse at a lower depth. In the event the protection string has not been cemented to the surface (i.e., an older well where cement did not reach the surface), that portion uncemented should be removed from the well prior to plugging. The third plug is placed in the top of the cased well and should extend 10 to 30 feet below the ground.
>
> Other zones that must be sealed off by a cement plug are strata productive of oil and gas and any known high pressure salt water zones. An emergency procedure is utilized by the Board should a well be abandoned during the initial drilling and completion operations. Where a drilling rig is on location and can be used for plugging, the Board's staff can verbally approve a plugging procedure. This method would be utilized in the event drilling tools were lost in the well, similar problems encountered preventing further drilling, or the proposed injection stratum was unsatisfactory for disposal.
>
> Upon completion of the plugging, a complete record of the operation is filed with the Board. A cementing affidavit from the service company that performed the cementing must accompany the plugging report.[233]

ORSANCO Program

The Ohio River Valley Water Sanitation Commission (ORSANCO), an interstate river basin commission made up of representatives from the states of Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia, and West Virginia, exists for the principal purpose of controlling pollution in the Ohio River Basin. The primary regulatory authority of the Commission is its power to issue orders for the reduction or elimination of waste discharges into interstate streams within its jurisdiction. However, such an order goes into effect only if it receives the assent of a majority of the commissioners from a majority of the signatory states, including the assent from a majority of the commissioners from the affected state.[234]

ORSANCO is not directly involved in the regulation of waste injection. Activities in this area have included adoption of a statement of policy, recommendation of administrative procedures for state regulatory programs, evaluation of the geology and geohydrology of the Ohio Valley region with regard to the feasibility of injection, and maintenance of an injection well registry.

ORSANCO policy states that "[u]nderground injection is a technically acceptable method of wastewater disposal or long-term storage whereby pollutants can be removed from the surface environment and placed in isolated underground locations . . . ."[235] In view of this finding and recognition that the techniques, trained personnel, and organizations are available in the ORSANCO district for evaluation of the geologic and engineering feasibility of underground disposal, the Commission declares as policy

> . . . that wastewater injection may be used when the regulatory authorities with legal jurisdiction have considered other alternative methods of waste management, and that, after weighing all available evidence, have determined that:
>
> I. Underground injection is the best available alternative in the specific circumstances of the case;
>
> II. Geologic and hydrologic conditions will, beyond a reasonable doubt, provide adequate protection of the public and natural resources;
>
> III. The volume, chemical and physical composition, and toxicity of the fluid to be injected are compatible with the geologic and hydrologic conditions;
>
> IV. The necessary safety factors and monitoring devices are incorporated in the design of the injection well and its auxiliary facilities;

V. The waste injection system will be operated in a manner compatible with the geologic conditions, waste character, and system construction;

VI. An approved alternative plan for waste management is available in the event that operational problems occur during the use of the injection system;

VII. The injection well will be properly plugged and marked before abandonment;

VIII. A permanent public record will be kept which documents the complete operational history of the injection system.[236]

Recommendations developed by ORSANCO list the following seven steps as essential in the administration of a state regulatory program:

1. Preliminary assessment by the applicant of the geology and geohydrology at the proposed well site and the suitability of the wastewater for injection. These initial studies should be made in consultation with the appropriate state agencies;

2. Application to the state agency with legal jurisdiction for permission to drill and test a well for subsurface wastewater injection. The application must be supported by a report that documents all details of the proposed injection system, including monitoring and emergency standby facilities. On issuance of a permit, the applicant will be informed of the geologic and geohydrologic parameters that will be employed by the state in reaching its final determination on feasibility of wastewater injection into the well, anticipated limitations on injection pressure and injected volumes, the probable monitoring requirements, and probable requirements for alternative wastewater management programs in the event that operational problems occur during the use of the injection well;

3. Drilling and evaluation of the well and submission of samples, logs, test information, and a well-completion report to the state;

4. Request by the applicant for approval to inject wastewater into the well. The request should indicate any changes from the original plan in system construction and operating program;

5. Evaluation by the state agency of the proposal on the basis of which it would issue either approval, approval-with-modification, or disapproval of the proposed injection system with respect to the geologic, geohydrologic, and engineering data submitted. On approval, the applicant will be provided with specific instructions as to the operating restrictions and monitoring requirements;

6. Issuance of instructions for operation of the injection system. This embraces requirements that the regulatory agency must be notified immediately if operational problems occur, if remedial work is required, or if

significant changes in the wastewater stream are anticipated;

7. Procedures for abandonment of the well in accordance with state regulations;

8. Where a proposed injection system is to be located within five miles of a state border, the appropriate regulatory agency in the adjacent state should be provided with an opportunity to review and comment on the application. Further, this agency should be posted when any significant problems occur during the operation of such a system.[237]

The evaluation of the Ohio Basin region with regard to physical feasibility for injection includes an analysis of structural geology, stratigraphic geology, ground water geology, mineral resources distribution, seismicity, hydrodynamic factors, and other general geologic features.[238]

The maintenance of an injection well registry is consistent with the ORSANCO policy declaration that permanent public records should be kept which document the complete operational history of each injection system. The following statement from the foreword of the published registry describes its scope:

> The registry serves as a central repository of disposal well information that includes the owner's name, location, geologic and geophysical logs, test results and operational characteristics. In addition to the above information, the type of wastes injected into the underground strata is classified according to chemical characteristics.
>
> Another phase of these activities detailed in the report relates to an appraisal of the Mount Simon Sandstone which is a widely used injection zone for underground disposal. The effort represents a pilot project in characterizing the geological and physical properties of this zone.[239]

The Registry states that 53 wastewater injection wells presently exist within the borders of the eight states signatory to the ORSANCO compact.[240] Location of these wells by state[241] is as follows:

Illinois	7
Indiana	13
Kentucky	3
New York	4
Ohio	10
Pennsylvania	9
West Virginia	7
	53

Injection wells have not been constructed in Virginia, the remaining state represented in ORSANCO. This data is generally consistent with EPA data presented earlier although there are minor discrepancies in the cases of Ohio and West Virginia.

The 53 wells included are divided into four classifications on the basis of operational status, including currently operational (28), standby (4), under development (9), and abandoned (12). Wells that have been abandoned are further classified as having been "once operational" (7) or "never operational" (5). Of the seven wells that were abandoned after utilization for injection, the reason for abandonment was equipment failure in three cases, failure of companion wells in two, design for temporary use only in one, and an unknown cause in one case. Information concerning well abandonment is considered to be important since ". . . it may provide clues concerning what might be considered deficiencies in operation or design."[242]

Impact of Citizen Action on Governmental Control

Management of wastewater is a complex undertaking requiring application of technological expertise, but it has become obvious that managerial decision making is not the exclusive province of the technical specialist. Such decisions must reflect concern for various public policies and attitudes relating to natural resources and environmental quality and therefore must be based on a broad range of input. Therefore procedures for evaluation of proposed alternative methods of waste disposal encompass citizen participation and multiple-agency review to supplement the technical evaluation conducted by the primary regulatory agency. Where a particular proposal is controversial, the broad scope of involvement increases the complexity of the decision making process far beyond the simple application of technical criteria. Due to the controversial nature of injection wells, management must be considered within this broader context.

Existing mechanisms for citizen involvement in injection well management consist of general provisions for review of proposals affecting the environment and provisions of injection well controls themselves.

General Provisions for Environmental Review

The most effective mechanism for citizen involvement in environmental decision making consists of the provisions of the National Environmental Policy Act of 1969 (NEPA),[243] particularly the requirement for preparation of environmental impact statements (EIS's).[244] NEPA requires that an EIS be prepared for each proposal for a major federal action affecting the quality of the human environment. Since the EIS must identify the adverse environmental consequences of a proposal and evaluate alternative courses of action, it has become the center of attention in citizen action with respect to development projects proposed or authorized by the federal government.

The issue of whether the permitting of injection wells is subject to the EIS requirement has not been definitely resolved. NEPA contains no exemption for EPA, but the legislative history of the act was interpreted by the Council on Environmental Quality in its original EIS guidelines to exempt ". . . environmental protective regulatory activities concurred in or taken by the Environmental Protection Agency . . ."[245] However, this exemption was dropped in the 1973 Guidelines.[246]

The application of NEPA to EPA's water quality program is somewhat clarified by the Federal Water Pollution Control Act Amendments of 1972 which provide that:

> Except for the provision of Federal financial assistance for the purpose of assisting the construction of publicly owned treatment works as authorized by section 201 of this Act, and the issuance of a permit under section 402 of this Act for the discharge of any pollutant by a new source as defined in section 306 of this Act, no action of the Administrator taken pursuant to this Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969.[247]

This provision creates an ambiguity as to its scope due to use of the phrase, "major Federal action significantly affecting the quality of the human environment," since the phrase appears only in the section of NEPA containing the EIS requirement. Thus the question arises as to whether the exemption applies only to the EIS requirement or to all the provisions of NEPA. Regardless of the outcome of this issue, the exemption explicitly does not apply to permits for new waste discharges under the National Pollutant Discharge Elimination System (NPDES).

However, a complication arises in determining the applicability of the EIS requirement in the case of new injection wells, since NPDES itself does not encompass subsurface waste discharge. The basis for direct federal regulatory authority over injection is the Safe Drinking

Water Act, which contains no specific reference to NEPA. In the absence of a specific exemption for permitting new injection wells, it would appear that the EIS requirement would apply to this activity due to its basic similarity to the permitting process under NPDES.

An example of a situation in which an EIS has encompassed injection wells is the statement prepared by EPA for disposal of treated municipal wastes in southeastern Florida.[248] This EIS does not focus on a specific project but includes an evaluation of the environmental impact of a number of potential alternative disposal methods, one of which is deep well injection. Preparation of an EIS in this instance was influenced by the fact that the waste involved was municipal effluent. Public disposal facilities generally involve federal construction grants, a program that has traditionally been subject to the EIS requirement.

With regard to the fundamental question of whether NEPA *should* apply to federal permitting of waste discharge, support exists on both sides of the issue. The basic support for exemption of certain elements of EPA's water quality program from the EIS requirement is that the sole mission of the agency is protection of environmental quality, therefore alleviating the need for the same type of external review applicable to agencies with a developmental mission. This view is further supported by the fact that the basic goals of EIS preparation are encompassed within the terms of EPA's regulatory authority itself, making application of the EIS requirement superfluous and therefore unnecessary.

However, there are potential gains from application of the requirements of NEPA. These have been summarized as follows:

> The principal reasons for applying NEPA to EPA's programs are the same as they are for any other agency: improved planning and coordination; an increased likelihood that decisions to further one environmental goal will be taken with awareness of the possible impacts on other environmental concerns; fuller use of available expertise through the comment process; the substantial benefits of public participation; and finally, careful decision making through a balanced weighing of costs and benefits. Having NEPA apply to EPA would ensure consistent application of NEPA to all agencies, with the advantages of equal treatment which a uniform government-wide policy would bring. Also, the decisions which EPA makes do not invariably bring benefits of unalloyed environmental protection; by law the agency must frequently trade environmental quality off against economic benefit. NEPA would help ensure that in making these decisions EPA was held to the highest standards in justifying its course of action.[249]

In addition to the federal EIS requirement, another mechanism for citizen involvement in injection well management consists of state provisions for environmental review of waste discharge proposals. For example, the State of Michigan requires the preparation of an EIS for all disposal wells that must include the identification of adverse environmental effects and evaluation of alternative methods of handling the waste involved. The degree of detail required in a particular case is dependent on whether the well in question is contested or whether a controversial environmental impact is likely.

Provisions of Injection Well Controls

Existing injection well controls contain a number of provisions for citizen involvement in the regulatory process. Both the FWPCA and the SDWA provide for citizen suits against violators of the acts' requirements and against the Administrator of EPA for failure to perform nondiscretionary duties established by the legislation. A second mechanism for broadening input into the decision making process consists of provisions in injection well regulations developed pursuant to SDWA concerning review of injection well permit applications. A third mechanism for citizen involvement consists of the provision in SDWA for special interim controls over injection in areas where a single aquifer serves as the sole or primary source of drinking water.

Citizen Suit Provisions

The FWPCA citizen suit provision[250] states that "any citizen" may bring suit to enforce compliance with the Act, but the term "citizen" is defined to include only those persons "having an interest which is or may be adversely affected."[251] The legislative history[252] of FWPCA indicates that Congress intended that the standing to sue requirements established in the supreme court decision of *Sierra Club* v. *Morton*[253] be applied in suits brought under FWPCA. The court in *Sierra* rejected the concept that a citizen group has standing to sue solely as a representative of the public interest without a showing that its members will be harmed by the challenged action. Thus the question of standing under FWPCA has not been completely resolved and still must be considered on a case-by-case basis.

Actual court determinations of standing under the FWPCA provision have produced varying results which make generalization difficult. An example of a situation in which the standing issue was resolved negatively is the 1974 case of *Stream Pollution Control Board of Indiana* v. *United States Steel, Inc.*[254] in which a citizen of Indiana attempted to intervene under the citizen suit provision of FWPCA and other laws. The party attempting intervention asserted an interest in the general environment of the State of Indiana and in the waters of Lake Michigan as a source of drinking water and recreation. The court held that the alleged interest was no different from that of many other citizens and would not allow intervention in the absence of special damages.

An opposite decision concerning standing was reached in the 1973 case of *Montgomery Environmental Coalition* v. *Fri.*[255] The following quotation explains the nature of the interest which the court accepted as a basis for conferring standing:

> The two community groups allege in their complaint that their members are citizens of the District of Columbia and Montgomery County, Maryland, two jurisdictions which are contiguous to the flow of the Potomac River. Unlike the plaintiff in *Sierra,* the instant plaintiffs are groups of citizens who claim to live within the environs of the natural object they seek to protect. General interest in the aesthetic and environmental well-being of a river running past one's community area is obviously on a higher plane than the interest a national environmental group composed of nonresident citizens or users might properly claim. It would be an unjustified presumption on the Court's part to think that none of the aesthetic and recreational values of the plaintiffs will be lessened by increased pollution of the Potomac River when the river itself passes within the midst of plaintiff's community.

The citizen suit provision[256] of SDWA provides that "any person" may bring suit against parties in violation of the requirements of the Act or against EPA to compel performance of nondiscretionary duties. The Act does not specifically limit the word "person" to those having a particular interest as is done in the FWPCA citizen suit provision with regard to the word "citizen". However, the Act's legislative history[257] indicates an intent to apply the same standard employed in FWPCA to determine standing to bring suit under the SDWA provision.

Review of Injection Well Permit Applications

The regulations developed by EPA pursuant to SDWA for state programs to control underground injection require that public notice be given in connection with each permit application that is made for a conventional injection well, including a preliminary determination with respect to agency action on the application. Interested persons may submit written comments regarding the preliminary determination, which are to be considered in the final agency determination. Government agencies are also to be given notice and may submit written comments. Provision is made for interested parties to request a public hearing in connection with such applications and a hearing must be held where significant public interest is expressed.[258]

Designating Areas for Special Interim Controls

The previously discussed provisions for interim EPA regulation of new injection wells in areas whose principal water supply comes from a single aquifer are an important mechanism for citizen involvement, since any person can initiate proceedings for designation by petitioning the EPA Administrator. Designation of such areas requires a finding that one aquifer does serve as the sole or principal drinking water source for an area, and that its contamination would create a significant hazard to public health. It has been reported that the Environmental Defense Fund has already petitioned EPA for designation of the aquifers underlying Long Island, New York.[259]

Part II Footnotes

[1]Bruce F. Latta, "Subsurface Disposal of Wastes in Kansas," *Preprints of Papers Presented at the Second International Symposium on Underground Waste Management and Artificial Recharge,* Vol. 1, The American Association of Petroleum Geologists, United States Geological Survey, and International Association of Hydrologic Sciences, 1973, pp. 622-633.

[2]*Texas Acts of 1961,* 57th Legislature, p. 159, ch. 82 (repealed 1971).

[3]*Texas Water Code Ann.,* sec. 22.011 (1971).

[4]*Ohio Rev. Code Ann.,* sec. 1509.051 (Page 1973).

[5]*Mich. Stat. Ann.,* sec. 13.141 (1-26) (1969).

[6]*W. Va. Code Ann.,* sec. 20-5a-5 (1969).

[7]This policy statement presently exists as "Industrial Wastewater-Deep Well Injection," *New York State Department of Environmental Conservation Policies and Procedures Manual,* ch. 9200 (hereinafter cited as "New York Policy").

[8]Edward J. Cleary and Don L. Warner, "Perspective on the Regulation of Underground Injection of Wastewaters," Ohio River Valley Water Sanitation Commission, Cincinnati, Ohio, 1969.

[9]Colorado Department of Health, "Rules and Regulations for Subsurface Disposal Systems," July, 1970.

[10]*Missouri Laws 1961,* H.B. no. 189 (Codified as *Mo. Ann. Stat.,* sec. 564.025 (Supp. 1971)).

[11]*N. C. Session Laws,* 1973, ch. 698, sec. 2 (Codified as *N. C. Gen. Stat.,* sec. 143-214.2 (1973)).

[12]For a discussion of this installation, *see* Harry M. Peek and Ralph C. Heath, "Feasibility Study of Liquid-Waste Injection into Aquifers Containing Salt Water, Wilmington, North Carolina," *Preprints of Papers Presented at the Second International Symposium on Underground Waste Management and Artificial Recharge,* Vol. 2, The American Association of Petroleum Geologists, United States Geological Survey, and International Association of Hydrologic Sciences, 1973, pp. 851-875.

[13]Federal Water Quality Administration, "Policy on Disposal of Wastes by Subsurface Injection," (Com. 5040.10) Oct., 1970.

[14]Federal Water Pollution Control Act Amendments of 1972, 33 *U.S.C.* sec. 1251 *et seq.* (Supp. 1976) (hereinafter cited as FWPCA).

[15]*Id.*, sec. 1342(b)(1)(D).

[16]*Id.*, sec. 1314(e)(2).

[17]U.S. Environmental Protection Agency, "Ground Water Pollution from Subsurface Excavations," EPA-430/9-73-012, 1973, (hereinafter cited as "Pollution from Excavations"), pp. 31-79.

[18]FWPCA, 33 *U.S.C.* sec. 1342 (*supra,* note 14).

[19]*Id.*, sec. 1362(12).

[20]*Id.*, sec. 1362(7).

[21]National Pollutant Discharge Elimination System, 40 *C.F.R.* sec. 125.26 (1973).

[22]Memorandum from Robert V. Zener, EPA Acting Deputy General Counsel to Regional Counsel, EPA Region IX, Dec. 13, 1973.

[23]*United States* v. *Armco Steel Corp.*, 333 F. Supp. 1073 (S. D. Tex. 1971) (hereinafter cited as *Armco*).

[24]Refuse Act, Act of March 3, 1899, sec. 13.

[25]*Armco,* pp. 1078-79 (*supra,* note 23).

[26]*United States* v. *GAF Corp.*, 389 F. Supp. 1379 (1975) (*supra,* note 23).

[27]*Id.*, p. 1384.

[28]*Id.*, pp. 1384-85.

[29]*Id.*, p. 1387.

[30]Safe Drinking Water Act, 42 *U.S.C.* 300f *et seq.* (Supp. 1976) (hereinafter cited as SDWA).

[31]U.S. Environmental Protection Agency, "Administrator's Decision Statement No. 5," Feb., 1973.

[32]*Id.*

[33]*Id.*

[34]*Id.*

[35]*Id.*

[36]*Id.*

[37]*U.S. Code, Cong., and Adm. News,* Vol. 4, p. 6481 (1974) (hereinafter cited as *U.S. Code News*).

[38]FWPCA, 33 *U.S.C.* sec. 1342(b)(1)(D) (*supra,* note 14).

[39]*Id.*, sec. 1314 B.

[40]"State Program Elements Necessary for Participation in the National Pollutant Discharge Elimination System," 40 *C.F.R.* part 124 (1972).

[41]*Id.*, sec. 124.80.

[42]*Id.*, sec. 124.80(b).

[43]*Id.*, sec. 124.80(c, d).

[44]FWPCA, 33 *U.S.C.* sec. 1342(d-f) (Supp. III, 1972) (*supra,* note 14).

[45]*Id.*, sec. 1314(e)(C).

[46]"Pollution from Excavations," pp. 47-74 (*supra,* note 17).

[47]*Id.*, pp. 51-57.

[48]*Id.*, p. 52.

[49]*Id.,* p. 58.
[50]*Id.,* pp. 63-67.
[51]*Id.,* p. 64.
[52]*Id.,* p. 67.
[53]*Id.,* p. 68.
[54]*Id.,* pp. 68-69.
[55]*Id.,* pp. 69-72.
[56]*Id.,* p. 72.
[57]*Id.,* pp. 72-73.
[58]*Id.,* Appendix, pp. IV-VII.
[59]*U.S. Code News,* p. 6482 (*supra,* note 37).
[60]SDWA, 42 *U.S.C.* 300h (*supra,* note 30).
[61]*Id.,* sec. 300h(d)(2).
[62]*U.S. Code News,* p. 6483-84 (*supra,* note 37).
[63]SDWA, 42 *U.S.C.* 300h-1 (*supra,* note 30).
[64]*Id.,* sec. 300h-2.
[65]*Id.,* sec. 300h-1(b)(3, 4).
[66]*Id.,* sec. 300h(b)(1).
[67]*Id.,* sec. 300h(b)(2).
[68]*U.S. Code News,* p. 6484 (*supra,* note 37).
[69]SDWA, 42 *U.S.C.* 300h-3 (*supra,* note 30).
[70]*Id.,* sec. 300h-3(e).
[71]*Id.,* sec. 300h(c)(1).
[72]*Id.,* sec. 300h(c)(2).
[73]*Id.,* sec. 300h(d)(1)
[74]"Draft Environmental Protection Agency Regulations on State Underground Injection Control Programs," 40 *C.F.R.* Part 146, Mar. 19, 1976 (hereinafter cited as "Draft EPA Regulations").
[75]*Id.,* part 146.2(r).
[76]*Id.,* part 146.70.
[77]"Draft Environmental Protection Agency Regulations on State Underground Injection Control Programs," 40 *C.F.R.* Part 146, April 14, 1975.
[78]*Id.,* part 146.1(v).
[79]*U.S. Code News,* p. 6483 (*supra,* note 37).
[80]"Draft EPA Regulations," introduction (*supra,* note 74).
[81]SDWA, 42 *U.S.C.* 300 j-l(a)(5, 8) (*supra,* note 30).
[82]"Draft EPA Regulations," part 146.21 (*supra,* note 74).
[83]*Id.,* part 146.22.
[84]*Id.,* part 146.24.
[85]*Id.,* part 146.26.
[86]*Id.,* part 146.30.
[87]*Id.,* part 146.27(a).
[88]*Id.,* part 146.30.

[89]*Id.*, part 146.32.
[90]*Id.*, part 146.33.
[91]*Id.*, parts 146.40 to 146.53.
[92]*Id.*, parts 146.70 to 146.73.
[93]*United States Constitution*, Art. I, sec. 8.
[94]*Id.*
[95]*Gibbons* v. *Ogden*, 22 U.S. (9 Wheat) 1 (1824).
[96]*United States* v. *Appalachian Electric Power Co.*, 311 U.S. 377 (1940).
[97]*Oklahoma ex. rel. Phillips* v. *Guy F. Atkinson Co.*, 313 U.S. 508 (1941).
[98]*United States* v. *Grand River Dam Authority*, 363 U.S. 229 (1960).
[99]*U.S. Code News*, p. 6461 (*supra*, note 37).
[100]*Wichard* v. *Filburn*, 317 U.S. 111 (1942).
[101]*United States* v. *Darby*, 312 U.S. 100 (1941).
[102]Delaware Department of Natural Resources and Environmental Control, "Regulations Governing the Control of Water Pollution," sec. 3.01, 3.04 (e) (March, 1974).
[103]Georgia does not have a formal policy in opposition to injection, but all proposals to date have been rejected (letter from R. S. Howard, Jr., Director, Environmental Protection Division, Georgia Department of Natural Resources to William E. Cox, February 27, 1974).
[104]Letter from Paul T. Anderson, Director, Bureau of Community Sanitation, Massachusetts Department of Public Health, to William E. Cox, February 21, 1974.
[105]*Mo. Ann. Stat.*, sec. 564.025 (Supp. 1971).
[106]Minnesota Pollution Control Agency, "Rules and Regulations," WPC 22(d) (1) (Aug., 1973).
[107]Letter from Douglas M. Clark, Supervising Environmental Engineer, New Jersey Department of Environmental Protection, to William R. Walker, July 23, 1973.
[108]*N.C. Gen. Stat.*, sec. 143-214.2 (1973).
[109]Letter from James W. Fester, Principal Sanitary Engineer, Rhode Island Department of Health, to William E. Cox, February 20, 1974.
[110]Letter from H. J. Webb, Assistant to the Commissioner for Environmental Affairs, South Carolina Department of Health and Environmental Control, to William E. Cox, February 21, 1974.
[111]Letter from Reginald A. LaRosa, Chief, Engineering and Operations Section, Vermont Agency of Environmental Conservation, to William E. Cox, May 21, 1973.
[112]Virginia State Water Control Board, "Commonwealth of Virginia Water Resources Policy," sec. 3.4-5, June, 1974 (hereinafter cited as "Virginia Policy").
[113]*Wis. Admin. Code*, sec. N R 112.12 (May, 1971).
[114]Letter from Louis F. Gieseke, Acting Water Commissioner, Iowa Natural Resources Council to William E. Cox, February 22, 1974.
[115]Letter from William Harold Martin, Assistant Director, Division of Water Quality Control, Tennessee Department of Public Health, to William E. Cox, February 28, 1974.
[116]Letter from Samuel L. Moore, Director, Division of Water Pollution Control,

Indiana State Board of Health, to William E. Cox, May 22, 1973.

[117]Letter from Don C. Ubel, Area Geologist, Division of Environmental Health, Kansas State Department of Health, to William R. Walker, February 26, 1973.

[118]Letter from Dwight K. Wylie, Chemical Engineer, Industrial Waste Section, Mississippi Air and Water Pollution Control Commission, to William R. Walker, September 21, 1972 (hereinafter cited as "Letter from Wylie").

[119]"New York Policy" (*supra*, note 7).

[120]*Wash. Admin. Code,* sec. 173-220-220 (Feb. 1974).

[121]*Ariz. Rev. Stat. Ann.,* sec. 36-1851(5), 36-1859(1) (Supp. 1973).

[122]*Conn. Gen. Stat. Ann.,* sec. 25-54(b), 25-54(c)(h) (1967).

[123]*Idaho Code,* sec. 42-3901 *et seq.* (Supp. 1973).

[124]*Md. Code Ann.,* sec. NR 8-1401(c) (1974).

[125]*Mont. Admin. Code.,* sec. 16-370.11 (Feb., 1974).

[126]Nebraska Department of Environmental Control, "Rules and Regulations for the Control of Disposal Wells to Protect Groundwater and Other Subsurface Resources of the State of Nebraska," June, 1975 (hereinafter cited as "Nebraska Rules").

[127]*N.D. Cent. Code.,* sec. 61-28-02(5) (1969), sec. 61-28-06(2) (1973).

[128]*Ore. Rev. Stat.,* sec. 468-700, 468-740 (1973); *Ore. Admin. Rules,* ch. 340, sec. 44-045 (Aug., 1972).

[129]*S.D. Compiled Laws Ann.,* sec. 46-25-24(6), 46-25-45(1) (1973).

[130]Disposal Well Act, *Texas Water Code Ann.,* sec. 22.001 *et seq.* (1971).

[131]Mineral Well Act, *Mich. Stat. Ann.,* sec. 13-141 (1-26) (1969).

[132]*Idaho Code,* sec. 42-3901 *et seq.* (Supp. 1973).

[133]*N.C. Gen. Stat.,* sec. 143-214.2 (1973).

[134]*Id.,* sec. 88-88(J).

[135]*Hawaii Rev. Stat.,* sec. 178-1, 5 (1963).

[136]*Ohio Rev. Code. Ann.,* sec. 1509.01 *et seq.* (Page 1967).

[137]*Ariz. Rev. Stat. Ann.,* sec. 36-1851(5), 36-1859 (Supp. 1973).

[138]*Cal. Water Code.,* sec. 13540 (1970).

[139]*Colo. Rev. Stat. Ann.,* sec. 66-28-2(F), 66-28-12 (Supp. 1967).

[140]*Conn. Gen. Stat. Ann.,* sec. 25-54(b), 25-54(c)(h) (1967).

[141]*Ill. Ann. Stat.,* ch. 111½, sec. 1012 (Smith-Hurd 1970).

[142]*Md. Code Ann.,* sec. NR 8-1401(c) (1974).

[143]*Miss. Code Ann.,* sec. 49-17-5, 49-17-29 (1972).

[144]*Mo. Ann. Stat.,* sec. 204.016(6), 204.051 (Vernon 1973).

[145]*Neb. Rev. Stat.,* sec. 81-1502(8), 81-1504 (1971).

[146]*N.M. Stat. Ann.,* sec. 75-39-2(G) (1967), sec. 75-39-4.1 (1973).

[147]*N.C. Gen Stat.,* sec. 143-214.2 (1973).

[148]*N.D. Cent. Code.,* sec. 61-28-02(5) (1969), sec. 61-28-06(2) (1973).

[149]*Ore. Rev. Stat.,* sec. 468.700, 468.740 (1973).

[150]*S.D. Compiled Laws Ann.,* sec. 46-25-24(6), 46-25-45(1) (1973).

[151]*Vt. Stat. Ann.,* tit. 10, sec. 1259 (Supp. 1975).

[152]*W. Va. Code. Ann.,* sec. 20-5A-5(7) (1969).

[153]*Wyo. Stat. Ann.,* sec. 35-502.3(c) (V), 35-502.18 (Cum. Supp. 1973).

[154]*Mo. Ann. Stat.,* sec. 564.025 (Supp. 1971).

[155]Letter from Reginald A. LaRosa, Chief, Engineering and Operations Section, Vermont Agency of Environmental Conservation, to William E. Cox, May 21, 1973.

[156]*e.g.,* an active regulatory program exists in Alabama although no explicit statutory reference is made to disposal wells.

[157]No state has been found which does not fit this category. Maine pollution control law prior to 1973 was limited to surface discharges but has been amended to include all discharges (*Me. Rev. Stat. Ann.* tit. 38, sec. 413 (1964)).

[158]*See., e.g., Conn. Gen. Stat. Ann.,* sec. 25-54(b) (1967); *Minn. Stat. Ann.,* sec. 115.01(5) (1948); *Neb. Rev. Stat.,* sec. 81-1503(20) (1971); *Wash. Rev. Code Ann.,* sec. 90-48.020 (1945); *Ohio Rev. Code Ann.,* sec. 6111.01(A) (Page 1953).

[159]Colorado Department of Health, "Rules for Subsurface Disposal Systems," Jan., 1974 (hereinafter cited as "Colorado Rules").

[160]Hawaii Department of Health, "Public Health Regulations," ch. 38, sec. 7C, 7D.

[161]Louisiana Geological Survey, "Waste Disposal Wells Approval Procedure," July, 1970.

[162]Michigan Department of Natural Resources, "General Rules Governing Mineral Well Operations," June, 1972 (hereinafter cited as "Michigan Rules").

[163]"Nebraska Rules" (*supra,* note 126).

[164]Oklahoma Water Resources Board, "Rules and Regulations," ch. V., sec. 530 (1973) (hereinafter cited as "Oklahoma Rules").

[165]*Cal. Adm. Code,* tit. 23, Waters, Chapter 3, secs. 2235.18, 2513, 2536 (1973).

[166]Pennsylvania Department of Natural Resources, "Rules and Regulations of the Pennsylvania Department of Natural Resources," ch. 97, Industrial Wastes: Underground Disposal, secs. 97.73 to 97.75 (Sept., 1975).

[167]*Alaska Admin. Code,* tit. 18, sec. 72.020 (Oct., 1973).

[168]Indiana Stream Pollution Control Board, "Regulation SPC-15," sec. 2(a) (Nov., 1973).

[169]Kansas State Board of Health, "Regulations." (May, 1966).

[170]*Mont. Admin. Code.,* sec. 16-370 (Feb., 1974).

[171]*Wash. Admin. Code.,* sec. 173-220-220 (Feb., 1974).

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[173]Delaware Department of Natural Resources and Environmental Control, "Regulations Governing the Control of Water Pollution," sec. 3.01, 3.04(e) (Mar., 1974).

[174]*Wis. Admin. Code.,* sec. N R 112.12 (May, 1971).

[175]Michigan Department of Natural Resources, "Mineral Wells: Instructions for Completing Environmental Impact Statement."

[176]N.Y. Official Compilation of Codes, Rules, and Regulations, tit. 6, part 703.4 (April, 1968) (hereinafter cited as "New York Regulations").

[177]Oklahoma Water Resources Board, "Injection Well Questionnaire" (hereinafter cited as "Oklahoma Questionnaire").

[178]Texas Water Quality Board, "Subsurface Waste Disposal in Texas," (Agency Publication No. 72-05) (Feb. 1972) (hereinafter cited as "Subsurface Disposal in Texas").

[179]West Virginia Department of Natural Resources, "Instructions and Addendum to Instructions: Filing Permit Applications" (hereinafter cited as "West Virginia Instructions").

[180]Alabama Water Improvement Commission, Water Improvement Commission Policy on Disposal of Industrial Waste by Subsurface Injection," approved January 14, 1971.

[181]Florida Department of Pollution Control, "Revised Policy on Drainage and Injection Wells." (Technical Memorandum No.: 8-12), issued June 1, 1972 (hereinafter cited as "Florida Policy").

[182]Michigan Water Resources Commission, Policy Statement on Disposal of Wastes by Subsurface Injection.

[183]"New York Policy" (*supra,* note 7).

[184]"Virginia Policy" (*supra,* note 112).

[185]Letter from Ralph C. Pickard, Executive Director, Kentucky Water Pollution Control Commission, to William R. Walker, September 18, 1972.

[186]"Letter from Wylie" (*supra,* note 118).

[187]Letter from Carlyle W. Westlund, Chief, Ground Water Section, Division of Water Quality, Pennsylvania Department of Environmental Resources to William R. Walker, March 13, 1973.

[188]Alabama Water Improvement Commission, Contract No. GS-73-10, November 29, 1972.

[189]*Fla. Stat. Ann.,* sec. 403.088 (Supp. 1972).

[190]*Texas Water Code Ann.,* sec. 22.015 (1971).

[191]*Id.,* sec. 22.017 (1971).

[192]*Ohio Rev. Code Ann.,* sec. 1509.08, 1509.081 (Page 1973).

[193]"Colorado Rules," sec. 4 (*supra,* note 159).

[194]Michigan Department of Natural Resources, "Feasibility Study for Subsurface Disposal" (hereinafter cited as "Michigan Feasibility Study").

[195]"Nebraska Rules," sec. 3.02(A, B) (*supra,* note 126).

[196]"Oklahoma Questionnaire" (*supra,* note 177).

[197]"Subsurface Disposal in Texas," figure 3 (*supra,* note 178).

[198]"West Virginia Instructions" (*supra,* note 179).

[199]"Michigan Feasibility Study" (*supra,* note 194).

[200]"Florida Policy," p. 11 (*supra,* note 181).

[201]Hawaii Department of Health, "Guidelines to Attain Affirmative Demonstration," September 28, 1973.

[202]*Idaho Code.,* sec. 42-3904 (Supp. 1973).

[203]*Ohio Rev. Code Ann.,* sec. 1509.06 (Page 1973).

[204]"Colorado Rules," sec. 3(b) (*supra,* note 159).

[205]"New York Regulations" (*supra,* note 176).

[206]"Nebraska Rules," sec. 3.02(B)(2)(a) (*supra,* note 126).

[207]"Subsurface Disposal in Texas", pp. 5, 6 (*supra,* note 178).

[208]Illinois Sanitary Water Board (now part of Illinois Environmental Protection Agency), "Administrative and Technical Procedures Controlling the Installation and Operation of Deep Well Injection of Industrial Wastes in Illinois," January

13, 1968, p. 4.

[209]"Letter from Wylie" (*supra,* note 118).

[210]Personal communication from Roy M. Alverson, Chief, Water Resources Division, Geological Survey of Alabama, to William E. Cox, March 20, 1973.

[211]"Michigan Rules," R 299.2216 (*supra,* note 162).

[212]"Colorado Rules," sec. 4(k) (*supra,* note 159).

[213]"Nebraska Rules," rule 4 (*supra,* note 126).

[214]"Michigan Rules," R 299.2268 (*supra,* note 162).

[215]"Oklahoma Rules," sec. 530.2-530.10 (*supra,* note 164).

[216]"Michigan Rules," R 299.2267 (*supra,* note 162).

[217]"Oklahoma Rules," sec. 530.10(b) (*supra,* note 164).

[218]*Texas Water Code Ann.,* sec. 22.055 (1971).

[219]"Subsurface Disposal in Texas," pp. 21-22 (*supra,* note 178).

[220]"Florida Policy," p. 12 (*supra,* note 181).

[221]"Colorado Rules," sec. 4(j)(7) (*supra,* note 159).

[222]*Id.,* sec. 3(e)(2).

[223]*Id.,* sec. 7.

[224]"Michigan Rules," R 299.2268(6) (*supra,* note 162).

[225]"Nebraska Rules," rule 5 (*supra,* note 126).

[226]"Oklahoma Rules," sec. 530.10 (*supra,* note 164).

[227]"Subsurface Disposal in Texas," p. 22 (*supra,* note 178).

[228]"Oklahoma Rules," sec. 530.11 (*supra,* note 164).

[229]*Ohio Rev. Code Ann.,* sec. 1509.13, 1509.15, 1509.16 (Page 1973).

[230]"Michigan Rules," R 299.2282(3) (*supra,* note 162).

[231]*Id.,* (1, 2).

[232]"Nebraska Rules," rule 6 (*supra,* note 126).

[233]"Subsurface Disposal in Texas," pp. 23-24 (*supra,* note 178).

[234]Ohio River Valley Water Sanitation Compact (Codified in Virginia as *Va. Code Ann.,* sec. 62.1-71 (1968)).

[235]Ohio River Valley Water Sanitation Commission, "Underground Injection of Wastewaters in the Ohio Valley Region," August, 1973, p. III.

[236]*Id.*

[237]*Id.,* p. 1.

[238]*Id.,* pp. 17-61.

[239]Ohio River Valley Water Sanitation Commission, "Registry of Wells for Use in Underground Injection of Wastewater in the Ohio Valley Region," March, 1974, foreword.

[240]*Id.,* p. 1.

[241]*Id.,* pp. 4-5.

[242]*Id.,* pp. 8-9.

[243]National Environmental Policy Act of 1969, 42 *U.S.C.* 4321 *et seq.* (1973), *as amended* (Supp. 1976).

[244]*Id.*

[245]CEQ 1971 Guidelines, sec. 5(d), 36 *Fed. Reg.* 7224 (1971).

[246]CEQ 1973 Guidelines, 40 *C.F.R.* sec. 1500.4 (a) (1973).

[247]FWPCA, 33 *U.S.C.* 1371(c) (1) (*supra,* note 14).

[248]U.S. Environmental Protection Agency, *Environmental Impact Statement, Final: Ocean Outfalls and Other Methods of Treated Wastewater Disposal in Southeast Florida,* Atlanta, Georgia, March 1973.

[249]Frederick R. Anderson, *Federal Environmental Law,* ed. by Erica L. Dolgin and Thomas G. P. Guilbert, West Publishing Co., St. Paul, Minn., 1974, pp. 238-419 at 263.

[250]FWPCA, 33 *U.S.C.* 1365 (*supra,* note 14).

[251]*Id.,* sec. 1365(g).

[252]Conference Report, Report No. 92-1236, 92d Cong., 2d sess., 1972, p. 146.

[253]*Sierra Club* v. *Morton,* 411 U.S. 920 (1972).

[254]*Stream Pollution Control Board of Indiana* v. *U.S. Steel, Inc.,* 62 F.R.D. 31 (1974).

[255]*Montgomery Environmental Coalition* v. *Fri.,* 366 F. Supp. 261, 264 (D.C. 1973).

[256]SDWA, 42 *U.S.C.* 300j-8 (*supra,* note 30).

[257]U.S. Senate, 93d Cong., 1st sess., Report No. 93-231, p. 17.

[258]"Draft EPA Regulations," parts 146.25 to 146.29 and 146.44 to 146.46 (*supra,* note 74).

[259]*The Ground Water Newsletter,* Vol. 4, No. 15, Aug., 1975.

III
Privately Enforced Constraints

Introduction

The owner of an injection well is normally subject to exacting statutory requirements regarding his operations, and failure to abide by applicable provisions of law is likely to result in the imposition of specific penalties. However, compliance with all provisions of statutory law does not give complete assurance of freedom from legal action. Legal and institutional constraints on use of disposal wells are not limited to direct governmental controls. They also include the institution of property rights and the system of civil law which define the relative rights and responsibilities of members of society and provide a mechanism for accountability where the activities of one party injure or infringe upon the rights of others.

This law is embodied in the accumulated decisions of the courts and is enforced primarily by means of litigation between private parties. Although governmental controls can have an impact on the operation of private constraints, the system of civil law is somewhat independent of requirements imposed by statute, and the private right of action generally remains in effect after adoption of other controls. Of course, the existence of statutory controls over a given activity reduces the likelihood of private legal actions because they decrease the possibility of injury to other parties—one of the general requirements for maintenance of court action.

There are two basic types of remedies[1] that might be sought in suits involving injection wells. The most common type of suit is an action for damages, usually of a compensatory or restitutionary nature. Compensatory damages are awarded to offset injury produced by the activities of another party while restitutionary damages are commonly employed in cases of unauthorized use of property, where they serve to return the property and any profits from its unlawful use to the rightful owner. An additional award for punitive damages can be assessed by the courts as a penalty in extreme cases, e.g., where the injury is intentional or where there has been a blatant disregard of rights.

The second type of suit involves the equitable remedy of injunction, which is an order by the court compelling or prohibiting certain acts. The issuance of an injunction is a matter within the discretion of the court and is reserved for those cases where an award of damages is not an adequate remedy. One of the major uses of injunction is to restrain activities which have not produced injury or violated the rights of others but are likely to do so if allowed to continue. However, the injury or legal infringement cannot be highly speculative but must be shown to be a relatively certain result if the activity were allowed to continue.

Privately enforced constraints on the use of injection wells involve two separate but related issues. The first is the question of whether the landowner located adjacent to a disposal well operator can prohibit the injection of waste material into space beneath his surface estate in the absence of impairment of his use and enjoyment of the property. The second issue concerns the rights and responsibilities of the parties involved where actual physical injury arises from a disposal well operation. Thus, the former involves considerations of the ownership of subsurface space, while the latter is concerned with the question of liability for injury and the legal procedures for the distribution of losses between injured parties and those responsible for the injury-producing activities.

Ownership of Subsurface Space

The principal issue to be considered here is whether deep-lying subsurface space is subject to the same laws of private property which govern use of much of the land surface, or whether such space is part of the public domain whose use is controlled exclusively by governmental bodies as trustee for the public. It should be noted at the outset that resolution of the ownership question does not in itself decide the appropriateness or desirability of using subsurface space for purposes of waste disposal and storage. It is true that private ownership places constraints on the use of property in addition to direct governmental controls, but constraints also exist on the use of public property in the form of limitations on the right of the government to allow use of property held in public trust for its citizens in derogation of the public interest.[2] The principal question, then, is whether use of subsurface space for waste disposal will be controlled solely by public regulation, with the associated public interest limitations, or by a combination of direct government controls and private property rights.

Subsurface property rights have evolved largely in relation to the development and utilization of extractable natural resources. In the case of hard minerals fixed in position, ownership has generally been vested in the owner of the overlying surface, except where reserved by government.[3] Complications arise where movable resources are involved since they are not permanently attached to specific parcels of land. In the case of ground water, ownership by capture and reduction to possession has played a basic role in defining rights. Common law doctrines of ground water rights have regulated use to some extent by tying ground water rights to land ownership and restricting certain uses having detrimental consequences on others, but systems of rights based on ownership have not proved to be very adequate where use is intense and have often had to be supplemented by direct governmental regulation.[4] Systems of rights based solely on land ownership have been even less successful in cases of more valuable resources of a movable nature such as petroleum. Although land ownership is still an important factor, administrative regulation is an integral aspect of production controls.[5]

Since subsurface space has rarely been viewed as a valuable resource in itself, consideration of its ownership has not been extensive. Subsurface space shares the hard mineral characteristic of being fixed in position and can therefore be attached to specific portions of the land surface. However, it is similar to those with mobility in that it can be utilized by operations on adjoining land. Just as petroleum can be extracted by pumping from other land, a liquid waste or other substance can be injected from other land. Thus subsurface space is a somewhat unique resource in that, although fixed in position, it can be utilized without the physical invasion of property, except by the waste material itself.

The possibility of subsurface invasion by injected wastes exists in most injection operations because confinement considerations are generally limited to vertical containment, with little attention given to horizontal movement where the overlying impermeable strata are extensive. Horizontal migration of injected fluids is the relief phenomenon by which excessive pressure buildups at the well are avoided and is therefore desirable from the viewpoint of the injector. Provided that the disposal zone is continuous for considerable distances, the lateral extent of this migration is controlled only by the characteristics of the disposal stratum (including its hydrodynamic features) and the rate of injection. Since this physical process is not affected by property boundaries, the potential exists for the invasion of the subsurface space of adjacent landowners. With respect to a given injection operation, the likelihood of occurrence of such invasion becomes a function of the location of the disposal well with respect to property boundaries and the amount of time that injection takes place.

In many instances, subsurface invasion of this type would not be discernible by the adjacent landowner and would not produce measurable damages. However, such an unauthorized invasion may constitute a technical violation of a property right. The principal factor upon which this determination depends is the extent of subsurface property rights recognized in the jurisdiction involved. One end of the spectrum of possibilities is represented by complete ownership and control by the surface landowner, a situation wherein storage space would be viewed strictly as a private resource. The other extreme is represented by nonownership, with subsurface storage space viewed as a public resource subject to use without regard to land ownership in the absence of interference with the overlying owner's use and enjoyment of his property. The choice between these two opposing positions has not been considered by most of the states, and the existing evidence as to how the issue might be resolved is somewhat contradictory.

Precedent for the Private Property View

The concept of exclusive private ownership of space above and below surface property to an unlimited extent is embodied in the maxim *cujus est solum, ejus est usque ad coelum et ad inferos,* which means "to whomsoever the soil belongs, he owns also to the sky and to the depths."[6] Of course this concept has been modified to the extent that a landowner cannot prohibit use of airspace above his land for aviation purposes when such use does not interfere with the landowner's use and enjoyment of his property,[7] but it still has considerable impact with regard to subsurface property rights.

The basic reason for establishment of this unbounded concept of ownership appears to have been the desire to assure the right to use overlying and underlying space to any extent necessary or desirable, and to protect such uses from interference by others. The simplest method of assuring such protection was the infinite extension of property rights. In cases involving mineral rights, for example, the courts have not always limited their consideration to actual resources physically or economically recoverable but have defined ownership without practical lower limits. This approach apparently gives no consideration to the possibility of use by others that would not affect or interfere with use by the landowner. A strict interpretation of such unbounded property rights excludes any use by others regardless of the lack of impact on the landowner or the surface owner's inability to make the use in question himself.

The 1936 Kentucky case of *Edwards* v. *Lee's Administrator*[8] is a good example of a strict application of the exclusive ownershio concept. The case supports the right of a landowner to exercise exclusive control over a portion of an underlying cave whose entrance was located on the property of another. The owner of the land underlain by the cave was awarded damages from the adjacent owner making commercial use of the cave. This decision was reached in spite of the fact that the plaintiff had no means of access to the cave located 360 feet beneath his land. The primary consideration appears to have been the fact that the defendant made an economic use of space theoretically owned by another, therefore incurring liability for a portion of the profits accruing from such use.

The concept of the surface owner's exclusive control over unusable subsurface space is also supported by the 1937 Indiana case of *Marengo Cave Co.* v. *Ross.*[9] This case also arose out of a dispute as to the ownership of a cave which extended beneath land adjacent to that where the entrance was located. In this instance, the party who controlled the cave's entrance did not contest the overlying owner's original claim to the portion of the cave in question but claimed title on the basis of adverse possession. Although possession for the necessary period of time was conceded, the court held that the conditions of the possession were not adequate to effect a transfer of title. One of the essential elements for the establishment of title by adverse possession is that the possession must be open and notorious, a condition not fulfilled since the overlying owner of the cave was not aware that it extended beneath his property during a major portion of the period of possession.

Acceptance of the concept of absolute ownership to the center of the earth by the jurisdiction where injection wells are being used or proposed has serious implications for the operators of those wells. Unauthorized injection into strata underlying the property of another could be interpreted as a violation of property rights, giving rise to a cause for legal action even in the absence of injury or interference with the landowner's use.

The theory of trespass has traditionally been employed to protect exclusive rights to property and prevent unauthorized entry. In the absence of actual damage, the courts will sometimes maintain that "constructive" damage has been produced since vindication of a legal right is the principal issue.[10] Although the issue of whether invasion of property by injected wastes constitutes trespass apparently has never been decided in the affirmative, the theory of trespass has been applied to protect against other subsurface invasions. For example, slant drilling wherein oil wells have been drilled at an angle such that they cross property boundaries beneath the land surface has been held to constitute trespass.[11] Also, it has been held that fracturing of a formation across property boundaries as a part of a natural gas recovery operation constitutes trespass. The following language is from the case of *Gregg* v. *Delhi-Taylor Oil Corp.*:[12]

> While the drilling bit of Gregg's well is not alleged to have extended into Delhi-Taylor's land, the same result is reached if in fact the cracks or veins extend into its land and gas is produced therefrom by Gregg. To constitute a trespass, "entry upon another's land need not be in person, but may be made by causing or permitting a thing to cross the boundary of the premises."

If the landowner is held to have exclusive control over use of underlying strata, utilization of such strata for injection purposes will require purchase of the land involved or acquisition of a lesser interest to use the underlying formations for waste disposal. Precedent for acquisition of storage leases exists in cases of natural gas storage operations which utilize natural geologic formations in lieu of artificial containers. The process for acquisition of storage rights where natural gas storage is involved is affected by the fact that gas companies typically possess powers of eminent domain. Acquisition of waste disposal rights would in most instances be accomplished solely by private negotiation. Regardless of this distinction, however, the principles that have been formulated for valuation of natural gas shortage strata are of interest since they involve the balancing of compensable private property interests against use of such property in the public interest.

The valuation of a natural gas storage stratum was the principal issue in the 1962 Illinois case of *Peoples Gas Light and Coke Co.* v. *Buckles.*[13] The landowner in the case sought compensation based on a proportionate share of the net future revenues from use of the storage stratum located partially beneath his land. The court rejected this measure of compensation and applied the rule that fair market value in such cases should be based on loss to the owner without consideration of special value arising from a use not available to the landowner.

> Plaintiff's [gas company] taking amounts to no more than an easement, and the usual measure of damages payable to such cases is based upon the diminution of the fair cash market value of the property burdened by the easement. [citations omitted]
>
> It is difficult for us to see how a commercially valueless salt-water-filled sandstone formation 1600 feet below the surface and which is unusable by the defendants, can take on any added value by virtue of a possible special use unavailable to them.
>
> . . . .
>
> [A]t the very heart of defendants' position is the fact that the St. Peter sandstone formation under the defendant's land achieves value solely because it is a part of the certified storage project of the plaintiff and therefore, runs headlong into a well-established rule in determining values, i.e., that no consideration is to be given to the value to the condemnor for some special use. [citations omitted] "the question is, What has the owner lost? not, What has the taker gained?" [citations omitted] The taking of a salt-water-filled sandstone strata lying some 1600 feet below the surface of the defendant's land would not appear to be of substantial monetary loss to the defendants.[14]

In reaching this conclusion, the court noted that the situation involving underground storage rights is analogous to water reservoir and hydroelectric power project cases wherein value of land for a special use by the taker had been rejected in determining the amount of the award. A principal reason behind the rejection of inherent physical adaptability in the determination of value was the lack of a reasonable possibility that the landowner could have successfully put the land to such use.

> In this case defendants' position relies on the "physical adaptability" of their land or what might be called the "strategic location" of their property. In *United States* v. *Chandler-Dunbar Water Power Co.,* [citation omitted] the court specifically rejected any value due to the fortuitous location of the property, stating: "It is not proper to attribute to it any part of the value which might result from a consideration of its value as a necessary part of a comprehensive system of river improvement which should include the river and the upland upon the shore adjacent. * * * The 'strategic value' for which $15,000 has been allowed is altogether speculative."
>
> Neither is there a "reasonable possibility" that the defendants could use their land together with the other lands necessary for a gas-storage field. Such a project not only depends on the putting together of some 5,000 acres, the minimum for the pilot operation of Mahomet, but also the obtaining of a certificate for the project from the Commerce Commission. Therefore potential value based on such use by the landowner was viewed as too remote and speculative for consideration in a condemnation proceeding.[15]

Another case giving consideration of the measure of damages for the condemnation of a permanent easement for the underground storage of natural gas is *Midwestern Gas Transmission Co.* v. *Mason,*[16] decided by the Illinois court in 1964. The court accepted the concept that the measure of damages was the difference in fair market value of the property before and after imposition of the burden of the easement. Since the award of damages for surface easements was not in controversy, the court limited its deliberations to the value of the storage formations. The court upheld the finding of a lower court that the formations involved, porous linestone strata lying in excess of 1800 feet below the surface, were valueless. It was held that a provision for just compensation in eminent domain proceedings did not necessarily mean that some award had to be made.

Although the court in the *Mason* case upheld the principle of exclusive landowner control of subsurface storage zones, in reality it gave no practical effect to such rights. The following quotation from a law review article concerning the legal problems of the underground storage of natural gas is critical of this decision:

It is submitted the court erred in the *Mason* case. If a storage easement is conceded to be a property right, as indeed it is, the owner of the right must be entitled to compensation for its taking. It is well established that when the damage is slight or diminutive, the taking will support a verdict for at least nominal damages. If no other evidence is presented, at least evidence of rental paid for competitive leasing of storage rights should be considered. The point is well stated in the following Discussion Note:

> It is a startling proposition that a thing of value to its would-be acquirer (for which he would otherwise have to pay) can be taken without compensation through condemnation. Value, in everyday life and law . . . is not what a thing is worth to an owner who cannot or will not develop it himself, but its market value, which means what buyers will pay for it. [citation omitted].

These observations are unquestionably correct. Failure to repudiate the result reached in the *Mason* case will undermine the most fundamental concept of property law embodied in the Fifth Amendment to the Constitution.[17]

Precedent for the Nonownership View

Although the concept of exclusive ownership to the center of the earth is still a viable aspect of property rights, there are definite exceptions. For example, the nonownership theory has been adopted in some states with regard to oil and gas. This theory holds that no person owns oil and gas until it is produced and that it is subject to capture by any person able to do so. Of course the right of capture is limited to those holding interest in land to drill wells for production purposes, but the rule allows one owner to produce oil which originally is located beneath adjacent property. The nonownership theory is only one of several given acceptance by the various states. Williams and Meyers, in *Oil and Gas Law,* indicate that the theories include nonownership, qualified ownership, ownership in place, and ownership of the strata. They note that the opinions of the various state courts are not always clear as to the theory accepted, and that the secondary authorities are not always consistent in their classification schemes. The states listed by Williams and Meyers as presenting some evidence of the adoption of the nonownership theory include Alabama, California, Illinois, Indiana, Kentucky, Louisiana, New York, Ohio, and Wyoming.[18]

In addition to these limitations on the ownership of oil and gas, there is evidence in some jurisdictions that the right of the landowner to exclude uses by others may be limited where there is no interference with the landowner's use of his property. The most direct support for the right of the injection well operator to inject waste into the subsurface space of another without accountability in the absence of injury is presented by the case of *West Edmond Salt Water Disposal Association* v. *Rosecrans,*[19] a 1950 decision of the Supreme Court of Oklahoma. The overlying owner in this case viewed the unauthorized injection as a taking of property and brought suit to enjoin the injection operation and to obtain damages for alleged trespass in connection with previous infringement of subsurface property rights. The landowner was requesting a monetary judgment for profits accruing to the injector as a result of the unauthorized use of the subsurface space; physical damages to the land, although no evidence of actual damages was presented and punitive damages for the disregard of property rights. The injectors admitted liability for any actual damages resulting from the injection but denied that damages had occurred, since the injection zone was saturated with salt water prior to the initiation of injection.

The court concurred with the contention of the defendant that liability should be limited to actual damages. Regarding the allegation of trespass, a principal consideration of the court was whether the salt water remained the property of the defendant upon its escape to the property of others. Had ownership remained with the injector, storage beneath adjoining land apparently would have constituted trespass. The court held, however, that ownership and control were lost upon escape; consequently, there was no trespass. In reaching this conclusion concerning loss of possession, the court compared the salt water with natural ground water and petroleum, materials that are not necessarily fixed in position beneath one proprietor's land but rather are subject to migration and change of ownership. The court specifically noted that the migration of the injected fluid under plaintiff's land constituted only a displacement of a similar resident fluid.

The decision of the court in this case was likely to have been influenced by the importance of subsurface injection in disposing of the large quantities of salt water produced during oil and gas extraction. The attorney general of Oklahoma had filed a brief in connection with the case calling attention to the large production of salt water as a necessary incident to the production of oil and gas and the detriment that would result if this waste material were to be allowed to enter into surface water and underground fresh water strata. This brief maintained that a requirement for oil producers to obtain the consent of all persons under whose lands injected salt water might migrate would practically prohibit the most logical solution to the salt water disposal problem.

It is therefore conceivable that the injection of a different type of waste material under the land of an adjacent property owner would not have been permitted by the court. An exotic chemical waste from an industrial plant, for example, could not so easily be compared to natural subsurface fluids, and the needs of the petroleum industry, a basic sector of the economy of the state involved, would not be a concern. Nevertheless, a key issue in the case was the absence of actual injury to the adjacent landowner, a condition which would not necessarily be altered by a change in the injected fluid. Emphasis of this factor might therefore have produced the same decision even if the waste had been a substance other than salt water.

In addition to cases arising from disposal of oil field brines, a number of cases concerning the issues of exclusive ownership and subsurface trespass have arisen in connection with the oil field practice of secondary recovery wherein water is forced into an oil-bearing stratum by means of injection wells for the purpose of pushing remaining oil toward producing wells. Since the injected water moves according to physical laws and is not restrained by property boundaries, such operations have the potential of affecting land beyond the immediate property on which the injection is carried out.

Although liability for actual damage resulting from secondary recovery may be imposed, the courts have generally shown a reluctance to prohibit such operations solely on the basis of exclusive property rights in subsurface formations. The contemporary trend of the law regarding oil field injection is indicated in the following quotation from *Oil and Gas Law:*[20]

> For purposes of cycling, recycling, secondary recovery operations, disposal of salt water produced with oil, or storage of gas near a market, a landowner (or his mineral grantee or lessee) may desire to inject fluids (gas, water or air) into an underground structure. The fluid injected may migrate to a portion of the structure underlying the land of another and in the course of such migration displace valuable substances in such land . . . .
>
> Contemporary authority appears to support the proposition that, apart from possible liability for such special damages as were incurred in the above-mentioned Oklahoma case, there is no liability for the migration of injected substances on a theory of trespass. Thus another Oklahoma case denied recovery for trespass on a showing of injection of salt water into a stratum which already included salt water and no other substance. The view was taken that when the salt water was injected into the formation by defendants, they thereby lost title thereto.
>
> What may be called a "negative rule of capture" appears to be developing. Just as under the rule of capture a landowner may capture such oil or gas as will migrate from adjoining premises to a well bottomed on his own land, so also may he inject into a formation substances which may migrate through the structure to the land of others, even if this results in the displacement under such land of more valuable with less valuable substance

> (e.g., the displacement of wet gas by dry gas). The law on this subject has not as yet been fully developed, but it seems reasonable to suggest the qualification that such activity will be permitted, free of any claim for damages, only if pursued as part of a reasonable program of development and without injury to producing or potentially producing formations.

As shown in the following language of the Supreme Court of Texas in *Railroad Commission of Texas* v. *Manziel*,[21] this position has been adopted because of the importance of secondary recovery as a conservation measure:

> Secondary recovery operations are carried on to increase the ultimate recovery of oil and gas, and it is established that pressure maintenance projects will result in more recovery than was obtained by primary methods. It cannot be disputed that such operations should be encouraged, for as the pressure behind the primary production dissipates, the greater is the public necessity for applying secondary recovery forces. It is obvious that secondary recovery programs could not and would not be conducted if any adjoining operator could stop the project on the ground of subsurface trespass . . . .
>
> The orthodox rules and principles applied by the courts as regards surface invasions of land may not be appropriately applied to subsurface invasions as arise out of the secondary recovery of natural resources. If the intrusions of salt water are to be regarded as trespassory in character, then under common notions of subsurface invasions, the justifying public policy considerations behind secondary recovery operations could not be reached in considering the validity and reasonableness of such operations . . . . Certainly, it is relevant to consider and weigh the interests of society and the oil and gas industry as a whole against the interests of the individual operator who is damaged; and if the authorized activities in an adjoining secondary recovery unit are found to be based on some substantial, justifying occasion, then this court should sustain their validity.

Since the restriction of private rights in the interests of secondary recovery and oilfield brine disposal is strongly influenced by considerations of the public interest, extension of these property rights limitations to industrial waste disposal requires the assumption that this type of operation also involves an overriding issue of public interest. Although waste disposal certainly falls within the scope of the public interest, there is a question as to whether industrial waste injection is currently viewed with the same importance as injection constituting an integral part of petroleum production.

Precedent for the right to use subsurface strata without accountability to the landowner in the absence of injury also exists in areas other than oil and gas production. A somewhat related area is that of subsurface storage of natural gas. One of the most interesting cases in this area is

Hammonds v. *Central Kentucky Natural Gas Co.*[22] In this 1934 Kentucky decision, a landowner brought suit under the concept of trespass for compensation from a company engaged in the storage of natural gas in an underground reservoir extending beneath the plaintiff's property. By applying the theory that oil and gas are of a wild and migratory nature, the court reasoned that the act of releasing the gas in question into the earth resulted in loss of exclusive ownership. Therefore the company was not liable for the value of the use of the adjacent property since it no longer exercised ownership and control over the gas. The loss of ownership holding has detrimental implications with regard to injection of substances for later recovery, and other courts have since refused to accept this aspect of the decision.[23] It should also be noted that specification of the rights to inject and recover natural gas are currently subject to statutory regulation in several states.[24] Thus the potential effect of this case on temporary storage operations has been somewhat nullified, but the decision still supports the use of subsurface space without accountability to the overlying owner and therefore may still have relevance with respect to permanent waste storage where the right of subsequent withdrawal of the injected fluid is not an issue.

Another case which somewhat restricts the exclusive rights of the landowner in subsurface space is the 1931 New York decision of *Boehringer* v. *Montalto.*[25] This case arose from a dispute between the buyer and seller of property involving an undisclosed sewer line located 150 feet below the surface. The court held that the sewer was not an encumbrance, on the basis of the view that a landowner's rights are restricted to a depth of "useful ownership." The absolute concept of indefinite ownership upward and downward was rejected as an unacceptable principle of law.

After holding the sewer line not to be an encumbrance, the court added that even if it were, the depth at which it was constructed and the absence of surface access would entitle the owner to nominal damages only. This conclusion is consistent with decisions in earlier New York cases concerning the construction of tunnels. In a 1913 case,[26] the court held the damage from a tunnel to be constructed approximately 150 feet below the surface to be so slight as to be practically negligible. On another occasion,[27] the construction of a tunnel at a depth of nearly 500 feet was described as only a technical damage to property which did not call for the award of more than nominal damages.

If subsurface space lying at considerable depth below private surface property is considered to be part of the public domain, the question arises as to whether the government is authorized to allow its use for the disposal of wastes from private industrial firms. Essentially the same question could be raised with regard to the right of the government to allow waste disposal beneath public lands presently held in trust for the public. Recent years have witnessed a proliferation of lawsuits in which citizens sue governmental agencies charged with protecting the public interest, e.g., those responsible for enforcement of air and water pollution laws.

Since this particular question concerning use of the public domain apparently has not been raised, a preliminary response must be based on considerations of the public trust doctrine in general. As Joseph L. Sax has noted, court decisions exist ". . . which seem to imply that a government may never alienate trust property by conveying it to a private owner and that it may not effect changes in the use to which that property has been devoted."[28] But as Sax points out, there is no complete prohibition against the disposition of trust properties or the ". . . transfer of some element of the public trust into private ownership and control, even though that transfer may exclude or impair certain public uses . . . . [N]o grant may be made to a private party if that grant is of such amplitude that the state will effectively have given up its authority to govern, but a grant is not illegal solely because it diminishes in some degree the quantum of traditional public uses."[29]

In the case of authorization of waste injection under specified conditions, the government would not be giving up its authority to govern, nor would impairment of public use be likely because of the limited usefulness of the disposal strata in their natural condition. It can be anticipated that arguments in opposition to such use of public property would be based on the possibility of mishaps leading to contamination of ground water, but enforcement of regulations reasonably designed to prevent such occurrences may override these objections. Governmental authorization of waste discharges to public surface waters appears to serve as strong precedent for subsurface waste disposal in the public domain. Of course passage of the Federal Water Pollution Control Act Amendments of 1972[30] signals a change in philosophy toward this use of surface waters, but complete implementation will certainly be a long-term process.

Airspace Rights: An Analogous Situation?

Although the exclusive rights of the landowner in overlying airspace, like those in the subsurface, were once considered to be without vertical limit, these rights have been expressly restricted in the interest of public use for aviation purposes. Since the existence of a major public need for use of airspace has resulted in greater consideration of the boundary between private and public property, it is of interest to consider the nature of the restrictions and the question of whether a close analogy exists between the two areas of law.

When confronted with a conflict between the infinite ownership concept and the public interest, the federal courts simply renounced the concept. The following statement is from *United States* v. *Causby,*[31] one of the landmark cases concerning rights in airspace:

> It is ancient doctrine that at common law ownership of the land extended to the periphery of the universe—*Cujus est solum ejus est usque ad coelum* [citation omitted]. But that doctrine has no place in the modern world. The air is a public highway, as Congress has declared. Were that not true, every transcontinental flight would subject the operator to countless trespass suits. Common sense revolts at the idea. To recognize such private claims to the airspace would clog these highways, seriously interefere with with their control and development in the public interest, and transfer into private ownership that to which only the public has a just claim.

The infinite ownership concept had also been considered in the earlier case of *Hinman* v. *Pacific Air Transport*[32] and disposed of in a similar manner.

> If we could accept and literally construe the *ad coelum* doctrine, it would simplify the solution of this case; however, we reject that doctrine. We think it is not the law, and that it never was the law.
>
> This formula "from the center of the earth to the sky" was invented at some remote time in the past when the use of space above land actual or conceivable was confined to narrow limits, and simply meant that the owner of the land could use the overlying space to such an extent as he was able, and that no one could ever interfere with that use.
>
> This formula was never taken literally, but was a figurative phrase to express the full and complete ownership of land and the right to whatever superjacent airspace was necessary or convenient to the enjoyment of the land.

Although the court in *Hinman* renounced the infinite ownership concept, the actual issue in the case was a narrower one. Two landowners located near an airport were seeking awards of damages for past trespasses and injunctions to prevent further invasions of airspace in connection with low elevation overflights. The landowners did not claim exclusive ownership to the sky but maintained that they had exclusive rights to such airspace as could reasonably be expected to be put to use, in this case to an altitude of not less than 150 feet above the land surface.

The court denied the contention that airspace can be reserved on the basis of its reasonable susceptibility to future use in the following statement:

> We believe, and hold, that appellants' premise is unsound. The question presented is applied to a new status and little aid can be found in actual precedent. The solution is found in the application of elementary legal principles. The first and foremost of these principles is that the very essence and origin of the legal right of property is dominion over it. Property must have been reclaimed from the general mass of the earth, and it must be capable by its nature of exclusive possession. Without possession, no right in it can be maintained . . . .
>
> We own so much of the space above the ground as we can occupy or make use of, in connection with the enjoyment of our land. This right is not fixed. It varies with our varying needs and is coextensive with them. The owner of land owns as much of the space above him as he uses, but only so long as he uses it. All that lies beyond belongs to the world . . . .
>
> Any use of such air or space by others which is injurious to his land, or which constitutes an actual interference with his possession or his beneficial use thereof, would be a trespass for which he would have remedy. But any claim of the landowner beyond this cannot find a precedent in law, nor support in reason.
>
> It would be, and is, utterly impracticable and would lead to endless confusion, if the law should uphold attempts of landowners to stake out, or assert claims to definite, unused spaces in the air in order to protect some contemplated future use of it.[33]

The court noted that use of the airspace in question by airplanes could not result in the creation of an easement by prescription. Thus the relative rights of the parties, in the event the landowners actually attempted to physically utilize the airspace in question, apparently would require further determination.

Renunciation of the infinite ownership concept does not, however, mean that no private rights in airspace are recognized. Consideration of the extent of these restricted rights was the principal issue in *Causby.* This case involved a suit brought by a landowner to recover for a taking of property and for damages resulting from use of the space over the property as a glide path for a nearby airport. The glide path passed over the property at a height of 83 feet, and use of the airport by military aircraft substantially interfered with the landowner's habitation of the property and conduct of a poultry business. The following quotation indicates the extent of the landowner's rights as recognized by the Supreme Court:

> We have said that the airspace is a public highway. Yet it is obvious that if the landowner is to have full enjoyment of the land, he must have exclusive control of the immediate reaches of the enveloping atmosphere. Otherwise buildings could not be erected, trees could not be planted, and even fences could not be run. The principle is recognized when the law gives a remedy in case overhanging structures are erected on adjoining land

[citation omitted]. The landowner owns at least as much of the space above the ground as he can occupy or use in connection with the land. See *Hinman* v. *Pacific Air Transport* [citation omitted]. The fact that he does not occupy it in a physical sense—by the erection of buildings and the like—is not material. As we have said, the flight of airplanes, which skim the surface but do not touch it, is as much an appropriation of the use of the land as a more conventional entry upon it. We would not doubt that, if the United States erected an elevated railway over respondents' land at the precise altitude where its planes now fly, there would be a partial taking, even though none of the supports of the structure rested on the land [citation omitted]. The reason is that there would be an intrusion so immediate and direct as to subtract from the owner's full enjoyment of the property and to limit his exploitation of it. While the owner does not in any physical manner occupy that stratum of airspace or make use of it in the conventional sense, he does use it in somewhat the same sense that space left between buildings for the purpose of light and air is used. The superadjacent airspace at this low altitude is so close to the land that continuous invasions of it affect the use of the surface of the land itself. We think that the landowner, as an incident to his ownership, has a claim to it and that invasions of it are in the same category as invasions of the surface [citation omitted].

The airplane is part of the modern environment of life, and the inconveniences which it causes are normally not compensable under the Fifth Amendment. The airspace, apart from the immediate reaches above the land, is part of the public domain. We need not determine at this time what those precise limits are. Flights over private land are not a taking, unless they are so low and so frequent as to be a direct and immediate interference with the enjoyment and use of the land . . . . We need not speculate on that phase of the present case. For the findings of the Court of Claims plainly establish that there was a diminution in value of the property and that the frequent, low-level flights were the direct and immediate cause. We agree with the Court of Claims that a servitude has been imposed upon the land.[34]

Thus the property rights issue regarding airspace has been restricted to considerations of actual interference with the use of property. The capacity of the landowner to exclude others to unlimited heights by means of trespass actions has been abolished, as is indicated by the following summary of existing law by the American Law Institute in *Restatement of Torts (Second)*:[35]

Flight by aircraft in the airspace above the land of another is a trespass if, but only if

(a) it enters into the immediate reaches of the airspace next to the land, and

(b) it interferes substantially with the other's use and enjoyment of his land.

In attempting to assess whether the restrictions on property rights in airspace have applicability to subsurface property rights, it is interesting to consider the similarity in development of the unlimited ownership concepts which existed in both cases prior to the birth of aviation. It appears that the principal reason for adoption of the infinite concept in both cases was the need to express the landowner's complete dominion over his property and to offer protection from interference with the proprietor's use by others. There was no obvious need to place limitations on the ownership of such space since use in excess of that within the capabilities of the landowner was essentially inconceivable.

As long as use of airspace was limited to erecting structures and the use of subterranean property limited to relatively shallow excavations for such purposes as mineral recovery, maintenance of the exclusive ownership concept was equally valid in both the upward and downward directions. The development of aviation created a need for restriction of private rights to airspace not existing in the case of subsurface space. Thus, the principal factor supporting a distinction between rights in airspace and those in underground space is the difference in their susceptibility and significance for public use. There is no question as to the involvement of the public interest in the case of use of airspace for aviation. The public right of interstate transportation, based on the commerce clause of the Constitution, has always been strictly upheld, as evidenced by the extensiveness of governmental controls over navigable waters. In contrast, most of the uses of the underground are largely private in nature. Underground "space" is in large part occupied by solids and fluids, some of which are potentially exploitable as economic resources by private enterprise. In comparison with airspace therefore, underground space has greater potential for being reduced to the landowner's possession and control.

However, the possibility of subjecting subsurface space to public use without interference with the landowner's use of property exists in certain cases. Subsurface waste disposal is one potential example. It does not appear that the typical property owner would be adversely affected to a greater extent by injection of waste into a stratum 3000 feet below his surface than he would be in the case where an air lane was established 3000 feet above. Of course it is conceivable that injection could result in unanticipated injury, but it is also possible that an aircraft could crash into his house. In both cases, appropriate rules of law could be employed to obtain compensation for the landowner's losses.

The disposal of industrial wastes has traditionally been viewed as a private responsibility, but environmental quality is definitely a matter of public concern. In disposing of wastes, industrial establishments are governed by existing legal and institutional restrictions, one of which consists of private property rights. A change in these restrictions is always possible if dictated by considerations of the public interest. Thus the question of whether the potential advantages of waste injection promote the public interest to an extent to merit a restriction of private property rights is the fundamental issue in the consideration of a possible analogy between rights in airspace and those in subsurface face.

Liability for Injection-Related Injury

The principal issue under consideration in this section is the extent of the injector's liability in the event that an injection well mishap occurs and produces actual physical injury to the person or property of another. Accountability for such injury may be imposed by the courts regardless of how the subsurface ownership issue is resolved. Any restriction of the concept of private property would likely leave intact the right to be protected against subsurface invasions producing actual injury or interfering with the landowner's use of his property.

In the event that injection does produce injury, the rights of the parties involved are likely to be determined by the principles of tort law[36]—that body of legal concepts for resolving civil wrongs that involve interference with person or property. The affected party can bring suit under one of several legal theories of action, including trespass, negligence, strict liability, and nuisance. There are distinguishing characteristics of each of these theoretical concepts, but the clear-cut differences sometimes disappear at the applied level where elements of the individual theories are combined to meet the needs of particular situations. Nevertheless, it is interesting to consider briefly the basic elements of each theory as a general framework for analysis of potential injection well liability.

The concept of trespass was introduced in the previous section because of its traditional utilization in cases involving the protection of exclusive property rights from infringement. In addition to use for vindication of legal rights without proof of injury, an action on the basis of trespass can also be maintained for recovery of actual damages. The elements of such an action are the same in either case, with the principal requirement consisting of an invasion of property by another party or something under another's control.

Negligence is a concept of liability based on fault arising out of conduct falling below the standard established by law for the protection of others. Negligent conduct may consist of an action involving an unreasonable risk of harm to others or the failure to take necessary action for the protection of others. The standard of "reasonableness" to which conduct is compared is of course a relative concept dependent upon the particular circumstances of the individual case and must ultimately be determined by the courts.

The important elements of a legal action that are based on negligence include damage, causation, foreseeability, and proof of negligent actions. The only party able to maintain an action for negligent conduct is one who has suffered actual injury—or, in the case of suits for injunction, is likely to sustain injury. The term "causation" refers to the necessity of showing that the injury was actually produced by the alleged source. The issue of foreseeability is concerned with the question of whether injury could have been reasonably anticipated as a consequence of the activity in question. In addition to these three elements, a successful case based on negligence must involve proof that negligent actions have taken place. Since in many cases the injured party has difficulty in proving the specific acts of negligence involved, a doctrine of circumstantial evidence has been developed which lessens the burden of proof to a general showing that negligence was likely to have occurred, leaving the final determination of the question to the jury. One of the principal applications of this relaxation of evidentiary requirements concerns the situation where the injury-producing activity was within the exclusive control and knowledge of the defendant.

The basic premise of the strict liability concept is in direct opposition to the theory of negligence. This theory imposes liability in the absence of fault and therefore is independent of the degree of care used in conducting an activity, a basic element of negligence. The application of the strict liability concept is generally restricted to those activities posing a considerable threat to others even when conducted with every possible precaution. The philosophy behind this concept is that certain activities, while useful enough to be tolerated, are inherently dangerous and should automatically absorb responsibility for injuries inflected on others.

The theory of nuisance falls somewhere between those of negligence and strict liability. The term is generally applied to the unreasonable interference with the use or enjoyment of land. Nuisances can be either "private" or "public," with the distinguishing feature being the scope of the impact and the party authorized to initial legal action. Only governmental bodies can take action in the case of public nuisances while individuals can take action under the private doctrine to obtain a remedy for any injury peculiar to himself. Although certain activities are nuisances *per se,* i.e., nuisances under all circumstances, most private nuisances arise because of the circumstances of the individual situation. The emphasis in the theory of nuisance is on the invasion of the injured party's rights rather than on the reasonableness of the defendant's conduct. However, a nuisance can result from negligent conduct, and proof of negligence is often introduced in support of an allegation of the existence of a nuisance. At the other extreme, nuisance begins to look very much like the strict liability concept when the results of an activity are considered without regard to the reasonableness of the conduct of the defendant.

Although the various theories of liability have seen fairly comprehensive development in general, their application to deep well waste disposal is largely hypothetical due to the limited amount of litigation in this area. Most of the few existing cases concern legal controversies arising from the injection of salt water for disposal purposes or in connection with secondary recovery methods of petroleum production. These cases have addressed some of the potential problems associated with injection wells but provide no guidance with respect to others.

As noted previously, law governing secondary recovery operations is strongly influenced by public policy considerations associated with conservation of petroleum resources, thereby creating questions concerning its transferability to industrial waste disposal operations. The injection of oil field brines strictly for disposal purposes is also somewhat distinguishable from injection of industrial wastes because of the fact that the waste is a naturally occurring substance being returned to an environment similar to that in which it originated. The absence of court decisions specifically involving industrial waste disposal wells and the existence of limitations on the general applicability of decisions regarding oil field waste disposal practices necessitate reliance on more general legal principles which might by analogy be applied in cases of injection-produced injury.

Since the right to recover for injury and the legal principles involved are dependent to some extent on the nature of the injury, the applicable law will be subdivided on this basis. The most likely type of injury associated with disposal wells is contamination of ground water; therefore the first category gives consideration to liability for ground water pollution. The second section deals with liability arising from instability problems affecting use of the land surface. A third section will consider the liability aspects of any other potential problems such as the direct escape of wastes to the surface environment, destruction of other natural resources, and interference with other subsurface storage operations.

Ground Water Pollution

Although there is a scarcity of court decisions concerning injection-related ground water pollution, there is a substantial body of law concerning pollution injury from various other sources from which certain governing principles can be derived.

In order to analyse ground water rights, it is first necessary to consider the legal distinction between "underground watercourses" and "percolating ground water." In general, the same legal principles apply to subsurface water flowing in a well-defined channel that apply to surface watercourses; otherwise, the water is subject to special doctrines of percolating water rights. It is generally assumed that all underground water is percolating unless conclusively shown to flow in a well-defined channel whose existence, location, and course are discoverable from surface indications without reliance on excavation.[37] These restrictive conditions which must be met to overcome the presumption that ground water is percolating result in classification of such water as percolating in most instances.

The use of percolating ground water in the United States is generally governed by one of four doctrines of rights—absolute ownership, reasonable use, correlative rights, and prior appropriation.[38] The absolute ownership doctrine, also known as the English rule, received widespread acceptance during the early developmental period of ground water law and continues to be given some degree of acceptance. This doctrine states that the landowner is the owner of all ground water beneath his land and can extract it or otherwise interfere with its natural movement without accountability to others who may be affected. The term "absolute ownership" is something of a misnomer, since the fact that every landowner has the right to withdraw as much water as he desires means that the individual property owner has no legal protection when water levels beneath his land are lowered by pumping on other lands. The doctrine is actually a rule of capture which awards ground water to the party who drills the deepest well and installs the largest pump.

The reasonable use doctrine is somewhat more restrictive than the absolute ownership rule. It states that the landowner can make any reasonable use of ground water in connection with the land from which it is taken. Thus a principal prohibition concerns export of water for use off the land from which it is pumped. With regard to on-site use, however, few restrictions are imposed except for a prohibition against waste and malicious use. Unlike the reasonable use concept of the riparian doctrine, the extent of the right of the individual landowner to use water is measured largely by his own needs and is not limited by the adverse impact on others. If engaged in a generally accepted water use or use of land affecting the availability of water to others, the use is likely to be considered "reasonable," and a landowner can legally exhaust his neighbor's supply. Thus the reasonable use concept consists of a somewhat qualified rule of capture which gives the landowner considerable freedom to develop ground water and land without regard to the detrimental effects that may be created.

The doctrine of correlative rights, which can be subdivided into eastern and western components, views the rights of overlying owners as equal and defines the extent of the individual's right in relation to those of other users. As developed in California, the doctrine requires an apportionment of the yield of an aquifer such that excessive drawdown does not occur. In the East, the doctrine is not well developed but appears to be similar to the surface water riparian doctrine which determines the extent of an individual right primarily on the basis of such factors as the amount of water available and the nature of the competing uses.

The doctrine of prior appropriation does not apply the concept of equality to individual rights but establishes priority among users on the basis of time. A given water right is subordinate to those established at a prior time and superior to rights established subsequently. In times of water shortage, water uses must be curtailed or terminated in the reverse order of their priority in order that "senior" rights be protected.

These four doctrines relate primarily to allocation of ground water among competing users but in some cases have been applied to rights regarding alteration of quality. For example, the principle of the absolute ownership doctrine that the landowner can make unlimited withdrawals was applied in the 1881 Michigan case of *Upjohn* v. *Board of Health of Richland,*[39] in which the following statement was made:

> But if withdrawing the water from one's well by an excavation on adjoining lands will give no right of action, it is difficult to understand how corrupting its waters by a proper use of the adjoining premises can be actionable, when there is no actual intent to injure, and no negligence. The one act destroys the well, and the other does no more; the injury is the same in kind and degree in the two cases.

However, extension of the right to withdraw ground water for use to encompass the right to contaminate it represents a minority position. A number of courts have distinguished between the right to put ground water to use and the right to degrade its quality to the detriment of others. An early Kentucky decision[40] explained the basis for the distinction as follows:

> It is a familiar doctrine that one must so use his property as not to injure his neighbor, and because the owner has the right to make an appropriation of all the underground water, and thus prevent its use by another, he has no right to poison it, however innocently, or to contaminate it, so that when it reaches his neighbor's land it is in such condition as to be unfit for use either by man or beast. One may be entitled by contrast with his neighbor to all the water that flows in a stream on the surface that passes through the land of both, and, while he can thus appropriate it, he has no right to pollute the water in such a manner as, when it passes to his neighbor, its use becomes dangerous or unhealthy to his family or to the beasts on his farm . . . .
>
> The owner of land has the same right to the use and enjoyment of the air that is around and over his premises as he has to use and enjoy the water under his ground. He is entitled to the use of what is above the ground as well as that below it, and still it will scarcely be insisted that he can poison the atmosphere with noxious odors that reach the dwelling of his neighbor, to the injury of the health of himself or family. If not, we see no reason why he should be permitted to so contaminate the water that flows from his land to his neighbor's, producing the same results, and still escape liability for the damages sustained.

Most of the cases concerning ground water quality have not been decided on the basis of water rights doctrines, but rather have been based on considerations of tort law. Development of the concepts of tort liability with regard to ground water pollution has not been uniform among the states. Decisions in certain states regarding the fundamental conflict between uncontaminated water and other land uses have tended to favor the water user, while other states have emphasized the freedom to use property to the detriment of water quality.

Liability Based on Proof of Negligence

A substantial number of court decisions exist which deny the right of the landowner to uncontaminated ground water where the source of the degradation consists of the lawful use of property by others, provided that negligence is not involved.

The general effect of this requirement is to limit the right of recovery because negligence involves a greater burden of proof than the other theories of legal action. In addition to being responsible for showing causation, the injured party must also prove that the pollution-caused injury was the result of the defendant's failure to employ a reasonable standard of care in his operations. One basic element of the proof of unreasonable conduct is the identification of the specific acts or omissions which constitute the alleged negligence. A second basic factor is foreseeability, which is concerned with the question of whether the injurious consequences of a given activity could have been reasonably anticipated.

Proof of negligent acts—Failure to prove specific acts of negligence where it is the basis of a legal action can be fatal to the case of the plaintiff. For example, the decision in *Bollinger* v. *Mungle*[41] was in favor of the defendant because the plaintiff was unable to offer adequate proof in support of her charge that the defendant had negligently allowed the escape of gasoline which resulted in the contamination of a well. This is indicated by the following statement:

> On the record now before us, appellant having alleged negligence on the part of respondent, it was incumbent upon her, in order to be entitled to recover, to prove negligence of respondent either in the original construction and installation of the gasoline tank and pump, or to prove negligence by his failure to repair or remedy defects in said equipment which were either known to him or by the exercise of ordinary care could have been discovered by him and remedied.

Because of the often insurmountable obstacle posed to the plaintiff by this requirement that specific negligence be proved, the courts have developed a doctrine of circumstantial evidence—*res ipsa loquitur,* which means "the thing speaks for itself"[42] —to be applied under special conditions. The doctrine states that where an injury has occurred as a result of an accident that does not normally occur in the absence of negilgence, the jury may infer from the fact that the accident occurred that negligence was involved.[43] The basic effect of the doctrine is to place the burden on the defendant to exculpate itself from fault. As was stated in *Watkins* v. *Gulf Refining Co.,*[44] a case involving injury from the drilling of an oil well, "[t]he defendant in a damage suit coming under the doctrine of *res ipsa loquitur* must show that he did not do anything that he should not have done, that he left undone nothing he should have done, and that he neglected no legal duty owed to the plaintiff."

There are certain criteria which have been accepted as guidelines in the application of the doctrine as indicated in the following quotation:

> The conditions usually stated in America as necessary for the application of the principle of *res ipso loquitur* were derived originally from the first edition of Wigmore on Evidence, which appeared in 1905. They are as follows: (1) the event must be of a kind which ordinarily does not occur in the absence of someone's negligence; (2) it must be caused by an agency or instrumentality within the exclusive control of the defendant; (3) it must not have been due to any voluntary action or contribution on the part of the plaintiff. Some courts have at least suggested a fourth condition, that evidence as to the true explanation of the event must be more readily accessible to the defendant than to the plaintiff.[45]

This doctrine has received wide acceptance and has been specifically applied to cases of subsurface pollution. For example, the court in *Texas Co.* v. *Giddings*,[46] where a well was polluted by leakage from an oil pipe line, held that the plaintiff was not required as a basis for establishing negligence to show what particular defect was causing the leak since such information would be peculiarly within the knowledge of the defendant.

The doctrine of *res ipsa loquitur* apparently has not been applied in cases involving injection wells, but this fact is probably due largely to the small amount of litigation in this area. Injection well operations appear to meet many of the criteria necessary for application. Location, design, construction, and operation of such wells involve complex technology which would usually preclude an injured party from having precise knowledge concerning possible defects. Thus it appears that the doctrine would be employed to lessen the burden of proof resting on the injured party in a negligence proceedings arising out of an injection well mishap.

Foreseeability—The issue of foreseeability has been subject to varying interpretations by the courts. One view is that a landowner cannot anticipate injury as a result of lawful uses of land, an interpretation which has been used to shield certain activities from all liability in connection with resulting ground water contamination. The underlying concept is that liability does not arise for accidents resulting from actions strictly lawful in themselves, conducted with ordinary prudence. One of the earliest cases involving ground water pollution where this reasoning was applied is *Dillon* v. *Acme Oil Co.*,[47] where the court made the following statement:

> The question is therefore presented as to whether there could be a recovery for contaminating a subterranean water stream or vein, when the defendant is pursuing a legitimate business with works constructed and operated as well as they could be. It is said to be a legal maxim that every man must so use his own property as not to injure that of another; but this maxim is not to be construed so as to deprive a party from using that which he owns for legitimate purposes provided, in so doing, he exercises proper care and skill to prevent unnecessary injury to others . . . .
>
> It is only in such exceptional cases that the owner can know beforehand that his works will affect his neighbor's wells or supply of water; and we are therefore of the opinion that, in the absence of negligence and of knowledge as to the existence of such subterranean watercourses, when the business is legitimate, and conducted with care and skill, there can be no liability if such subterranean courses become contaminated.

In reaching its decision in favor of the defendant in *Dillon*, the court relied in part upon the classic case of *Brown* v. *Illius.*[48] Although the *Brown* case upholds liability for contamination of a well resulting from the washing of pollutants along the surface of the ground, the court's comments with regard to ground water pollution have been given considerable authority. The court, in effect, said that liability does not arise in connection with activities that unknowingly contaminate subterranean water which supplies a well.[49] Thus a distinction is drawn in *Brown* between the situation where an activity pollutes a well by means of surface flow and where the mechanism for pollution is ground water flow. The court in *Dillon* went even further and distinguished the pollution of flowing ground water from pollution of a well by means of direct percolation of a contaminant itself through the soil. While direct seepage was held to produce liability, contamination of ground water did not, due to its "incomprehensible" nature.[50]

Another early case in which recovery for ground water pollution was not allowed on the basis that injury could not have been anticipated from the activity is *Long* v. *Louisville and Nashville R.R. Co.,*[51] which involved well pollution from burial of an animal carcass. The court applied the principle embodied in the maxim *damnum absque injuria*—loss without legal injury.[52]

> If the owner of the land may divert the water from his neighbor's well, it is hard to understand why he should be responsible in damages when, without fault on his part, he accidentally pollutes the water by burying a dead body on his own land without reason to suppose that the effect of this would be to pollute his neighbor's spring. The rule is elementary that a person is not liable for a mere accident which ordinary care on his part could not have anticipated or guarded against. If, in the lawful use of his property, a man accidentally does an injury to his neighbor which ordinary prudence would not have anticipated to result from his act, it is *damnum absque injuria.*[53]

The basis for the concept that injury from the contamination of ground water is not foreseeable is the mystery which has traditionally been associated with the movement of such water. The following quotation indicates the manner in which some courts have viewed ground water.

> It has been settled by a long line of decisions that percolating water is not governed by the same rules that are applied to running streams. 'The secret, changeable, and uncontrollable character of underground water in its operations is so diverse and uncertain that we cannot well subject it to the regulations of law, nor build upon it a system of rules, as is done in the case of surface streams. Their nature is defined, and their progress over the surface may be seen and known and is uniform. They are not in the earth and a part of it, and no secret influences move them; but they assume a distinct

> character from that of the earth, and become subject to a certain law—the great law of gravitation. There is, then, no difficulty in recognizing a right to the use of water flowing in a stream as private property, and regulating that use by settled principles of law. We think the practical uncertainties which must ever attend subterranean waters is reason enough why it should not be attempted to subject them to certain and fixed rules of law, and that it is better to leave them to be enjoyed absolutely by the owner of the land as one of its natural advantages, and in the eye of the law a part of it, and we think we are warranted in this view by well-considered cases.'[54]

However, the lack of knowledge concerning ground water, and the unpredictability of the consequences arising from its contamination, do not always bar recovery for pollution injury. In *Collins* v. *Chartiers Val. Gas Co.,*[55] the court noted that the absence of liability for injury to wells was generally based on the fact that damage could not be foreseen or avoided, but the court denied the defendant's contention that the landowner was not bound to pay any regard to the effect of his operations on subterranean waters. In deciding that the driller of an oil well was liable for injury resulting from the contamination of a fresh water aquifer by salt water from another stratum, the court gave specific recognition to advancements in geological knowledge.

> If this is the state of knowledge at the present day; if the existence of a stratum of clear water, and its flow into wells and springs of the vicinity, and the existence of a separate and deeper stratum of salt water, which is likely to rise and mingle with the fresh, when penetrated in boring for oil and gas, are known, and the means of preventing the mixing are available at reasonable expense, then, clearly, it would be a violation of the living spirit of the law not to recognize the change, and apply the settled and immutable principles of right to the altered conditions of fact.[56]

The foreseeability issue is a basic element of the concept of "custom of trade or industry" that has been used as a fundamental defense in negligence proceedings. The essence of this defensive tactic is the claim that the defendant, in his actions or inactions, was following the generally accepted practices and usages of his trade or industry and therefore could not have foreseen injury. The inability of the plaintiff to prove that the defendant has deviated from standard practices may defeat his case. This defense has been a significant factor in a number of cases concerning water pollution.[57]

On the other hand, a court may not adopt generally accepted practices as a reasonable standard of conduct but may impose higher standards such as usage of the best available technology. The best example of this point of view is expressed in *The T. J. Hooper.*[58] This case arose from the sinking of a barge and tug which had no radios on board to warn the crews of an approaching storm. The owners entered as evidence in their favor the fact that only one barge line out of all the coastal lines operating had such equipment. In rejecting this defense, the court said:

> There are no doubt cases where courts seem to make the general practice of the calling the standard of proper diligence . . . . Indeed, in most cases reasonable prudence is in fact common prudence; but strictly it is never its measure; a whole calling may have unduly lagged in the adoption of new and available devices. It may never set its own tests, however persuasive be its usages. Courts must in the end say what is required; there are precautions so imperative that even their universal disregard will not excuse their omission.[59]

The defense of custom of trade has also been rejected in cases of ground water pollution. An example is given by the 1952 Iowa case of *Iverson* v. *Vint*[60] which involved contamination of a well resulting from the dumping of a truckload of spoiled molasses into a ditch. In rejecting the defendant's claim that no liability should attach to this action since it was a customary means of disposal, the court made the following statement:

> Evidence of the custom or common usage of a business or occupation is generally admissible on the question of negligence although it is not a conclusive test . . . . However, such evidence is ordinarily inadmissible where the act itself is clearly careless or dangerous.[61]

Ground Water Contamination as a Nuisance

The question of whether ground water contamination constitutes a nuisance for which liability can be imposed in the absence of negligence has received varying answers. In some cases, legal actions based on this theory have been rejected. In *Rose* v. *Socony Vacuum Corp.*,[62] the owner of a polluted well sought recovery on the grounds that the escape of deleterious substances from an industrial concern created a nuisance even if the owner had not been negligent. The court refused this contention and held that liability must be based on fault and ruled that no recovery would be allowed for the nonnegligent ". . . contamination of percolating waters whose courses are not known . . . ."[63] The court in *United Fuel Gas Co.* v. *Sawyers* held that "[t]he doing of a lawful thing in a careful and prudent manner cannot be a nuisance,"[64] thus effectively barring recovery for ground water pollution in the absence of proof of negligence.

Although the attempt is sometimes made to equate nuisance with negligence, a case brought on the basis of nuisance generally is not dependent on proof of negligent conduct. The following quotation from *Swift & Co.* v. *Peoples Coal & Oil Co.*,[65] a case involving pollution from petroleum leakage, delineates between the two theories:

> Some decisions qualify the right of the one who suffers injury from the pollution of subterranean water to recover damages therefor by holding that no liability exists for its pollution unless the person causing that pollution has been negligent in the use of his property . . . If the pollution of subterranean waters constitutes a nuisance, it has been held to be immaterial whether or not the person responsible has exercised reasonable care in the conduct of his business . . . A nuisance may grow out of negligence . . . But it may exist where the use a person is making of his property is not in any respect negligent but nevertheless results in damage to his neighbor . . . As the percolating of oil into the plaintiff's premises would constitute a nuisance, it was not necessary for it to prove negligence on the part of the defendants.

Application of the theory of nuisance to ground water pollution is in effect recognition of the right to uncontaminated ground water as a basic property right to be protected from infringement. The fact that the enterprise responsible for the pollution is a lawful, carefully operated business is no bar to recovery in a nuisance proceeding. The following quotation is from *Hauck* v. *Tide Water Pipe-Line Co.*,[66] a case involving pollution by escaping oil:

> If the mere fact that the business is a lawful business, and has been conducted with care, would be a defense where a neighbor's land has been injured in consequence of the business carried on there, —the escape of gas, for instance, or the escape of oil, —the result would be that a man might lose his farm, might be compelled to leave it, and have no compensation, simply because the business which brought about this loss was a lawful business, and was carried on carefully. That is not the law. No man's property can be taken, directly or indirectly, without compensation, under the law of this state; hence there are cases—and a great many of them—where a defendant is held liable in damages, although his business is lawful, and he has exercised care in carrying it on.

The requirement of foreseeability is also modified in nuisance proceedings. In the case of *Beatrice Gas Co.* v. *Thomas*,[67] which involved pollution of a well as a result of waste disposal into a large excavation referred to as a "condense well," the court made the following statement:

> It is true that some of the cases base the right to recover upon defendant's knowledge that he was committing the injury; but the injury was as great before as after notice. An action in tort is not a proceeding to punish a defendant for a willful act, but to compensate the plaintiff for the invasion of his rights. It was not necessary, in order to constitute the pollution of the well a tort, that it should be done willfully. The most that can be said is that the defendant would not be liable for damages unless the injury

was one which was the natural and probable consequence of those acts. While the defendant may not have known, and probably did not know, that its condense well would pollute the plaintiff's well, it was bound to know that the natural and probable consequence of collecting waste matter in its condense well would be the injury of some wells which might be connected with the condense well by the stratum of sand referred to.

The determination of whether a given activity will be included with those protected from liability for their consequences in the absence of negligence or subjected to classification as a nuisance where other property is damaged has depended largely upon court discretion. The Supreme Court of Pennsylvania has elaborated upon this determination in *Hauck* cited above where the defendant attempted to bring a situation involving ground water pollution within the doctrine of *Pennsylvania Coal Co.* v. *Sanderson,*[68] a classic case representing the right of a corporate landowner to use property with immunity from legal action by those adversely affected thereby. In refusing to apply the doctrine, the court placed substantial restrictions on its scope.

In the consideration of this class of cases, care must be taken to distinguish between the natural and necessary development of the land itself and injuries resulting from the character of some business, not incident and necessary to the development of the land, or the minerals or other substances lying within it. The owner of the land has the right to develop it by digging for coal, iron, gas, oil, or other minerals; and if, in the progress of this development, an injury occurs to the owner of adjoining land, without fault or negligence on his part, an action for such injury cannot be maintained. If this were not so, a man might be utterly deprived of the use of his property. It is not so where the injury is caused by the prosecution of a business which has no necessary relation to the land itself, and is not essential to its development.[69]

Of course, the principle of *Pennsylvania Coal Co.* that private rights must yield to the needs of business operations has been generally rejected,[70] but the delineation in *Hauck* between development of land itself and business incidental to such development suggests that injection wells fit into the category of activities that would be treated as nuisances rather than the type of operation to be protected from liability in the absence of negligence. It is of interest that an injection well operation has been held to be a nuisance in a case[71] involving the oil field practice of secondary recovery. The waterflood project in question resulted in contamination of a water supply well, and the court found that the operation, although a lawful business, was being conducted so as to constitute a private nuisance for which the injured party could recover compensation. However, the decision in the case was affected by the existence of a state constitutional provision to the effect that private property shall not be taken or damaged for private use without compensation.

In addition to serving as a basis for recovery of compensable damages, the theory of nuisance also provides a basis for injunctive relief. While negligence may be applicable in cases of completed injury resulting from a single act or omission, nuisance generally applies to a maintained condition rather than one act or failure to act, a situation where injunctive relief is more appropriate. In a situation involving anticipated injury, an injunction generally will not be issued without a showing that injury is a relatively certain result of the activity in question.[72] Such proof is likely to be difficult where a regulatory agency has investigated the proposed activity and given its approval on the basis of compliance with regulations designed to protect against such injury. Short-term injunctive relief in the form of temporary restraining orders and preliminary injunctions also require a showing of irreparable harm but are more likely to be issued since the primary purpose is to preserve the status quo until a full trial can be held on the issue.

Nuisance also provides a frequent basis for injunctive relief where an activity has already produced injury. In considering the appropriateness of an injunction in a particular situation, the court in its decision may weigh social and economic factors in an attempt to balance the injury between the parties. Thus an injunction may be refused where its issuance would result in disproportionately greater hardship to the defendant and to the public than would accrue to the plaintiff by its denial.

The principal case illustrating the application of this so-called balance of convenience doctrine is *Boomer* v. *Atlantic Cement Co.,*[73] a recent New York case. The plaintiff in *Boomer* had brought suit to enjoin the operations of a cement factory, but the court, while admitting the injury and stating the case was a proper one for an injunction, limited the recovery to damages. The court cited several reasons for its decision, one of them being the argument that the issue of pollution was a political question not subject to judicial determination. A second basis for the decision was the disparity in economic loss. The court noted that, "[t]he total damage to plaintiffs' properties is, however, relatively small in comparison with the value of defendant's operation and with the consequences of the injunction which plaintiffs seek."[74] Thus the solution chosen was to refuse the injunction in order to avoid closing down the plant and instead make an award of permanent damages as compensation for a servitude on the land involved.

This limitation on the use of injunction has also been applied in cases of stream pollution. For example, the Supreme Court of Michigan in the case of *Monroe Carp Pond Co.* v. *River Raisen Paper Co.*[75] found the pollution by the paper company to be unreasonable and a violation of the lower riparian owner's rights, but it limited the remedy to an award of damages and refused the requested injunction. Reference was made to the size of the investment of the paper company and its significance as an employer, and the court held that the granting of an injunction would constitute disproportionate relief in view of the nature and extent of the injury to the plaintiff.

Imposition of Strict Liability

The particular concept of strict liability of principal interest with regard to disposal well mishaps is the doctrine developed from the English case of *Rylands* v. *Fletcher,*[76] which has seen wide application in situations involving abnormally dangerous conditions and activities. In the *Rylands* case, the defendant had constructed a reservoir in an area underlain by mines, and water subsequently escaped through abandoned shafts to the injury of plaintiff's mines. The court held that failure to restrain a dangerous substance brought onto one's land and stored there made the owner responsible for any resulting injury, regardless of the skill and care with which the operation was carried out.

In the United States, some courts have rejected the strict liability concept, but it has been accepted in a number of cases. For example, the court in *Berger* v. *Minneapolis Gaslight Co.,*[77] after noting that many courts had disapproved the authority of *Rylands,* applied the doctrine to the case before it where petroleum had escaped from storage tanks without proof of negligence. In *Berry* v. *Shell Petroleum Co.,*[78] strict liability was imposed for injury resulting from the escape of oil field brine. Plaintiff's water supply had been ruined by percolation of salt water from a municipal drainage canal into which the salt water had been allowed to flow. Liability under a state statute prohibiting the escape of oil field wastes was noted by the court, but accountability under the common law was also upheld:

> Such a statute was not needed, however, to make the oil companies liable for damages caused by the escape of salt water from the premises of the company. This has been the law ever since the case of *Fletcher* v. *Rylands, supra.* The statute only made possible that the companies could be compel'ed to keep the salt water confined without waiting for any person to be damaged.
>
> It must be remembered that negligence is not a necessary element of the right of recovery in a case like this. The right to recover results from the company having the harmful substance on its land and permitting it to escape to the damage of plaintiff.[79]

Strict liability for the pollution of fresh water by salt water has been imposed in Texas as a result of court interpretation of an administrative rule promulgated by the Texas Railroad Commission. The case where this interpretation was first enunciated, *Gulf Oil Corp.* v. *Alexander,*[80] consisted of an action for damages for pollution of a fresh water strata from a salt water disposal pit used in oil and gas operations on adjoining land. The defendant denied any liability because of the lack of evidence of negligence. The court's reasoning with respect to the impact of the Railroad Commission rule on the necessity for proving negligence is contained in the following statement:

> On the issue of whether there is any evidence of negligence, the fact that a large quantity of salt was deposited in the disposal pit is not evidence of negligence in itself. The record is wholly silent as to whether this amount of salt was so excessive as compared to the amount of salt deposited in other disposal pits in the oil field as to require appellant to take additional measures to contain the same. There is also no evidence that the soil where the pit was constructed was more porous than the soil in other disposal pits in the oil field and required additional care as to construction of the pit. The undisputed evidence reveals that appellant's method of disposal of the salt water was the universal method of disposal in the oil field in that territory. In fact, like disposal pits were located on appellee's tract of land.
>
> Since the uncontroverted evidence establishes that appellant's disposal of the salt water was wholly in conformity with the conduct of such business in that oil field there is no evidence in the cause establishing negligence in its usual sense. [citation omitted]
>
> The above ruling requires the examination of another principle of law as to liability or nonliability under the facts in the cause. Appellee pleaded and proved that Rule 20 as promulgated by the Railroad Commission of Texas makes the following requirement with reference to the disposal of salt water:
>
>> "Fresh water, whether above or below the surface, shall be protected from pollution, whether in drilling, plugging or disposing of salt water already produced."
>
> It is apparent this rule specifically prohibits the pollution of fresh water by the disposal of salt water without any reference to negligence. Since appellant admits, as established by the undisputed record, that it polluted appellee's fresh water strata with salt water, appellant is liable for such pollution by reason of its violation of Rule 20 above set forth.[81]

The result of this decision is a drastic alteration of the previously existing position of the State of Texas with regard to liability for the escape of salt water. Specific proof of negligence had been a requirement for liability in such cases since the decision in *Turner* v. *Big Lake Oil Co.*[82] in which the court thoroughly repudiates the strict liability concept embodied in *Rylands*. Since the position of the court regarding this common law concept has not been modified, its application to escape of deleterious substances outside the scope of the Railroad Commission rule is doubtful.

An Oklahoma statute[83] provides for strict liability in connection with surface contamination from salt water but does not apply to ground water pollution. The Supreme Court of Oklahoma has indicated that the provision is limited to pollution by surface flow,[84] and the court has stated that "[t]he basis of liability for injury or damages to property by pollution of subterraneous waters, from oil, gas, salt water or like substances, in oil wells must be either negligence or nuisance."[85]

In the case of industrial waste disposal wells, most existing controls do not appear to impose strict liability. The traditional approach requires compliance with specific conditions and subjugation of plans to state approval rather than placing emphasis on actual system performance. One apparent exception is the Michigan Mineral Well Act, which includes waste disposal wells within its jurisdiction. The statute provides that "[a] person shall not cause surface or underground waste in the drilling, development, production, operation or plugging of wells subject to this act,"[86] where "waste" means damage to water or other resources or to property.[87] This provision appears to establish a potential basis for imposition of strict liability in the event such damage occurs. Since some states have not adopted formal controls, imposition of strict liability through this mechanism may become more widespread in the future as such controls are established.

The strict liability concept generally appears to be gaining greater acceptance. The following quotation from Prosser's treatise on tort law[88] explains the weakening of the objection to the concept and the trend toward acceptance:

> One important reason often given for the rejection of the strict liability was that it was not adapted to an expanding civilization. Dangerous enterprises, involving a high degree of risk to others, were clearly indispensable to the industrial and commercial development of a new country and it was considered that the interests of those in the vicinity of such enterprises must give way to them, and that too great a burden must not be placed upon them. With the disappearance of the frontier, and the development of the country's resources, it was to be expected that the force of this objection would be weakened, and that it would be replaced in time by the view that the hazardous enterprise, even though it be socially valuable, must pay its way, and make good the damage inflicted. After a long period during which *Rylands* v. *Fletcher* was rejected by the large majority of the American courts which considered it, the pendulum has swung to acceptance of the case and its doctrine in the United States.

> At this writing, *Rylands* v. *Fletcher* still is rejected by name in seven American jurisdictions: Maine, New Hampshire, New York, Oklahoma, Rhode Island, Texas, and probably Wyoming. It has been approved by name, or a statement of principle clearly derived from it has been accepted, in some thirty jurisdictions, with the number expanding at the rate of about one a year.

In the absence of a legislative or administrative determination that industrial waste injection well mishaps should be subject to the strict liability concept, judicial application of the concept in a given jurisdiction is dependent on whether such operations are viewed as abnormally dangerous or ultrahazardous. In spite of the fact that little serious injury has of yet been attributed to injection wells, such operations appear to be typically viewed as somewhat exotic and are not generally accepted as a basic, natural use of land. Consideration of this attitude, along with the general movement toward greater acceptance of the strict liability concept, suggests that strict liability may play an important role in situations where ground water pollution results from disposal well mishaps.

Application of Trespass

Theoretically, trespass appears to be a valid basis for a legal action for recovery in connection with ground water pollution injury, since the pollution process involves the unauthorized invasion of property by a physical substance as the result of the action of another party. However, this basis of recovery for ground water pollution has not been employed to any appreciable extent, and the cases brought on this ground generally have been unsuccessful. The primary weakness in this theory of liability in such cases appears to be the indirect nature of the injury and the difficulty of establishing intent on the part of the defendant. The following quotation from *Phillips* v. *Sun Oil Co.*[89] expresses these obstacles to the establishment of liability on the basis of trespass:

> We will (with some doubt) assume that the chemist's opinion testimony proved, *prima facie,* that the polluting gasoline came from defendant's tank across the highway. There was no showing on the trial as to how the fluid found its subterranean way from defendant's to plaintiff's premises, and there is nothing to show that defendant knew, or had been put on notice, that gasoline was escaping from its underground tank . . .
>
> We hold, as did the courts below, that plaintiff did not make out a case in trespass. Trespass is an intentional harm at least to this extent: while the trespasser, to be liable, need not intend or expect the damaging consequence of his intrusion, he must intend the act which amounts to or produces the unlawful invasion, and the intrusion must at least be the immediate or inevitable consequence of what he willfully does, or which he does so negligently as to amount to willfulness . . . .

> The application of the above-stated rule, in the few pertinent New York cases, to damage claims arising from the underground movements of noxious fluids, produces this conclusion: that, even when the polluting material has been deliberately put onto, or into, defendant's land, he is not liable for his neighbor's damage therefrom, unless he (defendant) had good reason to know or expect that subterranean and other conditions were such that there would be passage from defendant's to plaintiff's land.

In the 1934 case of *Pan American Petroleum Co.* v. *Byars,*[90] also involving ground water pollution, the plaintiff had withdrawn an original complaint based on trespass, but the Alabama Supreme Court indicated that trespass might not have been a suitable grounds for recovery. The court noted that an injury is to be regarded as a trespass only when it is directly occasioned by and is not merely a consequence resulting from the act in question. It was also stated that trespass is not a proper form of remedy in the absence of a showing of intent in the production of injury. Thus it appears from the historical perspective that trespass is a questionable basis for recovery of injury resulting from ground water pollution.

Evidentiary Problems

The foregoing survey of the different approaches utilized by the courts with regard to ground water contamination indicates considerable variation in the burden of proof facing the injured party. Another element of proof which is largely independent of the nature of the legal theory involved is causation. This has to do with the cause-and-effect relationship between the injury and the alleged source of contamination. The injured party must be able, before the court, to produce evidence proving that the defendant was responsible for the contamination in question before the court will consider the extent of his legal rights and the merits of his claim against the defendant. This evidentiary question is a basic consideration regardless of the theory of liability involved in the case, and often becomes the central issue before the court.

This burden can sometimes be overcome by direct evidence such as the results of tests where some easily identified substance is deposited at the alleged source of pollution and detected at the site of the pollution damage. For example, the plaintiff in the 1922 Tennessee case of *Love* v. *Nashville Agricultural & Normal Institution,*[91] involving pollution of a well by a sewage system, established causation by having indigo, potassium iodide, and aniline poured into the sewer drain, all of which appeared in the contaminated well. The more recent case of *Reinhart* v. *Lancaster Area Refuse Authority*[92] involved the contamination of a well by a sanitary landfill operation. Causation was established by the fact that the well water turned red after a truckload of red paint was dumped into the landfill and became sudsy after a large quantity of "soap-like" material was deposited in the landfill.

In the case of injection wells, contamination by the injected waste itself in an identifiable form would likely establish a direct causal relationship, but proof of causation in injection-related pollution cases is likely to be complicated by the fact that contamination may be caused by naturally occurring fluids which migrate in response to subsurface pressure increases. The migration of resident fluids has been a significant problem in the Port Huron, Michigan, area, where industrial waste injection in Ontario, Canada, was apparently the cause of seepage of salt water, oil, and natural gas from abandoned oil wells. The situation was further complicated by the international aspect of the problem, but the fact that the pollution could not be directly connected with the injected waste was significant. It was not until a chemical analysis of the seepage indicated the presence of the injected substance that the Ontario officials took affirmative action to phase out the injection operations responsible.

Although this specific problem apparently has never been given consideration by the courts, the difficulties that are associated with direct evidence in many subsurface pollution cases have resulted in court acceptance of inference based on circumstantial evidence. There is no rule as to what kind of inferences constitute sufficient proof of causation, but several factors are generally relevant to this determination. Among them are the proximity of the alleged source, the existence of other possible sources, the time relationship between the alleged pollution-causing activity and the injury, the possibility for the pollutant to have escaped from the suspected source, and the existence of a feasible path for the waste to travel between the suspected source and the site of pollution.

The proximity of the alleged source and the existence of other possible sources are generally considered jointly. For example, the determination regarding causation in *Joldersma* v. *Muskegon Development Co.,*[93] involving ground water pollution from salt water, was resolved negatively after it was shown that the alleged source was located 600 feet from the site of the injury and that other possible sources of salt existed which had not been excluded by the evidence. In contrast, the plaintiff in *Hall* v. *Galey*[94] was successful in establishing a casual connection between salt water injury and defendant's oil well by eliminating four other oil wells as possible sources by showing that the other wells had been properly plugged to prevent seepage of salt water whereas the defendant's well had not. Although failure to eliminate other possible sources of pollution may be fatal in some cases to the establishment of causation, it is not always necessary for the plaintiff to eliminate all other possible sources. The following statement is from *Donley* v. *Amerada*

Petroleum Corp.:[95]

> It may, also, be noted that appellees were not obliged to exclude every other possible source of pollution after establishing facts from which it reasonably could be inferred that appellants had polluted the stream.

The relationship between the time of pollution and an action by the defendant has also been important in showing causation. The defendant in *Bumbarger* v. *Walker*[96] had removed water from his strip mine by a blasting procedure. Shortly after the blasting the water disappeared, and plaintiff's spring, which had been in use for almost 40 years, became contaminated. In considering the timing of the pollution along with other existing factors (the nature of the pollution, e.g., the high sulfur content of the polluted water, the proximity of the strip mine to the spring, and the elevation and slope of the land), the court said "[w]here conditions, which have continued for a long period of time, change coincidentally with the occurence of a new event which in common experience may have caused the change, there is sufficient evidence of causation present for the case to go to the jury."[97]

In *Harper-Turner Oil Co.* v. *Bridge*,[98] the contamination of plaintiff's water with salt water coincided with the drilling of defendant's oil well. After the plaintiff showed that defendant's well was improperly cased and that seepage of salt water had in fact occurred, the court held that the coincidence of the two events, along with the other evidence, was sufficient to infer causation. However, the only evidence presented in *Pine* v. *Rizzo*,[99] a case concerning alleged salt water pollution from defendant's oil well, was that plaintiff's well had always contained good water but had become polluted with salt shortly after the oil well was drilled. The court ruled that this evidence in itself was insufficient to show causation.

The plaintiff generally must show that the pollutant could have escaped from the suspected source. In many instances this capacity is self-evident, making it sufficient that the plaintiff merely alleged this factor. However, in cases involving such facilities as storage tanks, pipelines, and wells, the plaintiff must show actual seepage, leaks, or overflow. The plaintiff in *Hall* cited above showed that vegetation around the defendant's well died from the run-off of salt water from the well and that the soil surrounding the well was impregnated with salt water. In *Jackson* v. *U.S. Pipeline Co.*,[100] the plaintiff was able to show that a section of the defendant's pipeline was rusted out and that seepage had occurred. In both of these cases, the plaintiff was successful in showing causation.

In some cases, proof of the potential for a pollutant to escape has been held to be inadequate for an inference of causation in the absence of proof that escape actually occurred. In *Shell Oil Co.* v. *Blubaugh,*[101] the plaintiff showed that his water well was polluted with salt water and that the defendant's oil well which contained quantities of salt water was improperly plugged. The court held that this was insufficient to infer causation because there was no indication that any salt water had actually escaped from defendant's well. Similarly, in the 1934 Kentucky case of *Wynn* v. *Wilson,*[102] evidence of improperly sealed wells was in itself insufficient to determine causation without evidence that any oil had seeped from the well.

A final factor often considered in determining causation is whether there is a physical connection between the suspected source of the pollution and the contaminated water supply such that the pollutant could travel between the two. Elements considered in making this inference include elevation, slope, and drainage of the land between the suspected source of contamination and the contaminated water supply, the direction of movement of ground water, and the nature of rock strata. The plaintiff in *Haveman* v. *Beulow*[103] was able to establish causation by showing that defendant's refuse sump was higher than plaintiff's well and that natural drainage from the sump ran towards the well. In *Cities Service Gas Co.* v. *Eggers,*[104] it was shown that defendant's oil and gas wells polluted the creek which fed the plaintiff's water well. And in the 1927 North Carolina case of *Masten* v. *Texas Co.,*[105] the evidence indicated that the general contour of the land was sloping from defendant's gas tank to the plaintiff's well, that a strata of rock ran from the tank to the well, and that the vein of water running into the well came from the direction of the tank. This evidence, along with the evidence showing that the pollution began when a new pump was installed on the tank, was held sufficient to show causation.

As can be seen from this discussion of individual cases, the proof necessary to sufficiently show causation varies from the circumstances of each situation and from jurisdiction to jurisdiction. No one factor is sufficient in itself to successfully infer causation, but it is usually unnecessary in each case to make inferences involving all of the factors. However, the more positive inferences that can be made, the greater the chance of showing causation to the satisfaction of the court. As a general rule, a plaintiff must make sufficient inferences such that it reasonably can be concluded that defendant's suspected source is responsible for the contamination or pollution; causation cannot be based on mere speculation. If a defendant can use one of these elements in his favor, e.g., show that any seepage from his well would drain away from the contaminated water supply or that the plaintiff's well was contaminated before the defendant drilled his well, the chances of plaintiffs proving causation are reduced.

Instability Problems Affecting Use of Land Surface

Legal principles may serve to define liability in cases of injury produced by injection-induced seismic activity and subsidence resulting from dissolution of subsurface formations through chemical reactions with injected wastes. Law specifically applicable to injection-related instability problems does not exist, due to the fact that serious injury which would have given rise to consideration of the applicable legal principles has not occurred. However, certain general concepts likely to be relevant can be derived from consideration of law in possible analogous areas.

Seismic Activity

Historically, seismicity has been a phenomenon over which man has exercised no control. The realization that seismic activity may be stimulated by human activities is a relatively recent development. One of the best known manifestations of this potential is the series of minor earthquakes associated with injection of wastes at the Rocky Mountain Arsenal located near Denver, Colorado.[106] Thus an assessment of potential liability arising from injection well operation must give consideration to the seismicity factor.

A central element in any determination of liability in connection with an earthquake alleged to have been caused by waste injection is the ability of injured parties to prove that the earthquake resulted from the injection. This proof in effect requires a showing that the earthquake would not have occurred in the absence of injection, a difficult undertaking since most areas have some potential for natural seismic activity on the basis of historical records. Research currently underway concerning prediction and stimulation of earthquakes will make more knowledge available for such determinations, but this area of inquiry is not likely to be one where decisions can be made with a high degree of certainty for some time.

In addition to the question of causation, it is of interest to consider the issue of which theory of liability is the appropriate basis for court action concerning injection-related seismic activity. Negligence is always a sound basis for establishing liability in connection with injury-producing accidents, providing the various elements of required proof can be met. In a case involving the allegation of an artificially stimulated earthquake, relevant considerations would certainly include the reasonableness of locating an injection well at the site in question. Since artificially stimulated earthquakes involve the release of natural seismic forces and operate through natural mechanisms, assessment of the reasonableness of location would largely be a matter of evaluating the natural earthquake risk of the area in question. Specific aspects of this evaluation include such factors as history of seismic activity and the existence of faults along which movement may be possible. Knowledge of fault occurrence depends on the thoroughness of the geological investigation, therefore making this aspect of the operation subject to an evaluation for reasonableness as well as the decision to locate on the basis of the information actually available.

The most significant operational factor bearing on a determination of negligence would appear to be the injection pressures used since research results indicate a definite relationship between fluid pressure and the occurrence of seismic activity.[107] What constitutes an unreasonable injection pressure is of course a relative matter dependent on the physical circumstances. The operational standards of which reasonableness is based are determined to some extent by practices in common usage, but a court will have authority to make the final decision in any particular situation involving legal conflict.

Another theory of liability deserving consideration is that of strict liability. As noted in the previous section dealing with injection-related ground water contamination, injection well characteristics are such that courts may view them as falling within the category of hazardous activities, with the result that liability without fault will be imposed. This conclusion may have even greater applicability regarding seismic activity because of the more catastrophic nature of such potential occurrences.

It may be significant to note that strict liability has been imposed in situations where damages resulted from concussion associated with blasting operations. The statement of law in *Corpus Juris Secundum* concerning liability for injury caused by blasting says that ". . . as a general rule, although there is some authority to the contrary, one lawfully engaged in blasting is liable, irrespective of negligence, for personal injuries or property damage sustained either as a result of casting material on adjoining land or as the result of concussion."[108] It is noted that application of liability is sometimes limited to "direct injury," with the establishment of negligence necessary for the imposition of liability for concussion injury. The analogy between concussion injury from blasting and injury from artificially induced earthquakes may not be a strong one, but some similarity exists since both situations involve vibration injury emanating from man's activities.

Subsidence

Existing law in this area has been developed in connection with subsidence caused by extraction of natural resources such as coal, oil, sulphur, and ground water. With regard to damage resulting from the mining of coal or other hard minerals by subsurface excavation, the following summary is contained in *American Law Reports.*[109]

> The general conclusion to be drawn from the cases is that since the owner of land in which the minerals or mineral rights are held by another has the absolute right as against such other to the support of the surface in its natural state, when he has in no manner parted with or waived the right, the operator of mines beneath the surface will be absolutely liable for such damages to structures upon the surface as result from a failure to leave pillars or other supports sufficient to maintain an unburdened surface. The practical difficulty with which the surface owner appears to be confronted in such a case, of proving that the subsidence would have occurred in whole or in part in the absence of the structures, has been removed in certain jurisdictions through adoption of a doctrine to the effect that where subsidence of the surface is accompanied by damage to structures thereon and has followed the mining operations, with no evident cause for the subsidence other than those operations, the owner will ordinarily be entitled to recover for the damage as having resulted from a failure to leave the required support, unless, or to the extent that, it is shown that the subsidence would not have occurred but for the structures. The burden of proof thus placed upon the mine operator is one which thus far has rarely been sustained.

The status of the right to surface support is less certain where extraction of ground water or minerals in fluid form is involved. In some cases, the right to extract fluids has served as a shield against liability for resulting subsidence. For example, the Maryland Court of Civil Appeals, in *Finley* v. *Teeter Stone Inc.,*[110] refused to hold a quarry operator liable for injury to the land of another in the form of sink holes resulting from pumping conducted as part of the quarrying operation. The basis for the decision appears to have been the court's view that the quarrying company had the right to use the underlying percolating waters for any legitimate use of its land, a category held to include quarrying. A similar result had been reached in *Kenny* v. *Texas Gulf Sulphur Co.,*[111] where subsidence resulted from removal of sulfur by a liquification process. The decision in this case, of course, was affected by the fact that the sulphur was removed under a mineral lease by the only commercially known process. However, the right of withdrawal does not always serve as a defense for liability from subsidence. In *Prete* v. *Cray,*[112] for example, a city was held liable without regard to negligence for subsidence damage resulting from a flow of quicksand into a sewer excavation.

The previous statement of law on this point contained in the *Restatement of Torts (Second)*[113] was that "[t]o the extent that a person is not liable for withdrawing subterranean water from the land of another, he is not liable for a subsidence of the other's land which is caused by withdrawal." However, this position has been reversed in a subsequent revision which now states that "[o]ne who is privileged to withdraw subterranean water, oil, minerals, or other substances from under the land of another is not for that reason privileged to cause a subsidence of the other's land by such withdrawal."[114] This statement is not binding as law, but the reversal in position may indicate a general trend toward the imposition of greater accountability for subsidence in connection with ground water withdrawal.

Other Potential Problems

In addition to ground water contamination and instability problems, other detrimental consequences are possible in connection with injection well use. Other possibilities include the escape of the waste to the surface environment, destruction of natural resources other than water, and interference with other subsurface storage operations.

Damages to the Surface Environment

The fact that surface damages are possible in connection with injection wells is best exemplified by a well failure at Erie, Pennsylvania, in which rupture of injection equipment resulted in the backflow of injected wastes onto the land surface and into Lake Erie.[115] The likelihood of such occurrences is minimized by regulatory controls over equipment and operations, particularly where provision is made for standby facilities in the event of primary facility malfunction. The potential for extensive damages is also restricted by the fact that escape to the surface would be more easily detectable than subsurface escape, thereby allowing quicker remedial action. Nevertheless, the possibility of surficial damage cannot be totally discounted.

Legal proceedings arising out of such injury would likely be free of certain complications existing in the case of subsurface contamination. The primary simplification would be in the area of proving the casual connection between the mishap and any injury resulting from it. While the party injured by ground water pollution often must build his case on inferences which may or may not be adequate in a given situation, direct evidence of the source of surficial pollution would be more readily available. Determination of the particular defect or condition responsible for escape of the waste would also likely be simpler in the case of surface escape. While subsurface escape is largely a function of geological conditions, escape to the surface is likely to involve direct deficiencies of equipment or construction procedures. Ease of locating defects would facilitate proof of negligence where this theory of liability is utilized.

The most appropriate theory of liability to serve as the basis for a legal action may be different where surface injury is involved than in the case of ground water pollution. The concept of absolute ownership of ground water, which has shielded the landowner from liability for contamination in connection with uses of his property in the absence of negligence, has never seen application to surface water. Thus in some jurisdictions the ability to recover for injury may be considerably enhanced in the case of surface damage because of acceptance of a theory of action with a lesser burden of proof.

It should be noted that strict liability is sometimes imposed for surface contamination where comparable provisions for subsurface pollution do not exist. For example, a previously cited Oklahoma statute[116] imposes strict liability for injury produced by salt water allowed to flow over the surface of the ground but does not apply to subsurface contamination.[117] A more general example of strict liability applicable only to surface water exists in the form of provisions in pollution control statutes concerning responsibility for fish kills.[118] Of course the restriction of applicability of such provisions is due to physical differences between the two environments, but the situation does illustrate the possible variation in legal principles applicable in the two areas.

Destruction of Other Natural Resources

Although ground water pollution is the most likely impact of waste injection on natural resources, injury to other resources can occur. The waste may impart objectionable characteristics to solid minerals, affecting their recovery or ultimate use. Where fluids such as oil and gas are involved, an additional form of potential injury to the owner consists in their displacement from within his property boundaries.

The likelihood of occurrence of damage to natural resources is mitigated by precautions encompassed within regulatory procedures. One mechanism for providing such safeguards is to require that proposals for waste disposal wells be reviewed and approved by governmental agencies responsible for management of resources likely to be affected.[119] In addition, potential impact on natural resources would generally be a basic concern of the permit-granting agency as well. These procedures can be expected to protect presently recognized resources to the extent that their locations are known, but changes over time in the concept of what constitutes a resource may produce future problems. Changes in technology and human demands may create resources from natural materials now considered to be without appreciable value.

Precedent with regard to natural resource destruction exists primarily in connection with secondary recovery operations for oil and gas production. The recovery program of one landowner or leaseholder often has the potential of destroying or damaging the production potential of other parties. As noted previously, such operations are usually subject to approval by state management agencies, and the courts generally will not interfere to the extent of granting prohibitory injunctions. However, this restraint has not prevented the award of damages where actual injury can be shown. One of the leading cases in this area is *Tidewater Oil Co.* v. *Jackson,*[120] in which plaintiffs who had failed to enjoin a waterflooding plan in the Kansas courts[121] were successful in obtaining a substantial damage award in federal court because of the interference with property rights in connection with the flooding of producing oil wells.

Cases have also arisen in connection with injury to mineral rights to oil and oil producing facilities resulting from salt water injection for disposal purposes. In *Sunray Oil Co.* v. *Cortez Oil Co.,*[122] the court refused to enjoin salt water injection which the plaintiff claimed would damage its mineral rights. The principal reason for the court's refusal was the plaintiff's failure to prove with reasonable certainty that damages would result from the operation. Liability for damages caused by salt water injection was upheld in *West Edmund Hunton Lime Unit* v. *Lillard.*[123] Damages did not include loss of production but encompassed the value of oil well casing lost and extraordinary expenses incurred in attempting to retrieve the casing and in shutting down the well.

Interference with Other Storage Operations

With increasing usage of subsurface formations for storage purposes, legal conflicts concerning rights of opposing interests appear inevitable. Conflicting interests may involve storers of wastes, natural gas, potable water, or other substances. Conflicts conceivably could develop between operators engaged in the same type of storage or in different operations. Examples exist where individual waste injection wells owned by one party apparently have interfered with one another, resulting in less efficient operation of both.[124] Extensive use of a common injection zone by a number of injectors could be expected eventually to produce mutual interference as the individual areas of pressure buildup begin to overlap.

Because of the limited number and finite capacity of subsurface reservoirs suitable for natural gas storage, conflicts could normally be expected as in the case of any scarce resource. However, governmental regulation generally precludes competition and conflict between individual utilities and would be a mitigating factor with regard to conflicting storage operations.

With regard to the subsurface storage of potable water, the potentially significant conflicts are those involving storage of materials which could contaminate the water. The likelihood of such contamination is minimized by the fact that water is usually stored in fresh water aquifers while other storage operations generally utilize saline zones. Successful implementation of the concept of injecting fresh water "bubbles" into saline aquifers for later withdrawal[125] would tend to disrupt this separation and increase the chance of conflict.

The legal standing of the various parties involved in storage conflicts depends on the nature of the respective interests held. Ownership of overlying land is a major factor since the owner in the absence of a conveyance of subsurface rights generally has the right to make any use of the subsurface space. Although a question may exist with regard to the owner's right to exclude injection not detrimental to his own land use, the proprietor's right to make such use as he is capable without interference appears well established. In addition to ownership of land, lesser property interests would be significant in resolution of conflicts. For example, storage of natural gas by public utilities frequently involves acquisition of storage leases which would establish a preferred position with respect to parties not having such interest.

The respective rights of injectors who do not base their standing on property rights are undefined. A significant possibility of conflicts under these circumstances exists since waste injection may involve space underlying property of others. The right of the overlying owner to prohibit such injection has been considered in a previous section, but the question remains as to the rights of individual injectors relative to one another. Such conflicts could become quite significant in the event that subsurface space comes to be viewed as part of the public domain. Under these circumstances, the principal determinant of individual rights would be governmental authorization granted pursuant to policy with regard to use of subsurface space. Ideally, such policy should provide guidance with respect to priorities among different types of injection and with respect to allocation of the storage space within interest groups. Public policy and administrative procedures for implementation would actually serve as replacements for controls exerted by the institution of property rights. Thus conflicts would be subject to administrative resolution, with review by the courts reserved for final ajudication of individual rights.

Impact of Governmental Controls on Private Constraints

Although private constraints with respect to injection generally function concurrently with direct governmental controls, their application can be affected by the provisions of such controls. The effect of direct statutory or administrative controls on the status of private constraints may take one of three forms: (1) they may be strengthened; (2) they may be restricted in scope, or (3) they may simply be preserved by the governmental controls, presumably to retain the same status existing prior to adoption of the other controls.

Enhancement of Private Rights

The rights of the individual to be free from the adverse consequences of a particular activity are enhanced whenever his prospects for a favorable court decision are increased. One mechanism through which such prospects can be increased involves imposition of strict liability on the party responsible for the injurious activity. This approach has been adopted by the courts in some instances, but legislative or administrative action is another means of adoping strict liability. Reference has already been made in a previous section to a prime example of this latter course—the evolution of controls in the State of Texas with regard to handling and disposal of oil field brines. The courts of Texas had traditionally refused to impose liability for water pollution resulting from the escape of these substances without specific proof of negligence,[126] but an administrative rule adopted by the Texas Railroad Commission, the agency responsible for regulation of oil and gas production, has been interpreted as establishing strict liability in connection with damage from such substances.[127] Since the doctrine of strict liability facilitates recovery for injury, the rights of the individual adversely affected by such operations are significantly enhanced.

Although this administrative ruling would encompass brine injection wells operated in Texas, existing legislative and administrative controls applicable to injection of industrial wastes have not specifically been interpreted as imposing strict liability. As noted previously, the possibility for this interpretation of injection well controls appears to exist in Michigan where legislation provides that a person shall not cause damage to surface or underground water in connection with the use of injection wells,[128] but no ruling has been made by the courts.

Another mechanism for enhancement of the role of private constraints consists of legislative provisions which expand the right of the individual to initiate legal action. Examples of such expansion include the citizen suit provisions of FWPCA[129] and SDWA.[130] As discussed previously, these provisions do not completely remove the requirements concerning standing to bring suit. In part they consist of statutory recognition of liberalized standards developed by the judiciary, but incorporation into basic pollution control legislation publicizes the widespread acceptance of these principles and promotes greater citizen involvement in the regulatory process.

Restriction of Private Constraints

Governmental controls can restrict the application of private constraints to a particular activity by reducing the scope of individual legal action or by limiting the basis for recovery of damages in the event of injury. Such action has the effect of reducing the extent of legal accountability for injury arising from certain activities and apparently is based on the rationale that compliance with applicable regulatory measures reflects a reasonable standard of conduct which should create a limited degree of immunity from accountability for adverse consequences. Adoption of provisions having this effect would appear to indicate a preferred status for the particular activity, probably arising out of its recognition as a basic need.

An example of a situation wherein governmental controls explicitly restrict private rights is given by the Virginia Erosion and Sediment Control Law.[131] The Law provides that any party making a legal complaint in connection with damages from erosion, siltation, or sedimentation must show negligence in order to recover damages where there has been compliance with the requirements of the Law.[132] This provision therefore precludes judicial acceptance of a theory of liability such as strict liability that is more favorable to an injured party.

Governmental regulation of oil and gas production operations has also resulted in restriction of private rights in some cases. For example, the Supreme Court of Texas has indicated that certain private property interests may have to yield to the necessities of the oil and gas industry. In the following statements from the 1962 case of *Railroad Commission of Texas* v. *Manziel,* the court explains the extent to which private property rights must be considered by the state oil and gas regulatory agency, the Texas Railroad Commission, and the weight which the court will give to the decisions of the agency:

> The Commission has two primary duties in the administration and control of our oil and gas industry. It must look to each field as a whole to determine what is necessary to prevent waste while at the same time countering this consideration with a view toward allowing each operator to recover his fair share of the oil in place beneath his land. In carrying out these duties, there has developed upon the Commission the power to promulgate rules, orders and regulations that control the industry, and such are issued pursuant to the police power of the state, and that power may invade the right of the owner of the land to the oil in place under his land as long as it is based on some justifying occasion, and is not exercised in an unreasonable or arbitrary manner.[133]
>
> Regardless of the other questions that may appear, as to matters within the discretion of the Railroad Commission, the ultimate decision of this court, as to the validity of the Commission's orders, must turn upon the application of the substantial evidence to rule. Of course, we recognize that it is not the province of this court to substitute itself for the Commission in determining the wisdom and advisability of the particular order in question, but the Court will sustain the action of the Commission so long as its conclusions are reasonably supported by substantial evidence . . . . When the orders are supported by evidence establishing that they are necessary in order to prevent waste or to protect correlative rights, *the fact that the application of the order has resulted in economic loss to some does not warrant a finding that there has been a deprivation of property without due process of law* [emphasis added] . . . .
>
> We conclude that if, in the valid exercise of its authority to prevent waste, protect correlative rights, or in the exercise of other powers within its jurisdiction, the Commission authorizes secondary recovery projects, a trespass does not occur when the injected, secondary recovery forces move across lease lines, and the operations are not subject to an injunction on that basis. The technical rules of trespass have no place in the consideration of the validity of the orders of the Commission.[134]

None of the existing governmental controls over industrial waste injection explicitly restricts private rights that may be adversely affected by such operations, and no situation involving injection well injury has arisen where compliance with applicable controls has been interpreted as a bar to recovery. Adoption of this position would likely require acceptance of the view that waste injection is a necessary means of waste disposal whose utilization should be encouraged in the interests of society. In view of the considerable amount of negative sentiment that exists toward injection, this development does not appear likely.

Preservation of Private Rights in Existing Status

Rather than enhancing or restricting private rights, governmental controls generally leave such rights unchanged, either through explicit preservation or without specific mention. An example of a specific reservation of the private right of action in the case of injection well controls is given by the Texas Disposal Well Act which states that "the fact that a person has a permit issued under this chapter does not relieve him from any civil liability."[135]

The concept that governmental regulation of waste disposal activities does not eliminate the private right of action has been upheld in a number of cases arising out of surface water pollution. In the 1966 New Hampshire case of *Urie* v. *Franconia Paper Corp.,*[136] for example, a waste discharger unsuccessfuly argued that a private action for resulting pollution could not be maintained due to the fact that the state legislature had placed the stream in the lowest classification with respect to water quality and provided a specified period of time for improvement, within which sanction was given to maintenance of a polluted condition. The Supreme Court of New Hampshire noted the absence of any indication of legislative intent to take away the private right of action and stated that it was doubtful if the legislature had constitutional power to permit the continuance of a private nuisance since such action would constitute the taking of private property for a nonpublic purpose.

Neither does the specific governmental approval of a particular waste discharge eliminate the private right of action. As was stated in *Kennedy* v. *Moog, Inc.,* a 1964 New York case, "the defendant's receipt of a public agency's approval of its plans and specifications for a sewage disposal plant . . . does not *per se* cloak defendant with immunity from liability . . . ."[137]

However, the fact that private rights are not abolished by adoption of governmental control measures does not mean that such rights are unaffected. The court in a particular case may give considerable weight to agency determinations, and it may completely defer to agency judgment in some instances. A 1957 case decided in U. S. district court, *Ellison* v. *Rayonier, Inc.,*[138] is a good example. The case arose from the complaints of owners of tideland property in the State of Washington that the discharge from an industrial establishment resulted in damage to oyster beds. Although the court gave recognition to the continuing existence of private rights of action concerning water quality, it held that primary jurisdiction for pollution control has been vested in an administrative agency and that exercise of court jurisdiction should involve consideration of administrative determinations. Since the complaint before the court made no allegations as to the improper nature of administrative action concerning the waste discharge in question, the court assumed that the discharge was in compliance with all applicable controls, and on the basis of that assumption, held that no recovery could be granted for violation of private rights. The court indicated that it would consider an allegation that the actions of the administrative agency had been arbitrary, capricious, or unreasonable, but in the absence of such a finding, relief for private injuries would not be granted.

The court in this case adopted a rather restricted role for the judicial process with regard to the degree of water pollution to be allowed in a particular case. The position was taken that the trial of individual damage claims does not provide specific standards for resolving complicated technical and scientific problems and that the scope of such proceedings does not allow adequate consideration of the public welfare. Administrative procedures were viewed as the preferred mechanism for decision making where the issues involve many overlapping and conflicting private interests as well as the public welfare.

This case was decided before the development of widespread interest and activism with regard to environmental quality. The courts in recent years have had to deal with an increasing amount of environmental litigation and have assumed a more active role in review of administrative decision making. Nevertheless, compliance with governmental controls continues to be a factor that is considered by the courts in resolving conflicts concerning water quality.

A possibly analogous area of law, where the question of the impact of governmental regulation on private constraints applicable to a particular activity has been considered by the courts, is that concerning aviation-related interferences with the use of property. A substantial number of cases has arisen in this area due to the necessity for low overflights of property adjacent to airports during takeoffs and landings.

The issue of the impact of governmental regulation arises in overflight cases because the United States by means of the Air Commerce Act of 1926[139] and subsequent legislation[140] has specified the federal government's sovereignty in "navigable airspace," a term which is defined to include ". . . airspace needed to insure safety in takeoff and landing of aircraft."[141] The leading case concerning aviation interference with the use of property, *United States* v. *Causby*,[142] was decided prior to inclusion of glide paths in the definition of "navigable airspace," and the Supreme Court in that case made specific reference to the fact that the overflights in question were not within these boundaries. Although the definition was expanded shortly after the *Causby* decision, most courts have continued to uphold the principle established in *Causby* that flights at low altitudes which interfere with surface uses are a compensable taking. For example, the court in *Matson* v. *United States*[143] made explicit reference to the change in definition but held that the change does not affect the cause of action where damages are imposed on the landowner.

In addition to interference with the use of property in the form of noise and psychological impact associated with low overflight, interference can also take the form of restrictions on physical utilization of property for erection or maintenance of various structures that intrude into airspace needed for airport glide paths. One case to deal with this problem is *Reaver* v. *Martin Theatres of Florida, Inc.,*[144] where the plaintiff, an airport, sought to enjoin the defendant from constructing a drive-in theatre on property contiguous to the airport on the grounds that it would constitute a nuisance and hazard to the airport and to the public generally. The Florida Supreme Court found for the defendant and refused to issue the injunction. The court noted that "our independent research has revealed [no case] where the 'privilege' of an airplane to invade the airspace above land in the possession of another has been held superior to the lawful and reasonable use of such airspace by the owner of the land. It appears that their rights are generally held to be co-equal, with the balance, if any, in favor of the landowner."[145] The court went on to say that "the placing of obstructions near the property line of an airport solely for the purpose of harassing the owner thereof, and without relation to any reasonable use which the adjoining landowner might wish to make of his property, might well be held to be a nuisance . . . ."[146] The court, however, found that the operation of a drive-in threatre was a legitimate business and a reasonable use of the land and that the screen would not measurably add to the hazards which already existed.

Another case in this area is that of *Roosevelt Field* v. *Town of North Hempstead,*[147] where the airport sought to enjoin the defendant from maintaining a water tower which penetrated 38 feet into the maneuvering zone of the airport, the size of which had been determined by federal regulations. The court refused to issue the injunction for a variety of reasons. First, the court pointed out that the water supply was very important to the community and that the use of the private airport had been steadily decreasing. Second, and most important, the court held that the airport had failed to show that the tower constituted a significant hazard to the airport even though it penetrated into the navigable airspace. The court also appeared to indicate that if it had been shown that the tower constituted an unlawful danger to aircraft approaching and leaving the airport, the airport would be under a duty to help compensate the defendant for the cost of removing and reconstructing the tower.

Indiana Toll Road Commission v. *Jankovich*[148] involved a suit for damages brought against the owners of a toll road in violation of a zoning ordinance prohibiting construction exceeding certain heights within specified distances of an airport. The court upheld the principle that the landowner owns as much of the space above the ground as he can occupy or use in connection with the land and found the ordinance to be an unconstitutional appropriation of such rights since it did not provide for compensation.

In *Jackson Municipal Airport Authority* v. *Evans*,[149] a municipal airport authority sought to compel a property owner to top or remove trees growing more than 50 feet above the surface in an area located above 3,500 feet from the main instrument runway which had been declared an instrument approach zone. The Mississippi Supreme Court refused to issue an injunction and stated that the "Federal Aviation Act provision defining navigable airspace as meaning airspace above minimum altitudes of flight prescribed by regulations and as including airspace needed to insure safety in takeoff and landing of aircraft did not give carte blanche authority to municipalities to appropriate whatever airspace they desired to insure safety in takeoff and landing."[150] The court also stated that a provision in the Federal Aviation Act of 1958 to the effect that "nothing contained in this chapter shall in any way abridge or alter the remedies now existing at common law"[151] makes it clear that the intent of Congress was not to cut off common law and statutory rights of private landowners. It was the court's decision that to so restrict the height of the landowner's trees was an unconstitutional "taking" unless the landowners were compensated for their loss.

Another case concerning the right of the landowner to maintain trees on his property near an airport is *Shipp* v. *Louisville and Jefferson County Air Board*.[152] The trees in question interfered with rays emitted by special landing equipment, but the Kentucky Court of Appeals held that the right to maintain the trees could be taken only by condemnation since the trees had exceeded the elevation objected to prior to use of the equipment and the adoption of rules and regulations applying thereto. However, the court stated that "[a]fter the adoption of the rules and regulations . . . , no property owner in the path of the rays . . . may erect or allow to grow any structure or tree so as to interfere with the operation of such equipment."[153] This decision therefore places a considerable burden on future uses of the affected property.

Although the courts generally have not viewed compliance with governmental regulations as a bar to the exercise of property rights in connection with the use of airspace, cases can be found where the language of a court in resolving conflicts between landowners and aviation interests appears to indicate that property rights have been diminished by the adoption of governmental controls over operation of aircraft. For example, the Supreme Court of California in *Loma Portal Civic Club* v. *American Airlines, Inc.* stated that an injunction is not available for ". . . the operation of aircraft with federal airworthiness certificates in federally certificated, scheduled passenger service, in conformity with federal safety regulations, in a manner not creating imminent danger, and in furtherance of the public interest in safe, regular air transportation of goods and passengers . . . ."[154] Although this statement may provide some support for the position that compliance with regulations creates immunity from injunction, a more likely interpretation is that issuance of an injunction would simply have been contrary to the public interest. At another point in the decision, the court noted that the determination of the availability of an injunction requires consideration of the general public and that "[i]t is well established that public policy denies an injunction and permits only the recovery of damages where private property has been put to a public use by a public service corporation and the public interest has intervened."[155] The court also notes that "[n]othing herein is intended to be a determination of the rights of landowners who suffer from airplane annoyances to seek damages from the owners of operations of aircraft or to seek compensation from the owner or operator of an airport."[156] Thus the actual impact of compliance with governmental controls appears minimal.

Part III Footnotes

[1]The discussion of remedies included in the text has been kept brief in order to avoid a diversion from the primary purpose of this section. The reader who desires a more detailed treatment is referred to a standard treatise on the subject, *e.g.,* D. B. Dobbs, *Handbook on the Law of Remedies,* West Publishing Co., St. Paul, Minn., 1973.

[2]*See,* J. L. Sax, "The Public Trust Doctrine in Natural Resources Law: Effective Judicial Intervention," 68 *Michigan Law Review* 471 (1970) (hereinafter cited as Sax, "Public Trust Doctrine").

[3]*American Jurisprudence 2d,* The Lawyers Cooperative Publishing Co. and Bancroft-Whitney Co., Rochester, N.Y., and San Francisco, Calif., Vol. 54, Mines and Minerals, sec. 1, 3, 102 (1948).

[4]*See,* Robert Emmet Clark and Edward W. Clyde, "Western Ground-Water Law," *Waters and Water Rights,* Ed. by Robert Emmet Clark, Vol. 5, Allen Smith Co., Indianapolis, 1972, pp. 407-446.

[5]*See, e.g. Alaska Stat.,* sec. 31.05.090 (1962); *Ark. Stat. Ann.,* sec. 53-116 (1971); *La. Rev. Stat. Ann.,* sec 30:9 (1975); *N.M. Stat. Ann.,* sec. 65-3-12 to 65-3-14

(supp. 1975); *Okla. Stat. Ann.,* tit. 52, sec. 86.3, 105(1969); *Tex. Rev. Civ. Stat. Ann.,* sec. 6014 (1962).

[6]Henry C. Black, *Black's Law Dictionary,* Rev. 4th ed., West Publishing Co., St. Paul, Minn., 1968 (hereinafter cited as *Black's Law Dictionary*), p. 453.

[7]A discussion of airspace rights is included later in this section.

[8]*Edwards* v. *Lee's Administrator,* 265 Ky. 418, 96 S.W.2d 1028 (1936).

[9]*Marengo Cave Co.* v. *Ross,* 212 Ind. 624, 10 N.E.2d 917 (1937).

[10]W. Prosser, *Law of Torts,* 4th ed., West Publishing Co., St. Paul, Minn., sec. 13, p. 66 (hereinafter cited as Prosser, *Torts*).

[11]*See,* "Comment — Oil and Gas: Liability and Damages for Underground Trespasses," 27 *Cal. L. Rev.* 192 (1939).

[12]*Gregg* v. *Delhi Taylor Oil Corp.,* 152 Tex. 26, 344 S.W.2d 411, 476 (1961).

[13]*Peoples Gas Light and Coke Co.* v. *Buckles,* 24 Ill.2d 520, 182 N.E.2d 169 (1962).

[14]*Id.,* pp. 176, 180.

[15]*Id.,* p. 179.

[16]*Midwestern Gas Transmission Co.* v. *Mason,* 31 Ill.2d 34, 201 N.E. 379 (1964).

[17]R. Scott, "Underground Storage of Natural Gas: A Study of Legal Problems, 19 *Oklahoma Law Review* 47 (1966).

[18]H. Williams & C. Meyers, *Oil & Gas Law,* Vol. 1, Matthew Bender, New York, N.Y., 1972, p. 31 (hereinafter cited as *Oil & Gas Law*).

[19]*West Edmond Salt Water Disposal Association* v. *Rosecrans,* 204 Okl. 9, 226 P.2d 965 (1950).

[20]*Oil & Gas Law,* pp. 53-58, (*supra,* note 18).

[21]*Railroad Commission of Texas* v. *Manziel,* 361 S.W.2d 560, (Tex. 1962) (hereinafter cited as *Railroad Commission*).

[22]*Hammonds* v. *Central Kentucky Natural Gas Co.,* 225 Ky. 685, 75 S.W.2d 204 (1934).

[23]*See e.g. Lone Star Gas Co.* v. *Murchison,* 353 S.W.2d 870 (Tex. Civ. App. 1962); *White* v. *New York State Natural Gas Corp.,* 190 F. Supp. 342 (W.D. Pa. 1960).

[24]*See e.g., Ga. Code Ann.,* sec. 93-801 *et seq.* (1972); *Ind. Stats. Ann.,* sec. 32-11-4-1 *et seq.* (Burns 1973); *Ohio Rev. Code Ann.,* sec. 4161-01 *et seq.* (Page 1973); *Consol. Laws of N.Y.,* sec. ECL 23-1301 *et seq.* (McKinney 1973), *as amended* (supp. 1975-76).

[25]*Boehringer* v. *Montalto,* 142 Misc. 560, 254 N.Y.S. 276 (Special Term 1931).

[26]*In re Tunnel Street in City of New York,* 160 App. Div. 69, 144 N.Y.S. 1002, aff'd 212 N.Y. 547 (1913).

[27]*Application of Gillespie,* 173 Misc. 591, 17 N.Y.S.2d 560, aff'd 285 N.Y. 771, 22 N.Y.S.2d 127 (1940).

[28]Sax, "Public Trust Doctrine," pp. 485-86 (*supra,* note 2).

[29]*Id.,* pp. 488-89.

[30]Federal Water Pollution Control Act Amendments of 1972, 33 *U.S.C.* sec. 1251 *et seq.* (Supp. 1975) (hereinafter cited as FWPCA).

[31]*United States* v. *Causby,* 328 U.S. 256, 260-61 (1946) (hereinafter cited as *Causby*).

[32]*Hinman* v. *Pacific Air Transport,* 84 F.2d 755, 757 (4th Cir. 1936).

[33]*Id.*, p. 758.
[34]*Causby*, pp. 264-67 (*supra*, note 31).
[35]*Restatement (Second) of Torts*, Vol. 1, American Law Institute Publishers, St. Paul, Minn., 1966, sec. 159.
[36]For a detailed treatment of tort law, the reader is referred to a standard legal treatise, *e.g.* Prosser, *Torts* (*supra*, note 10) or *Restatement (Second) of Torts.*
[37]*Corpus Juris Secundum*, Vol. 93, The American Law Book Co., Brooklyn, N.Y., Waters, sec. 88, 89 (1956).
[38]For a detailed discussion of ground water doctrines, *see* Richard R. Powell, *The Law of Real Property*, Vol. 5, Matthew Bender, New York, N.Y., 1975, pp. 413-429.
[39]*Upjohn* v. *Board of Health of Richland*, 46 Mich. 542, 9 N.W. 845, 848 (1881).
[40]*Kinnaird* v. *Standard Oil Co.*, 89 Ky. 648, 12 S.W. 937, 938-39 (1890).
[41]*Bollinger* v. *Mungle*, 175 S.W.2d 912, 916 (Mo. App. 1943).
[42]*Black's Law Dictionary*, p. 1470 (*supra*, note 6).
[43]Prosser, *Torts*, sec. 39 at 214 (*supra*, note 10).
[44]*Watkins v. Gulf Refining Co.*, 206 La. 942, 20 So.2d 273, 275 (1944).
[45]Prosser, *Torts*, sec. 39, p. 214 (*supra*, note 10).
[46]*Texas Co.* v. *Giddings*, 148 S.W. 1142 (Tex. Civ. App. 1912).
[47]*Dillon* v. *Acme Oil Co.*, 49 Hum. 612, 2 N.Y.S. 289, 291 (N.Y. 1888) (hereinafter cited as *Dillon*).
[48]*Risson* v. *Illins*, 25 Conn. 583 (1857).
[49]*Id.*, p. 589.
[50]*Dillon*, p. 291 (*supra*, note 47).
[51]*Long* v. *Louisville and Nashville R. Co.*, 128 Ky. 26, 107 S.W. 203 (1908), (hereinafter cited as *Long*).
[52]*Black's Law Dictionary*, p. 470 (*supra*, note 6).
[53]*Long*, p. 205 (*supra*, note 51).
[54]*Ryan* v. *Quinlan*, 45 Mont. 521, 124 P. 512 (1912), citing *Chatfield* v. *Wilson*, 28 Vt. 49.
[55]*Collins* v. *Chartiers Valley Gas Co.*, 131 Pa. 143, 18 A. 1012 (1890).
[56]*Id.*, p. 1014.
[57]*See e.g.*, *Wohlford* v. *American Gas Production Co.*, 218 F.2d 213 (5th Cir. (1954); *Lynn* v. *Maag*, 220 F.2d 703 (5th Cir. 1955); See also *Ellis* v. *Louisville & Nashville R. Co.*, 251 S.W.2d 577 (Ky. 1952); *Southern Ry.* v. *Bradshaw*, 73 Ga. 472, 37 S.E.2d 150 (1946).
[58]*The T. J. Hooper*, 60 F.2d 737 (2d Cir. 1932).
[59]*Id.*, p. 740.
[60]*Iverson* v. *Vint*, 243 Iowa 949, 54 N.W.2d 494 (1952).
[61]*Id.*, p. 495.
[62]*Rose* v. *Socony Vacuum Corp.*, 54 R.I. 411, 173 A. 627 (1934) (hereinafter cited as *Rose*).
[63]*Id.*, p. 632.
[64]*United Fuel Gas Co.* v. *Sawyers*, 259 S.W.2d 466, 468 (Ky. 1953).
[65]*Swift & Co.* v. *Peoples Coal & Oil Co.*, 121 Conn. 579, 186 A. 629, 633 (1936).

[66]*Hauck* v. *Tide Water Pipe-Line Co.,* 153 Pa. 366, 26 A. 644-45 (1893) (hereinafter cited as *Hauck*).

[67]*Beatrice Gas Co.* v. *Thomas,* 41 Neb. 662, 59 N.W. 925, 938 (1894).

[68]*Pennsylvania Coal Co.* v. *Sanderson,* 113 Pa. 126, 6 A. 453 (1886).

[69]*Hauck,* pp. 645-46 (*supra,* note 66).

[70]*See, Sullivan* v. *Jones & Laughlin Steel Co.,* 208 Pa. 540, 57 A. 1065 (1904); *Sussex Land & Livestock Co.* v. *Midwest Refining Co.,* 294F. 597 (8th Cir. 1923); *Packwood* v. *Mendota Coal & Coke Co.,* 84 Wash. 147, 146 P. 163 (1915); *Arminius Chemical Co.* v. *Landrum,* 113 Va. 7, 73 S.E. 459 (1912); *H. B. Bowling Coal Co.* v. *Ruffner,* 117 Tenn. 180, 100 S.W. 116 (1907).

[71]*Gulf Oil Corp.* v. *Hughes,* 371 P.2d 81 (Okla. 1962).

[72]*See, e.g., Sunray Oil Co.* v. *Cortez Oil Co.,* 118 Okl. 690, 112 P.2d 792 (1941) (hereinafter cited as *Sunray*).

[73]*Boomer* v. *Atlantic Cement Co.,* 26 N.Y.2d 219, 309 N.Y.S.2d 312, 257 N.E.2d 870 (1970).

[74]*Id.,* p. 872.

[75]*Monroe Carp. Pond Co.* v. *River Raisin Paper Co.,* 240 Mich. 279, 215 N.W. 325 (1927).

[76]*Fletcher* v. *Rylands* (1865), 3H & C. 774, 159 Eng. Rep. 737; rev'd *Fletcher* v. *Rylands* (1866), L.R. 1 Ex 265; aff'd *Rylands* v. *Fletcher* (1868), L.R. 3 H.L. 330.

[77]*Berger* v. *Minneapolis Gas Light Co.,* 60 Minn. 296, 72 N.W. 336 (1895).

[78]*Berry* v. *Shell Petroleum Co.,* 140 Kan. 94, 33 P.2d 953 (1934).

[79]*Id.,* p. 957.

[80]*Gulf Oil Corp.* v. *Alexander,* 291 S.W.2d 792 (Tex. Civ. App. 1956).

[81]*Id.,* p. 794.

[82]*Turner* v. *Big Lake Oil Co.,* 128 Tex. 155, 96 S.W.2d 221 (1936) (hereinafter cited as *Turner*).

[83]*Okla. Stat. Ann.,* tit. 52, sec. 296 (1969).

[84]*Norman* v. *Greenland Drilling Co.,* 403 P.2d 507 (Okla. 1965) (hereinafter cited as *Norman*).

[85]*Cities Service Oil Co.* v. *Merritt,* 332 P.2d 677, 684 (Okla. 1958).

[86]*Mich. Comp. Laws Ann.,* sec. 319.212(s), (t) (Supp. 1975).

[87]*Id.,* sec. 13.141 (3).

[88]Prosser, *Torts,* sec. 78 at 509 (*supra,* note 10).

[89]*Phillips* v. *Sun Oil Co.,* 307 N.Y. 328, 125 N.Y.S.2d 161, 121 N.E.2d 249, 250-51 (1954).

[90]*Pan American Petroleum Co.* v. *Byars,* 228 Ala. 372, 153 So. 616 (1934).

[91]*Love* v. *Nashville Agricultural & Normal Institution,* 146 Tenn. 550, 243 S.W. 304 (1922).

[92]*Reinhart* v. *Lancaster Area Refuse Authority,* 201 Pa. Super. 614, 193 A.2d 570. (1973).

[93]*Joldersma* v. *Muskegan Development Co.,* 286 Mich. 520, 282 N.W. 229 (1938).

[94]*Hall* v. *Galey,* 126 Kan. 699, 271 P. 319 (1928).

[95]*Donley* v. *Amerada Petroleum Corp.,* 152 Kan. 518, 106 P.2d 652, 655 (1940).

[96]*Bumbarger* v. *Walker,* 193 Pa. Super. 301, 164 A.2d 144 (1960).

[97]*Id.,* pp. 148-49.

[98]*Harper-Turner Oil Co.* v. *Bridge,* 311 P.2d 947 (Okl. 1957).

[99]*Pine* v. *Rizzo,* 186 Okl. 35, 96 P.2d 17 (1939).

[100]*Jackson* v. *U.S. Pipeline Co.,* 325 Pa. 436, 191 A. 165 (1937).

[101]*Shell Oil Co.* v. *Blubaugh,* 199 Okl. 353, 185 P.2d 959 (1947).

[102]*Wynn* v. *Wilson,* 252 Ky. 352, 76 S.W.2d 483 (1934).

[103]*Haveman* v. *Beulow,* 36 Wash. 2d 185, 217 P.2d 313 (1950).

[104]*Cities Service Gas Co.* v. *Eggers,* 186 Okl. 466, 92 P.2d 1114 (1940).

[105]*Masten* v. *Texas Co.,* 194 N.C. 540, 140 S.E. 89 (1927).

[106]For a discussion of this injection-related incident, *see* C. B. Raleigh, "Earthquakes and Fluid Injection," in *Underground Waste Management and Environmental Implications,* American Association of Petroleum Geologists Memoir 18, 1972, pp. 273-279 (hereinafter cited as Raleigh, "Earthquakes").

[107]Raleigh, "Earthquakes" (*supra,* note 106).

[108]*Corpus Juris Secundum,* The American Law Book Co., Brooklyn, N.Y., Vol. 35, Explosives, sec. 8 (1960).

[109]"Annotation: Mines-Damage to Surface Structures," *American Law Reports 2d,* Vol. 32, Lawyers Cooperative Publishing Co., and Bancroft-Whitney, Rochester, N.Y. and San Francisco, Calif., p. 1311.

[110]*Finley* v. *Teeter Stone Inc.,* 251 Md. 428, 248 A.2d 106 (1968).

[111]*Kenny* v. *Texas Gulf Sulphur Co.,* 351 S.W.2d 612 (Tex. Civ. App. 1961).

[112]*Prete* v. *Cray,* 49 R.I. 209, 141 A. 609 (1928).

[113]*Restatement of Torts,* Vol. 4, American Law Institute Publishers, St. Paul, Minn., 1939, sec. 818.

[114]*Restatement (Second) of Torts,* sec. 818 (Tentative Draft No 15, American Law Institute, Philadelphia, Pa., 1969).

[115]For a discussion of this failure, *see* Ohio River Valley Water Sanitation Commission, "Registry of Wells for Use in Underground Injection of Waste-Water in the Ohio Valley Region," 1974, p. 11.

[116]*Okla. Stat. Ann.,* tit. 52, sec. 296 (1969).

[117]*Norman* (*supra,* note 84).

[118]*See, e.g. Conn. Gen. Stat. Ann.,* sec. 25-54ee (1967), *Fla. Stat. Ann.,* sec. 403.141 (supp. 1972); *Va. Code Ann.,* sec. 62.1-44.15(11) (Supp. 1976).

[119]*See, e.g. Tex. Water Code Ann.,* sec. 22.015 (1971); *Ohio Rev. Code Ann.,* sec. 1509.081 (Page 1973).

[120]*Tidewater Oil Co.* v. *Jackson,* 320 F.2d 157 (10th Cir. 1963).

[121]*Jackson* v. *State Corporation Commission,* 183 Kan. 246, 326 P.2d 280 (1958).

[122]*Sunray* (*supra,* note 72).

[123]*West Edmond Hunton Lime Unit* v. *Lillard,* 265 P.2d 730 (Okla. 1954).

[124]Erle C. Donaldson and Robert T. Johansen, "History of a Two-Well Industrial-Waste Disposal System," *Underground Waste Management and Artificial Recharge: Preprints of Papers Presented at the Second International Symposium*

on Underground Waste Management and Artificial Recharge, Vol. 1, American Association of Petroleum Geologists, United States Geological Survey, International Association of Hydrological Sciences, 1973, pp. 603-21.

[125]Donald L. Brown and William D. Silvey, "Underground Storage and Retrieval of Fresh Water from a Brackish-Water Aquifer," *"Underground Waste Management and Artificial Recharge: Preprints of Papers Presented at the Second International Symposium on Underground Waste Management and Artificial Recharge,"* American Association of Petroleum Geologists, United States Geological Survey, International Association of Hydrological Sciences, 1973, pp. 379-419.

[126]*Turner* (*supra,* note 82).

[127]*Gulf Oil Corp.* v. *Alexander,* 291 S.W.2d 792 (Tex. 1956).

[128]*Mich. Comp. Laws Ann.,* sec. 319.212 (s), (t) (supp. 1975).

[129]FWPCA, 33 *U.S.C.* 1365 (*supra,* note 30).

[130]Safe Drinking Water Act, 42 *U.S.C.* 300 j-8.

[131]Virginia Erosion and Sediment Control Law, *Va. Code Ann.,* sec. 21-89.1 *et seq.* (1975).

[132]*Id.,* sec. 21-89.11 (d).

[133]*Railroad Commission,* p. 572 (*supra,* note 21).

[134]*Id.,* pp. 565, 568-69.

[135]Disposal Well Act., *Tex. Water Code,* sec. 22.104 (1971).

[136]*Urie* v. *Franconia Paper Corp.* 107 N.H. 131, 218 A.2d 360 (1966).

[137]*Kennedy* v. *Moog, Inc.,* 264 N.Y.S. 608 (N.Y. 1964).

[138]*Ellison* v. *Rayonier, Inc.* 156 F. Supp. 214 (W.D. Wash. 1957).

[139]Air Commerce Act of 1926, 44 Stat. 568 (1926).

[140]Federal Aviation Act of 1958, 49 *U.S.C.* 1301 *et seq.* (1976).

[141]*Id.,* sec 1310(24).

[142]*Causby* (*supra,* note 31).

[143]*Matson* v. *United States,* 171 F. Supp. 283 (Ct. Cl. 1959).

[144]*Reaver* v. *Martin Theatres of Florida, Inc.,* 52 So.2d 682 (Fla. 1951).

[145]*Id.,* p. 683-84.

[146]*Id.,* p. 684.

[147]*Roosevelt Field* v. *Town of North Hempstead,* 88 F. Supp. 177 (E.D.N.Y. 1950).

[148]*Indiana Toll Road* v. *Jankovich,* 244 Ind. 574, 193 N.E.2d 237 (Ind. 1963).

[149]*Jackson Municipal Airport Authority* v. *Evans,* 191 So.2d 126 (Miss. 1966).

[150]*Id.,* p. 130.

[151]Federal Aviation Act of 1958, 49 *U.S.C.* sec. 1506 (1976).

[152]*Shipp* v. *Louisville and Jefferson County Air Board,* 431 S.W.2d 867, (Ky. 1968) cert. denied 393 U.S. 1088.

[153]*Id.,* p. 870.

[154]*Loma Portal Civic Club* v. *American Airlines, Inc.,* 61 Cal. Rep.2d 502, 394 P.2d 548.

[155]*Id.,* p. 552.

[156]*Id.,* p. 554.

IV
Recommendations

The following policy-oriented recommendations are based on the preceding analysis of injection well usage and the institutional framework within which industrial waste injection is carried out. They derive from the premise that subsurface waste injection, under appropriate conditions, is a viable method of wastewater management. Comprehensive governmental regulatory programs do seem essential, however, due to the potential of waste injection to produce detrimental external effects not likely to be controlled by other mechanisms.

Selection of a particular waste-disposal technique should be based on a comparison of the total costs of each potentially feasible alternative, including environmental and social costs. Environmental cost assessments should include not only expected damages, but also other possible damages, even if they are not anticipated. Injection costs include a predictable commitment of certain resources and an assumption of risk concerning other resources and environmental quality. For example, materials such as water and minerals existing in the disposal formation may be permanently altered with regard to their suitability for other uses. In addition, waste injection may preclude other uses of the space involved, such as for storage of retrievable products. Even where these subsurface resources have little or no present value, changes in technology and the demands of society may make them valuable at a future time. A further cost consideration is that some potential exists for completely unanticipated events, such as escape of the waste from the disposal zone or stimulation of seismic activity. Thus the range of potential adverse consequences of injection is quite broad.

These potential costs, of course, must be fully considered in the formulation of injection well policy. They can be properly evaluated, however, only by considering both the possible extent of unpredictable environmental damage and the probability that it will occur. It is possible that overemphasis on isolated mishaps and low probability risks can prevent full consideration of the positive contributions of subsurface disposal when compared to alternative waste disposal methods.

Just as subsurface injection involves certain social costs extending beyond the direct outlays of the injector, other waste-disposal techniques also involve negative impacts that must be borne by society. These external effects, as discussed earlier, include decreased surface water quality, aesthetic degradation of land used for treatment facilities, and increased energy consumption. Since subsurface injection can reduce the magnitude of these detrimental factors, a benefit to society is created which must be balanced against any additional social costs imposed. All external effects, both positive and negative, need to be given consideration in the formulation of injection well policy.

The necessity of considering injection policy within a broad framework of natural resource and environmental quality management is emphasized by existing governmental policies. For example, criteria set forth by EPA policy require that injection be the most satisfactory alternative in terms of environmental protection.[1] A narrow view of environmental protection may lead to the conclusion that complete treatment, where available, is always to be favored over injection. However, it must be remembered that complete treatment has its own set of indirect environmental costs which should also be analyzed. For example, production of the energy utilized in such treatment processes may involve such adverse environmental consequences as those associated with the mining of coal or the operation of a nuclear generating facility. Thus it is imperative that the formulation and implementation of policy be accomplished within the context of a broad view of environmental protection, so all relevant considerations enter into the decision-making process.

The following recommendations reflect and develop these basic policy concepts.

Management Concepts

Management of subsurface waste injection must reflect a broad concern for general natural resource and environmental quality management. Seven concepts have been singled out for consideration.

1. *Final responsibility for approving deep well waste injection should be placed with the state agency in charge of wastewater management, but input from other agencies such as those responsible for water supply or mineral resources should be legislatively mandated.*

Evaluation of injection well proposals involves consideration of the hydrogeologic framework of the site and determination of the potential impact on natural resources and environmental quality in general. Since different aspects of the evaluative process are likely to come within the jurisdiction of different administrative agencies, injection well management requires multi-agency involvement. At a minimum, it appears management should involve agencies with the following responsibilities: (a) environmental protection; (b) water supply; (c) geology, and (d) mineral resources, including oil, gas, brines, and hard minerals. In some cases, the jurisdiction of a single agency may encompass two or more of these areas, but it is unlikely that the responsibilities of any one agency will be broad enough to include all these areas. Thus it is necessary that responsibilities and coordination mechanisms be clearly defined.

There appear to be two basic approaches for organization of the various agencies involved into an effective decision-making unit. One possibility is for one agency to be vested with final authority, with the other agencies acting in advisory capacities. In the other approach, each agency makes a separate determination regarding the desirability of a given proposal on the basis of its own area of responsibility, with final authorization depending on the consent of all. This approach decreases the probability of approval, since one negative viewpoint can deny an authorization. In the other approach, negative and positive factors are balanced to arrive at an overall decision.

Since injection is a wastewater management issue, logic suggests that final authority for approval should rest with the agency generally responsible for control of wastewater discharges. Any other administrative arrangement creates an artificial distinction between alternative disposal techniques. Injection technology is somewhat unique, but the decision concerning authorization of its use should be made in the context of comprehensive wastewater management. Other agencies having related responsibilities should serve in an advisory capacity. To assure input from these other agencies, review of injection proposals and submission of written comments should be required procedure.

2. *Management of subsurface waste injection should include a general assessment of the physical potential for injection within the area over which the management agency has jurisdiction.*

Due to the specialized physical requirements for injection well feasibility, any geographically extensive area—such as that contained within the boundaries of an individual state—is likely to exhibit considerable variation in potential. This variation in many instances will range from completely acceptable sites to those where injection is totally infeasible. The identification of special zones or regions on the basis of differing potential can serve as an important management tool. Delineation of such zones prior to the formulation of specific site proposals will assist in concentrating interest in the areas most suitable. Those regions lacking the necessary geologic conditions, or where injection would represent a significant danger to natural resources, can be identified and ruled out as potential injection sites. Specific regulations for approval of injection installations can be formulated to reflect differences in potential existing among regions. The scope of preliminary site investigations required, for example, may vary considerably among regions.

Assessment of physical feasibility of injection and delineation of zones of differing potential obviously go beyond minimum regulatory activity and require an active management program. This approach requires considerable funding and has not seen wide application, but offers definite advantages. It is consistent with the concept of long-range planning for wastewater management, and can be viewed as a basic element of natural resources planning and management in general. The alternative to this approach is to have the regulatory body respond to applications for disposal well authorization on a case-by-case basis without the benefit of guidance from a general plan. The comprehensive approach is inherently more rational as a basis for efficient and consistent decision-making, even though the case-by-case approach is workable and has seen much use.

3. *Effective management of waste injection may require coordination among different managerial jurisdictions.*

Because geologic formations often are continuous across political boundaries, effective regulation of subsurface waste disposal may require cooperative arrangements between separate governmental units. Without coordination, the existence of non-uniform regulations may result in the less restrictive requirements of one jurisdiction negating or compromising controls in effect in another. For example, the efforts of one state to protect brackish waters below a certain salinity level may be nullified if an adjacent state allows waste injection into interstate aquifers containing such waters.

Thus it may be desirable for the jurisdictions involved in such cases to develop consistent regulations or otherwise coordinate their regulatory programs. One mechanism for coordination is the interstate compact. This device has seen application in the case of river basin management and may be significant with regard to the control of subsurface waste disposal. The regulatory guidelines for waste injection published by the Ohio River Valley Water Sanitation Commission[2] represent an attempt by an interstate body organized primarily for river basin management purposes to provide coordination for control of subsurface waste disposal. Although existing organizations of this type may be able to serve in this capacity in some cases, it may be necessary under some conditions for special geologic basin commissions to be created. For example, boundaries of river basins and geologic basins may not coincide, creating the situation where no single river basin authority encompasses all of the appropriate geographical area within its jurisdiction.

Another mechanism for achieving consistency of regulatory provisions is provided by federal regulations[3] developed pursuant to the Safe Drinking Water Act.[4] These regulations leave some room for variation among the states, but will result in a more standardized approach by imposition of minimum requirements.

It may also be necessary in some cases to consider coordination of management at the international level. In some situations injected wastes have migrated across national boundaries and produced injury. Where the site of injury lies outside the jurisdiction of the management agency, there is a tendency for such injury to be viewed as external to decision-making. Thus effective regulation requires that the scope of considerations be broad enough to include the total area likely to be affected, and not be restricted by political boundaries.

4. *The management agency should keep thorough records regarding all aspects of waste injection within its jurisdiction.*

Comprehensive management of the subsurface for waste disposal and other purposes requires that complete, up-to-date information on all injection well operations be available at any given time. Injection wells may interfere with one another, and injected wastes may conflict with other subsurface operations. Thus it is important that the zone of influence of each injection installation be determined as a function of time since operations began. This determination is complicated by the heterogeneity of subsurface conditions, but location based on theoretical calculations and actual observations should be estimated as accurately as possible.

5. *Continuing study is needed to determine the long-range impact of injection, so that the uncertainty regarding the environmental soundness of this disposal method can be reduced and the adequacy of control measures can be evaluated.*

At present, disposal well management is carried out in an atmosphere of considerable uncertainty regarding the long-range impact of subsurface waste injection. This uncertainty often seems based on intuitive evaluations which make possible the introduction of subjective biases into the analysis procedure. Injection well experience suggests that the probability of occurrence of serious mishaps is low, but the period of record for significant use of injection is not long enough for conclusive determinations to be made. Thus continuing investigation concerning the consequences of injection is an essential aspect of a comprehensive management program.

6. *Governmental controls applicable to injection wells should be made explicit and incorporated into formally adopted regulations, to the maximum extent possible.*

The comprehensiveness of formal regulations can vary over a wide range. At one extreme, an administrative agency can function under a general grant of regulatory responsibility and exercise almost complete discretionary authority with regard to the specific controls imposed in a particular situation. On the other hand, specific regulatory controls and procedures can be encompassed within the terms of statutes and formal regulations to a considerable extent.

Although there are limits on the degree of formalization possible, there appear to be sound reasons for making control measures explicit by putting them into written form. The process of formalization does subject such controls to a critical review which may not be possible as long as they retain their informal status. Regulations should be objectively arrived at under conditions free from the pressures of any individual injection proposal, and formalization of controls appears to be the best mechanism for achieving this goal.

A certain amount of discretionary authority is necessary for efficient regulatory operations. Each injection proposal is a unique package, and flexibility to deal with special conditions is essential. Special circumstances may justify the relaxation of certain requirements in some cases, while in other instances control measures supplementing the standard regulatory provisions may be necessary. The need for flexibility, however, does not completely preclude adoption of regulations, since provision for discretionary authority can be made within the framework of formal control measures. One method of achieving this result is by utilizing administrative regulations to specify detailed control provisions, limiting statutory provisions only to broad regulatory considerations. In this form, controls can be modified more readily when change is needed. In addition, the regulatory agency can be vested with authority to grant exceptions to the regulations or to impose additional requirements under specified conditions. Some provisions should not be subject to modification at all, alteration within specified limits may be appropriate in some cases, and complete discretionary authority may be necessary in others. The extent of any discretionary authority should be defined within the terms of the controls.

7. *Since waste injection creates a potential source of injury for other individuals and may result in infringement of private property rights, the relative rights and responsibilities of the injector and others affected by his operations should be clarified within the framework of the management program.*

If injection well controls are silent with regard to the relative rights and responsibilities of injectors and others who may be affected by their operations, any conflicts which arise concerning injury or property rights will have to be resolved by the courts on the basis of very incomplete precedent. It may be desirable to remove some of the legal uncertainty concerning injection by means of legislative or regulatory provisions. With regard to physical damage, one approach is to impose absolute liability on the injector. This approach has seen application in regulation of the disposal of oil field brines. The same result is possible if the outcome is left to the courts since the trend is toward greater acceptance of the strict liability concept with regard to actions producing private injury.

With regard to invasion of space underlying the land of other owners, two approaches appear conceivable. One possibility is for regulatory controls to declare underlying space to be the exclusive property of the surface owner and to prohibit all injection across property boundaries in the absence of an agreement between the owners. The alternative is for subsurface space not being used by the overlying owner nor reasonably subject to use to be declared public property, with the right to inject conditioned only on governmental approval. This second approach might raise constitutional questions as to the taking of private property which would have to be resolved by the courts.

Of course, provisions concerning private rights and responsibilities are not an essential aspect of injection well management. The decision to adopt such measures and the nature of the provisions themselves are matters of public policy to be resolved within the political process.

Regulatory Guidelines

The purpose of regulatory guidelines for injection wells is to enumerate the various elements of a control program necessary for reducing the potential hazards from injection to an acceptable level. Such guidelines also should indicate the relative significance of the different control measures and the factors which determine the applicability of each to an individual situation.

The approach taken here is based on a review of all existing regulations as well as general consideration of the physical and economic determinants of feasibility. The guidelines attempt to incorporate the positive attributes of existing regulations and to remedy any apparent deficiencies. Although the particular combination of applicable control measures may vary with the situation, the guidelines are comprehensive and address a wide range of issues which may be significant in a regulatory context. Seven specific aspects of regulation are covered in the recommendations discussed below.

1. *The process for authorization of deep well injection should consist of a two-stage permitting process in which approval of well construction is based on a preliminary site evaluation and approval of injection is based*

on analysis of information obtained during well construction and testing.

Determining the feasibility of injection at a proposed site depends upon analysis of information on the characteristics of the site and its surroundings. If collection of the necessary data is outside the scope of the regulatory agency's operations, adequate information must be presented by the applicant or, perhaps preferably, by an independent consultant. The decision as to what is relevant for inclusion should be made by the agency and not left to the discretion of the applicant, since changes in the type of information considered can determine the outcome of the decision.

The scope of the necessary site investigation is strongly influenced by the physiographic characteristics of the proposed injection area. In some regions, geologic structure and water quality relationships are well known or can easily be predicted due to uniformity over large areas, thus reducing the need for extensive exploration. In other areas, geologic complexity and variability indicate the need for extensive geologic and hydrologic investigations to verify that conditions are appropriate for waste injection.

Since it is difficult to draw boundaries on what information may be pertinent to feasibility determinations, there is a tendency to make requirements all-inclusive for the area in question. While it is generally true that too much information is better than too little, it must be remembered that data collection is costly and should not be required beyond what is reasonably necessary. The test for including a particular requirement is whether it relates directly to criteria established for the evaluation of proposals.

Complete evaluation of a proposed site involves two phases. The first phase consists of preliminary site evaluation on the basis of general data, while the second is concerned with the analysis of data obtained during well construction and testing. Since it is advantageous to structure the authorization process so that all information from the evaluation can be fully utilized, a two-stage permitting procedure appears desirable. On the basis of the preliminary site data, the decision concerning construction of a proposed disposal well can be made, but final authorization of its completion and use as a disposal well should not be given until the information acquired during construction and testing has been considered. Since construction of a deep well involves a substantial investment, the fact that authorization of construction does not automatically lead to approval of use as an injection well should be clearly set forth in the regulations.

2. *Criteria for the evaluation of proposed injection well sites should be developed to guide decision-making relative to the authorization process.*

The physical feasibility of injection at a particular site is a function of the interrelationship of a wide range of site characteristics, making it impractical to formulate a comprehensive list of conditions for approval of injection sites. Nevertheless, certain criteria can be developed. Examples of factors that might be incorporated into criteria include: (a) water quality restrictions for disposal zones; (b) thickness of confining strata; (c) distance from a possible break in confinement such as a fault; (d) depth to disposal zones; (e) distance to potable water or other natural resources; (f) permeability and mineral composition of disposal and confining strata, and (g) fluid pressures.

The principal advantage of adopting specific criteria for decision-making is to make the process more objective and systematic. If a decision is approached as a logical sequence of steps, the outcome is more likely to reflect proper concern for all relevant considerations. Development of explicit criteria will not eliminate the need for judgment but will provide a framework to complement and improve its application.

3. *Regulations should require an explicit comparison of subsurface injection and other possible alternative means of waste disposal, including specific consideration of social and environmental costs not easily measured in monetary terms as well as actual construction and operating costs.*

The number of alternative waste disposal methods in a given situation is restricted by technological, economic, and institutional constraints, but some range of possibilities generally exists. Selection of the method to be employed consists of finding the alternative whose total adverse consequences are a minimum. Adverse impact must be viewed from the perspective of society as a whole and can be measured as a function of resources consumed, both environmental and economic.

A basic problem of comparing alternatives arises from the difficulty of reducing the total impact of each of the various alternatives to commensurable terms. For example, alternatives in a given situation may include one involving high consumption of electric energy, another requiring devotion of substantial surface acreage to waste storage purposes, and a third involving risk of ground water contamination. Although the actual expenditures to install each system may be determinable, it is not likely that the full range of consequences of each can be reduced to monetary or other directly comparable terms. Since decisions between alternatives must be made regardless of these limitations, it is essential that the potential effects of each alternative be enumerated in sufficient detail to assure their consideration in the evaluative process.

An increasing awareness has developed recently of the need for a comprehensive approach to environmental quality management, with particular emphasis on full consideration of alternatives. For example, a major intent of the National Environmental Policy Act[5] is to assure adequate evaluation of alternatives where federal action is involved. The Water Resources Council guidelines for planning water and related land development[6] facilitate the comparison of alternatives by broadening the format for evaluation of proposals. The multi-objective evaluative framework developed in these guidelines is designed to be used in the planning and evaluation of public investment projects, but the concept of measuring the impact of a proposal with regard to different objectives such as economic development *and* environmental quality also appears applicable to evaluation of alternative means of waste disposal. The basic need in the evaluative process is a broader perspective and greater input of information, and the multi-objective framework facilitates this development.

Attention also has been focused on the full evaluation of alternatives from the standpoint of their cost effectiveness in the case of publicly financed waste treatment facilities. Guidelines prepared by the Environmental Protection Agency for cost effectiveness analysis provide that "[a]ll feasible alternative waste management systems shall be initially identified. These alternatives should include systems discharging to receiving waters, systems using land or *subsurface disposal techniques,* and systems employing the reuse of wastewater [emphasis added]."[7] These guidelines also express an intent that costs of waste treatment facilities encompass monetary and social and environmental costs that cannot be measured in monetary terms. These nonmonetary costs are to be accounted for in descriptive terms so their significance can be determined in the analysis procedure.

Although these guidelines apply specifically to publicly owned waste treatment facilities receiving federal financial assistance, the underlying concepts also are relevant to private waste management practices. To promote efficiency, policy for guiding the selection of alternative disposal methods should reflect concern for finding the least-cost method. Where costs are broadly defined to encompass all negative impacts of a given waste disposal method, this approach also serves to optimize decision-making from an environmental viewpoint.

4. *All aspects of well design, construction, and operation should be subjected to regulatory controls.*

Injection well design and construction utilize technology that has largely been developed in the petroleum industry. To the extent that design features, construction procedures, and materials have been standardized, they can be incorporated into formal regulations. All requirements that must be adapted to the conditions of the individual site should be subject to agency approval.

After a well is drilled, its completion as an injection well differs from completion for production purposes. Certain design features required by the special characteristics of injection have been widely used and should be accepted as basic rquirements. Examples of such provisions include use of separate injection tubing within the casing, use of special corrosion-resistant materials with certain waste types, and installation of alarms and automatic shut-offs that would be activated by facility malfunction.

All aspects of well operation should be reviewed and approved prior to implementation. Limits should be established for injection rates and pressures. Procedures to stimulate the receiving formation should be controlled. Due to the danger of loss of waste confinement to the disposal zone, use of hydro-fracturing to increase the permeability of the disposal formation should be restricted and carefully supervised when allowed. The operator of an injection well should be required to report immediately any operational mishap or unanticipated occurrence.

5. *Regulations should require development of contingency plans adequate to prevent natural resource destruction or environmental degradation in the event of temporary injection well shut-down or permanent failure.*

Provision must be made for alternative means of handling an injection well waste stream during inoperative periods caused by regular maintenance operations, equipment malfunctions, nonscheduled remedial measures, or permanent failure of the well. Contingency plans may encompass a number of alternatives, including standby injection wells, surface storage facilities, or standby treatment facilities. Authorization of a short-term alternative should include provisions for shut-down of waste-producing operations before the capacity of the alternative is exceeded.

6. *Regulations should establish a monitoring philosophy and set forth specific monitoring requirements to the extent possible.*

Monitoring is an essential aspect of injection well control, since it is the principal mechanism for indicating the performance of an injection well and the migration of injected waste. Possible locations for monitoring include the injection well, the disposal zone, overlying aquifers, springs, and bodies of surface water hydraulically connected to ground water.

At the injection well, monitoring should encompass measurement of the volume of injected waste, injection pressures, quality of the injected waste, and pressures within the casing-tubing annulus. Pressure monitoring within the annulus allows leaks in the injection tubing to be detected and remedial action to be taken while the waste is still confined within the casing, thereby decreasing the likelihood of its escape to valuable strata.

Use of separate monitor wells is the principal means of determining the extent of waste migration. Within the disposal formation, monitoring is primarily concerned with determining the rate of migration, while monitoring of other strata is concerned with detecting the escape of wastes from the disposal zone. Monitoring of aquifers may consist of water quality or pressure measurements. Water quality determinations are more direct and give an indication of the fate of the injected waste, but pressure measurements also are useful in defining the zone of injection influence.

There has been some controversy concerning the need for and value of separate monitor wells. Some contend that monitor wells are unnecessary in many cases. One reason put forward in support of this position is that adequate information concerning operation of the system can be obtained from monitoring conducted at the injection well. Such monitoring is primarily limited to detecting changes in the system. For example, fracture of the confining bed or movement of the waste into an easy route of escape probably would be indicated by a decrease in injection pressure. Another objection to monitor wells concerns the validity of information obtained. Heterogeneity of subsurface materials and undefined hydrodynamics make waste movements unpredictable, and consequently make selection of adequate sites for monitor wells difficult. Of course, in some instances, the difficulty of monitoring and predicting waste movements may serve as a reason for prohibiting injection.

There are situations where use of monitor wells appears desirable. For example, monitoring of the disposal zone appears merited to indicate the rate of waste movement where the direction of migration is toward a fault. Also, monitoring of other aquifers may be necessary where they serve as important sources of water supply. Since the decision to require separate monitor wells can be critical in determining the economic feasibility of an injection proposal, an attempt should be made to require their use only where they are an essential precautionary measure. In some cases, the construction of separate monitor wells can be replaced or supplemented by monitoring the quality of water from existing water supply wells and springs that are properly located with regard to information needs.

One important consideration in monitoring the migration of injected wastes is the length of time over which monitoring is to be conducted. Monitoring may have to continue after injection has ceased, since waste movement is likely to continue. Waste already placed in the disposal zone may continue to respond to the pressure differential produced by previous injection, and hydrodynamic forces will continue whether or not injection has ceased. Thus monitoring may be a long-term responsibility, and the nature and duration of the commitment should be specified within the regulatory provisions.

Where injection is to take place in the vicinity of geologic faults, seismic monitoring may be desirable. Information concerning seismic activity is of interest because injection can stimulate its occurrence and also because seismic action can damage injection facilities and breech geologic confinement of the injected waste.

One important aspect of monitoring philosophy is assignment of responsibilities for the necessary operations. It often is taken for granted that the injector will be given full responsibility for all necessary monitoring as a condition for subsurface waste injection. However, there are reasons why this arrangement may not be completely desirable. One question that arises is whether the party being regulated should be responsible for an important aspect of the regulatory program. A way to resolve this difficulty is through use of independent consultants. This allows financial responsibility to be placed with the injector although the actual monitoring operations are conducted by other parties.

Another alternative is assumption of monitoring responsibility by the regulatory agency. Under certain conditions, public expenditures for monitoring may be in the public interest. One advantage arises from the fact that complete control by the regulatory agency helps assure the objectivity and validity of data collected. Another possible reason for public support of monitoring concerns the scope of the operations that may be necessary. Although it appears equitable that on-site monitoring expenses should be borne by the injector, costs incurred at more distant locations appear less assignable to the individual injector, especially where monitoring operations also serve to indicate the movement of pollutants from other sources. Thus it is possible that an equitable arrangement may involve apportioning monitoring costs between injectors and the public, where the public expenditures are viewed as falling within the physical data collection activities that have traditionally been undertaken by government. An example of precedent for this type of public involvement is given by an EPA grant for the monitoring system at an injection well constructed by Reichhold Chemicals in Alabama.

The decision as to whether monitoring should be publicly subsidized depends ultimately on prevailing subsurface injection well policy. If the social benefits of injection are viewed as exceeding the costs, some amount of subsidy may be justified to encourage greater use of this waste disposal technique. On the other hand, a subsidy would not be indicated if the direct costs and risks which make up the total social cost of injection are assessed as equal to or exceeding the gains. There are other mechanisms to encourage or discourage use of deep well disposal, but the issue of monitoring costs provides one means through which influence could be exerted.

7. *Regulations should specify requirements for abandonment of waste injection wells.*

It is essential that abandoned disposal wells be properly sealed in order to prevent migration of the waste material or other substances between strata via the well itself. Although some variation among different wells is to be expected, the existence of somewhat standardized well-plugging technology allows regulatory provisions to be more explicit than in many other areas. In addition to specification of materials and methods, regulations should require that the regulatory agency be notified of the intention to abandon so inspection of abandonment procedures is possible. It is desirable that the location of abandoned disposal wells be marked and permanently recorded, along with information concerning the type and volume of waste injected. This information is necessary for long-term planning in connection with waste injection and management of other subsurface resources.

Areas Meriting Further Investigation

The principal informational deficiency with regard to subsurface waste injection is incomplete knowledge of the physical system involved and its response to the injection process. Although no complete solution to this problem appears feasible, there are five areas in which research has potential to reduce its magnitude.

1. *Basic hydro-geologic data collecting programs need to be reevaluated with regard to their effectiveness in providing adequate information for determining waste injection feasibility.*

Assessment of physical potential for injection is hindered by present data deficiencies resulting from incomplete collection techniques. One example of the incomplete state of data is the fact that the depth to water of various quality levels is often unavailable, although one depth to mineralized water in general may be available. Since requirements for waste injection may specify a certain quality level as the minimum for injection zones, information concerning the variation of quality with depth is necessary. Data collection programs carried out in connection with oil exploration and other operations should be reviewed and modified where necessary to maximize the information made available for determining the feasibility of injection.

Another basic problem results from the unorganized and uninterpreted form in which much data exists. Interpretation of well logs is a time-consuming task requiring specialized skills, and a general effort should be made to convert all such data into a more usable form.

2. *Research is needed to further substantiate and refine certain concepts of subsurface hydrodynamics, with emphasis on determination of injection potential.*

One of the most significant hydrodynamic concepts with regard to subsurface injection is the delineation of different zones of water circulation. A downward classification of zones of circulation—consisting of rapid, delayed, lethargic, and stagnant—has been proposed.[8] The existence of zones with essentially no or very little water movement has important implications for the long-term confinement of injected wastes. Hydrodynamic forces often constitute an essentially unknown factor with regard to future waste migration. Thus the existence of zones where these forces are largely absent would remove some of the uncertainty generally associated with injection.

3. *Improved methodology needs to be developed for evaluating alternative methods of waste treatment and/or disposal.*

Determination of the most acceptable method of waste treatment and/or disposal in a given situation should be based on a comparative evaluation of all available methods, with the final decision made on the basis of least total adverse impact.

As noted earlier in the recommendations, a basic difficulty in the evaluative process is determining the full range of consequences attributable to each individual method, and reducing these consequences to commensurable terms. An effort is needed to systematize a procedure whereby consideration can be given to the total impact of each alternative even if all the effects cannot be reduced to monetary terms.

One aspect of the evaluative process where the need for analysis is especially evident is the handling of risk and uncertainty associated with waste treatment and disposal. Where the chance of occurrence of an adverse effect is unknown, evaluation often is accomplished by an intuitive process which makes possible the introduction of subjective biases into the analysis procedure. The outcome may be that such effects are virtually ignored or, on the other hand, may be given almost infinite effect, with the result that the alternative from which they arise is prohibited. There is need for study to explore the possibility of applying the principles of probability theory where risk can be evaluated, and there is need for devising more objective procedures for handling uncertainty associated with waste treatment and disposal in general.

4. *Research is needed to explore the legal implications of artificially-induced instability problems affecting the use of property.*

The fact that subsurface injection and certain other of man's activities have the potential of inducing seismic activity and affecting land stability in other ways has been increasingly documented in recent years. These instability problems may be inadvertently caused by natural resource development or other engineering operations, and consideration is being given to the possibility of controlling catastrophic earthquakes by inducing smaller quakes through the release of seismic energy.

Since damage to others is a possible result of any intentional inducement of seismic activity or inadevertently created instability problems, the legal implications of such activities are potentially significant. The legal principles concerning artificially created instability problems have been given little consideration. In fact, law with respect to injury arising from man's interference with natural processes in general is not well developed. Nevertheless, the issue of liability in connection with injury resulting from instability is likely to become more prominent, and an assessment of the rights and responsibilities of the person engaging in such activities is needed. Such an assessment would be based largely on a compilation and analysis of all court decisions concerning instability problems and other areas of law from which possible analogies could be drawn.

In addition to the liability issue, another important legal consideration is the need for and adequacy of legislative and administrative controls over activities with the potential to cause instability problems. An example of this type of control is state injection well regulation which requires that seismic risk be considered along with other factors in prescribing conditions for the location and operation of such wells. Another example is found in controls over subsidence included within regulations applicable to natural resource recovery operations such as petroleum extraction or ground water pumping. An evaluation of the extent such controls are utilized and their effectiveness should be a basic part of the suggested research in this area.

5. *There is need for research to clarify the ownership of subsurface space and to suggest appropriate policies for management.*

The increasing utilization of subsurface space for waste injection and a variety of other purposes requires a reevaluation of the concepts of private property as they apply below the land's surface. At an earlier period of more absolute property rights, the surface proprietor was generally held to hold exclusive rights to all space from the sky to the center of the earth. The needs of aviation have required a restriction of the upward extent of property, but the absence of an overriding public need for the use of subsurface space has resulted in less consideration being given to the lower limits of property.

The concept is well established that recoverable resources such as hard minerals fixed in position belong to the overlying owner. Fluids which can migrate in response to pressure differentials pose ownership problems, but some concept of property generally attaches. A less defined situation exists concerning the right to use space beneath a given parcel of land. This space may be artifically created by excavation (e.g., tunnel construction) or it may be used in its natural condition (e.g., waste injection into the pore spaces of geologic formations).

An interesting aspect of many uses of the space itself is that the average landowner does not have the capability to make the use himself. Thus the question that generally arises is whether the landowner can prohibit or control use by others on the basis of a theoretical property right to all space lying below his surface estate. There is legal precedent concerning the rights of the landowner in this situation, but court rulings on this subject are not consistent, making the determination of a general principal impossible.

Since some of the potential uses of subsurface space are public, the question arises as to whether property rights should be restricted to a depth bounded by the capability of use, as has been done in the upward direction. Research to further define the extent of private interests in subsurface space at present and the possible implications of the recognition of certain public rights in such space appears to be needed.

Part IV Footnotes

[1]U.S. Environmental Protection Agency, "Administrator's Decision Statement No. 5," Feb. 6, 1973.

[2]Ohio River Valley Sanitation Commission, "Underground Injection of Wastewaters in the Ohio Valley Region," August, 1973.

[3]"Draft Environmental Protection Agency Regulations on State Underground Injection Control Programs," 40 *C.F.R.* Part 146, March 19, 1976.

[4]Safe Drinking Water Act., 42 *U.S.C.* 300f *et seq.* (Supp. 1976).

[5]National Environmental Policy Act of 1969, 42 *U.S.C.* 4321 *et seq.* (1973), *as*

amended (Supp. 1976).

[6]U.S. Water Resources Council, "Principles and Standards for Planning Water and Related Land Resources," 38 *Fed. Reg.*, No. 174, Part III-1.

[7]U.S. Environmental Protection Agency, "Cost Effectiveness: Proposed Analysis Guidelines," 40 *C.F.R.* Part 35, Appendix A, sec. e(1) (July 1, 1975).

[8]Edmond G. Otton, "Geologic and Hydrologic Factors Bearing on Subsurface Storage of Liquid Wastes in Maryland," Maryland Geological Survey, 1970, p. 7.