# A PRELIMINARY INVESTIGATION OF THE POTENTIAL FOR DEEP WELL WASTE DISPOSAL

by

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# INTRODUCTION

## Background

An industrial firm is required to make numerous decisions concerning its daily operations. Output quotas, input acquisitions, and investment decisions are but a few of the questions to be resolved by industrial corporate heads. Likewise, governmental organizations face similar decisions in attempting to serve the people. Environmental concerns constitute one area on which private firms, municipalities, and other governmental agencies have been required to focus increased attention. One particular decision out of many which must be made in this area is the selection of a waste management system.

The decision to employ a particular waste management scheme is a multi-faceted one involving, to various degrees, several factors, either separately or in combination. The industrial firm, municipality, concerning a liquid waste system must consider the physical, economic, regulatory, and public relation aspects of various waste management alternatives.

The physical aspects involve the characteristics of the waste to be disposed. The waste's composition, concentration, and rate at which it is produced are essential factors to be weighed in choosing a waste management plan. Choice of disposal practice and treatment plant size may in effect be based on the waste's properties. Physical factors also involve the environment in which the waste management system is to exist. The presence or absence of suitable dumping grounds such as rivers, lakes, and ocean, the climate of the area, and the subsurface geology can all be instrumental in finalizing a waste disposal type decision.

Though it is difficult to make generalizations as to which of the criteria is the most important to the individual deciding between a set of alternatives, economics is possibly the single most significant aspect gaining attention by the industrial firm. The industrial producer may view the economics of waste management in the realm of profit maximization. That is, a particular waste treatment scheme may be selected over others due solely to the fact that it is the least cost alternative facing that producer. In this instance, a firm producing a known volume of waste would elect to implement the process that would minimize cost and would maximize profit.

Instead of a purely economic decision, as is the case with the least cost alternative idea, the firm might initiate a waste disposal plan subject to a cost constraint. That is, from a firm's point of view, the system is considered suitable if its cost does not exceed a predetermined level. This type of criteria better lends itself to the consideration of other decision making standards.

The municipality or other governmental agency has broader objectives in its day to day operation than those of the private firm, caused by serving a more diverse set of interest groups. Whereas a private firm's existence might be dependent upon minimizing waste treatment costs, economics in this sector may be delegated to a less vital role. The public sector is generally not placed under the strict control of cost minimization, and often times receives funds for the construction of waste pollution control facilities.

Policy considerations are rapidly gaining in importance to all parties concerned with liquid waste treatment. Involved in this category are not only the meeting of standards set at the federal, state, and local level, but also legal suits brought against parties for damage incurred as a direct result of failure of the waste treatment system. On a case to case basis, policy implications might find direct conflict with the economic considerations, resulting in a compromise solution. Such a solution might be the least cost waste disposal technique for a given set of environmental standards.

The firm involved in the process of selecting a waste management plan must also lend thought to public relations. For instance, where a bond issue is needed for funding the construction of a waste disposal system, as is the case often times in municipalities, the image the voting population holds of the system can be vital to the passage of the bond issue. Public opinion is also influential in the adoption of a competitive firm's waste management choice. It is highly unlikely that an industry would adopt a least private cost alternative meeting legal standards, if it had a drastic negative effect on its consuming majority; for example, the wastes were being dumped into a local body of water thereby destroying various natural amenities.

It is only on rare occasions that a single criteria is involved in electing a wastewater management alternative. The determination to employ one process rather than others is based on all of the factors with certain criteria given more attention in the decision than others. One alternative to which these criteria may be applied is a relatively recent liquid waste treatment practice known as deep well waste disposal. Oversimplified, deep well waste disposal (DWWD) is the idea that certain liquid wastes can be injected into confined geologic strata not having other potential uses, thereby furnishing a long term isolation of the waste from man's environment.

## DWWD History

Deep well injection of liquid waste had its beginnings in the petroleum industry. Vast quantities of salt water resulting from petroleum extraction were being discharged into surface waters and surface evaporation pits. Many problems resulting from these practices led to their virtual elimination in favor of returning these oil field brines to aquifers already contain saline waters. Over 40,000 injection wells for oil field brine disposal were in existence in 1973. (11)

The history of DWWD practices other than brine disposal is a relatively brief one. The growth of using the waste injection method perhaps can best be seen by viewing the history of regulatory activity governing its use. The first controls mentioning waste injection activity were applicable to oil field brine disposal and administered by state agencies responsible for the regulation of the petroleum industry. One of the earliest examples of such legislation occurred in 1934 when the Kansas State Corporation Commission was granted control over the subsurface disposal of oil field brine by the Kansas Legislature. The Texas state legislature is generally credited with enacting the first set of laws dealing specifically with waste injection other than oil field brines. The Injection Well Act of 1961 vested authority of the Texas Board of Water Engineers for the issuing of permits for the injection of all types of wastes other than oil field brines. Since this time such authority now belongs to the Texas Water Quality Board. DWWD activity increased considerably in the late 1960's as testified by the adoption of several more regulatory programs. From 1967 through 1969, Ohio, Michigan, West Virginia, and New York enacted legislation covering injection wells. During this period, the Ohio River Valley Water Commission also issued a policy statement for its member states commenting on DWWD activity.

The early 1970's have seen even a greater expansion of DWWD use and related regulatory controls. In addition to several states adopting legislative policy on injection wells, including Missouri and North Carolina prohibiting disposal wells, the federal government legislatively commented on DWWD activity. In 1970, the Federal Water Quality Administration adopted a policy statement regarding injection wells, while the Federal Water Pollution Act Amendments of 1972 provided that states desiring to administer a waste discharge permit program in lieu of a federally administered program must have adequate authority for the issuance of disposal well permits. The successors of the Federal Water Quality Administration, the Environmental Protection Agency, published regulations in 1973 stating that it would subject disposal wells to its terms and conditions where such wells are used as a part of a total waste disposal program. These terms and conditions covered such areas as the issuance of permits and well monitoring requirements.

## Identification of the DWWD Process

For purposes of this study, "deep well waste disposal" is defined as the injection of liquid wastes into confined geologic strata located at depths below the occurrence of potable groundwater or their extractable natural resources. Such a definition does not include all subsurface waste disposal operations. Among those operations excluded are the disposal of solids in landfill operations and excavated chambers, an often used method for disposing of high level radioactive wastes. The disposal of intermediate level radioactive wastes by means of cement slurry injection can also be distinguished since the waste and cement mixture does not retain its liquid nature after cement solidification. A second major difference in cement slurry injection is that it utilizes impermeable strata which are artificially fractured to give the access rather than the permeable strata used in the conventional case. Also, by definition, any operations which place liquids in the zone of potable groundwater are excluded. Drainage wells, recharge wells, septic tanks, and land treatment operations such as spreading are included in this excluded category. Likewise, this study considers the disposal of oil field brine as a special case of DWWD and excludes it from further analysis.

It is possible for a disposal stratum to overlie resources in certain cases where it is isolated from both overlying and underlying strata by means of impermeable formations which will confine the waste. Thus the concept of "deep" is relative and cannot be subjected to absolute quantitative limits. A recent injection well survey states that over three-fourths of the existing 1972 wells were within the 1000-6000 feet depth range. (24) The depths of the remaining wells were outside both extremes of this range.

Since a relatively insignificant percentage of underground space exists in the form of large cavernous openings, the principal space utilized in injection operations consists of inter-granular pore space of high porosity materials. Space made up of fractures, joints, and solution channels where certain other materials such as limestone, sand, sandstone, or dolomite are involved is also suitable for disposal zones. Another factor of importance is that most of the subsurface space is already occupied by natural water, either fresh or to some degree mineralized. Thus, injection does not usually involve the filling of the unoccupied, but rather consists of a compression or displacement of existing fluids. For this reason, the DWWD system generally operates under pressure. The wastes to be injected are forced into the disposal zone at rates ranging from gravity flow to 1500 pounds per square inch. The aforementioned 1972 DWWD study indicates that approximately three-fourths of the wells use a pressure below 600 pounds per square inch. Since the compressability of water is small, creation of significant volumes of storage space through this mechanism requires disposal zones of large capacity. Displacement of resident fluids is in itself a potential problem area since movement of saline water into other strata or to the surface can in itself constitute pollution.

Although DWWD is frequently thought of as an ultimate disposal practice, it is more closely aligned to a process of long term waste storage. A primary characteristic of the wastes usually injected is their lack of susceptibility to conventional treatment processes. The majority of the wastes being injected are relatively nondegradeable; however in certain cases, there is evidence of some degree of subsurface alteration of the waste's composition. For example, prolonged contact between acidic wastes and a carbonate rock injection horizon will result in at least partial neutralization of the waste.

For ease of explanation, Moseley and Malina have classified a general DWWD operation into five sub-systems. (14) The first is designated as treatment and includes such things as initial and final flow equalization basins and whatever physical and chemical pretreatment facilities which may be required. Filtering and pH adjustment are two of the more common pretreatment practices. Only a few wells flow under gravity head alone, hence a pumping system is required. Pumping entails a force created by pumps to drive the fluid through the well and into the receiving formation. The third classification made is the distribution system which is simply the equipment involved in transporting the waste to the wellheads. For facilities having a single wellhead, this process is obsolete. The well apparatus itself is designated as the fourth sub-system which is responsible for carrying the waste from the surface environment to the final component, the disposal zone. The heterogenous nature of the earth's subsurface makes any additional description of the injection reservoir virtually impossible.

## Current Practice

A late census of DWWD activity, published in 1972, lists 246 wells operated by industries in the United States. (24) Their distribution is not uniform, however, as they occur in twenty-four states with just three states containing approximately one-half the total. These are Texas with 71, Louisiana with 40, and Michigan with 27 wells. The Mid and South Atlantic region, the area upon which this study is focused, contains only a small number of disposal wells. At this time there are seven wells in West Virginia, six in Florida, four in Tennessee while Delaware, Georgia, Maryland, South Carolina and Virginia are without wells. North Carolina has had such a system, but injection was halted because of complications in 1972. These complications arose out of the disposal zone being unable to accept the desired injection rate and thereby clogging resulted.

Though DWWD is employed by a diversified group of industries, the majority of the existing wells are operated by the chemical, petrochemical, and pharmaceutical companies. Other significant users are refineries, natural gas plants, and metal product firms.

As stated earlier, the injection of industrial wastes other than brine has a relatively brief history. The 246 wells indicated in the census is the result of a late increase in DWWD use. An inventory taken in 1964 disclosed the existence of only 30 industrial wastewater injection wells. By 1967, the number had grown to 110, and the 1972 count shows 246. These statistics indicate an average growth rate of about 27 wells per year since 1964.

## Statement of the Problem

Recent amendments to the Federal Water Pollution Control Act provide for major changes to eventually eliminate water pollution by 1985. Waste load projection studies indicate that the waste volumes generated by population and economic growth over the next several decades will be very large, and the cost of treating it by present standards will be extremely high. Hence, all possible systems and methods of waste disposal must be carefully considered in attempting to attain the goal of zero waste discharge.

Within the overall research and planning required for ways of improving and reducing wasteload discharge into surface waters, the feasibility of using deep well waste disposal methods must be evaluated as a viable alternative in certain situations.

The Environmental Protection Agency has proposed guidelines to develop procedures for analyzing cost effectiveness of various waste management schemes. Listed in the guidelines under the heading "Identification, Selection, and Screening, of Alternatives" (sec. e.) is the following statement: "These alternatives should include systems discharging to receiving waters, systems using land or subsurface disposal techniques and systems employing the reuse of wastewater." (8)

A March, 1973, Environmental Impact Statement, by the EPA concerning methods of treated wastewater disposal in Southeast Florida recommends DWWD as a viable method of wastewater disposal for that particular area. The study further states that diversion of wastewater from surface waters to deep wells will substantially and immediately improve the quality of those surface waters, and will contribute to the long term enhancement of surface water quality. (20)

DWWD has also been credited with permitting firms not only to remain in operation, but to stay competitive as well. For example, a particular pulp mill faced with the order to cease the discharging of wastes into surface waters or halting operations, piloted several research projects designed to discover a suitable alternative. These attempts showed a DWWD alternative to be both technically and economically suitable, and resulted in the continued operation of the plant. (4)

The concern for DWWD indicated here as well as the growth of policies governing its use, point to the fact that DWWD is a viable form of waste management. As such, deep well waste disposal must be evaluated with respect to both its positive and negative environmental consequences. This analysis must be made within an overall environmental management framework in order for all long and short run as well as direct and indirect effects to be accounted for. An analysis of this nature is difficult as the measurement of these hard-to-quantify environmental costs and benefits often creates problems.

Particular problems arise in attempting an economic analysis of this waste management choice. That DWWD is a conceivable method has been established, but exactly which economic principles are relevant in the decision making process of whether or not to employ this option is not at all certain. Economics is not only a relevant consideration of the DWWD users, but of the regulatory agencies as well. These are problems that must be dealt with if deep well waste disposal is to play an essential role in long term waste management planning.

# CHAPTER II

# OBJECTIVES OF THE STUDY

This chapter deals with the statement of objectives and the reasons for them. The chapter also introduces the concepts of environmental benefits and costs of employing DWWD for purposes of gaining an insight into the justification of the objectives.

The objective of this study is to conduct a preliminary investigation of the potential of DWWD as a waste management tool. Identification and examination of the economic concepts and issues involved in the utilization and regulation of the method will be made. The study also focuses on the current and potential state of DWWD in the Mid and South Atlantic states.

The identification of economic considerations relevant in determining feasibility for industries and municipalities contemplating the use of DWWD is essential for an overall sound evaluation of its environmental impact. Likewise, the determination of economics' role in policy formulation is necessary if proper regulation of its use is to occur. Thirdly, a working knowledge of pertinent economic aspects is valuable to the public for purposes of effectively evaluating proposed guidelines and creating a total awareness of the benefits and disbenefits of the method.

Full consideration of both the positive contributions and adverse effects of DWWD is necessary for a comprehensive and objective evaluation of this disposal technique. Knowledge of these environmental consequences should be essential to users, policy makers, and the general public in formulating decisions with regard to deep well disposal. Although discussed in economic terms later, a brief description at this time of both environmental advantages and disadvantages may be beneficial in gaining an insight into the justification of these needs.

Possible environmental benefits resulting from employing DWWD could be identified as additional recreational use of surface water, reduced land use in waste treatment, aesthetic benefits, and others depending upon the particular case in question. The elimination of a large discharge of a highly toxic waste would of course produce very significant benefits. The emphasis in recent years on pollution abatement, however, has already resulted in the elimination or modification of the most serious pollution sources. Damages resulting from most present authorized discharges are of a more subtle or unknown nature. Therefore, such benefits are hard to measure in absolute terms; nevertheless, when a discharge to surface waters is prevented, benefits in some form will normally be produced.

DWWD may also produce desirable environmental benefits by reducing the need for waste treatment facilities. A reduction in the amount of land devoted to waste treatment can result directly from employing injection wells. This benefit would most easily be recognized in urban areas where land is relatively scarce. In the case where waste settling lagoons are replaced with injection wells, the greatest potential benefit from reduced land requirements exists as lagoons often occupy considerable land area. Lagooning wastes results in almost continuous environmental problems such as leakages and damages to wildlife as well as aesthetic pollution. Hence, even greater benefits stand to be gained.

The substitution of traditional treatment facilities with DWWD may produce additional benefits by reducing the demand for energy. Conventional forms of wastewater treatment which require vast amounts of energy for their operation create an environmental cost as the production of energy involves to some degree environmental degradation. For example, production of electricity can involve the mining and burning of coal with associated consequences, and its generation by nuclear power plants involves some release of radiation to the environment. These environmental costs are decreased whenever waste disposal methods involving less energy consumption are adopted. Hence, DWWD with its lower energy requirements has less of an environmental impact in this area than do many waste treatment operations, particularly where advanced or complete treatment is required prior to discharge into surface waters. Any savings in energy consumption takes on special significance in view of the increasing scarcity of energy resources.

Specific knowledge of environmental damages resulting from using deep well waste disposal is limited by the uncertainty of exactly what happens to the waste after injection. The majority of identifiable DWWD disadvantages arise out of the results of potential well failures.

For instance, improper well operation may jeopardize potable groundwater supplies as well as effect future opportunities for the utilization of other resources such as minerals and natural gas reserves.

Much emphasis has been given to the potential environmental costs by individuals believing that putting the waste out of sight via DWWD creates more concern than dumping the waste where any detrimental effects are more noticeable. Such emphasis has been reinforced by a small number of disposal well malfunctions, and appears to be based in part on a deep seated, intuitive mistrust of the technique. As indicated, injection wells do present potential environmental hazards, but it is possible that an overemphasis on isolated mishaps and low probability risks can prevent full consideration of the positive contribution of DWWD which is necessary for a comprehensive and objective evaluation of this disposal alternative.

# CHAPTER III

# THEORETICAL ISSUES

The purpose of this chapter is to present the theoretical issues involved in the employment of deep well waste disposal. The issue of property rights is defined and discussed with regard to utilizing subsurface area for purposes of this disposal alternative. The term resources is defined, and the concept of underground space as a resource is presented as a means of creating an awareness to the need for a well developed public policy to guide the development and govern the use of the area for purposes of DWWD. Third, the cost categories expected to be encountered when DWWD is implemented are specified to facilitate their discussion in a later chapter. Finally, the chapter introduces a theoretical approach to social costs and benefits as they apply to deep well waste disposal and elaborates on the problems encountered in attempting to quantify them.

## Property Rights

Underlying an individual's justification to employ underground space for purposes of deep well waste disposal is the concept of property rights. Where there exists a conflict between individual competing users over a specified area, the relevant issue becomes who owns the space in question and who holds the right to its use in resolving the problem of allocation. Even when conflict is absent, the property rights issue is the basic permission granting force behind the individual's utilization of the underground.

A common error is to think in terms of property as opposed to property rights. Such a tendency leads to conceiving of property in terms of objects rather than a group of rights to designate the use of the objects. This bundle of rights could generally be classified into: (1) a set of rights to use property in certain ways (and a set of negative rights or prohibitions, that prevent its use in other ways); (2) a right to prevent others from exercising those rights, or to set terms on which others may exercise them; and (3) a right to sell or trade property rights. (6, p. 59) The first two categories of rights are specifically defined by a society's system of law while economics deals with the buying, selling, trading, leasing, and using of property rights. The price one pays for objects bought and sold are merely prices for the property rights to these objects. Hence, the concept of property rights serves to bring together the legal and economic disciplines.

The utilization of underground space for purposes of DWWD complicates the concept of property rights by the mere nature of its process. The initial determination of to whom property rights belong for a specific area is by no means the end of property rights implications with regard to deep well use. Ultimate disposal or long term confinement, the goals of DWWD, are based on the assumption that an impermeable stratum overlies the disposal zone. Vertical migration may take place, however, by means of natural features such as faults; abandoned wells which penetrate the confining layer; by means of the injection well itself, if poorly constructed; or by means of pressure alterations causing limited fracturing. If vertical migration does occur, the property rights issue is thrown open to debate once again by parties involved as the waste obviously does not realize boundaries.

A characteristic of a properly functioning DWWD system is that vertical movement of the waste is non-existent. Nevertheless, the property rights issue is still involved with the adjacent landowner's concern over horizontal movement within the injection zone. As increased volumes of waste enter the disposal receptor the waste front is forced outward in all directions, and as injection continues the front will eventually cross subsurface boundaries. The question to be raised here is whether the landowner has the right to prevent the invasion of underlying space by injected wastes without proof of harm being done. Although there is definite lack of case law involving injection wells, some insight through analogy might be gained through actions and decisions in related areas.

In the past a commonly held idea was that the property rights to a parcel of land extended to "the heavens above" and "to the center of the earth" in addition to the surface. The concept of ownership of air space over the land has gradually lost effectiveness with the evolution of air travel and various forms of communication utilizing the air space. The increased demand placed on the relatively shallower depths of the subsurface by the undergrounding of utilities, various types of storage, and habitation, however, has recreated an awareness of the concept of exclusive property rights "to the center of the earth." This concept has been a point in favor of surface owners as few desired users of the shallower depths have challenged these exclusive interests in the absence of explicit permission to use the area in question. For example, a proposed Chicago water storage project calling for a 20 billion gallon storage to be provided as an answer to the city's flooding and water quality problem will be constructed beneath public rights of way to the extent possible. (15)

A recently held conference entitled "Need for a National Policy for the Use of Underground Space" raised the question of the desirability of employing exclusive rights "to the center of the earth." (15) There were those who felt the concept should be preserved, depending on the process of eminent domain to resolve conflicts with the public interest. Eminent domain permits the government to take one's property for public use by virtue of its superior dominion over all lands under its jurisdiction. The eminent domain process, however, has been controversial as there is much case to case variation. These variations range from time consuming and expensive settlements to purely mechanical procedures whereby landowners receive small checks and notification that some of their property has been taken. Such a policy also leaves unresolved the disagreements between private groups over the use of the space. This is the case of DWWD-related property rights controversies. Others attending the conference felt the problem could be settled by imposing a restriction on that space which would be statutory in nature or that developers of underground space might bring challenge in the courts with greater frequency to achieve the same effect. The landowner's right to prevent use by others regardless of harm actually being done has been the subject of controversies concerning air space, mineral rights, and underground caves as well. It must be emphasized, however, that any argument based on analogy is somewhat fragile, and can be useful only for very general guidance.

## Underground Space as a Resource

The increased interest in the utilization of underground space for purposes of DWWD, undergrounding of utilities, various types of storage, commercial enterprises, habitation, as well as an intensification of the traditional uses of mineral and water extraction creates more than a one to one confrontation and often involves numerous individuals and groups of individuals further complicating the already obscure definition of subsurface property rights. Hopes of avoiding or resolving these conflicts hinge on alerting the public to the fact that the area often labeled as having little or no value is in fact a resource and as such requires a well developed public policy to guide its development and govern its use within an overall environmental waste management framework.

For many years resources were divorced from economic analysis. If they were considered at all it was only in so far as they were recognized through their effects on cost or price and supply or demand. Economically considered, resources were assumed to be completely absorbed into the market process without regard for misallocations and second party effects. (25) Pigou's definition of resources in 1920, is one of the term's earlier linkings with economics: "infinitesimal transferable units of land, labor, and capital subject to entrepreneurial control or disposition." (18)

A common misconception held concerning the topic is to identify resources with objects or tangible substances. One need only to think of coal, oil, or forests to realize the resource role objects play. Less obvious and much more intangible in appearance are such things as health, government, freedom, and human capital; often ignored, but just as important as their visible counterparts. The attention given the natural resources while ignoring the human aspect of resources blocks a complete understanding of their true nature and magnitude. Thinking of a resource as a single asset fails to account for the interrelated complex of forces, actions, institutions, policies, and substances which, in reality, explain the manner in which that particular asset in question functions as a resource at a given time and place. (25) Such rationale also creates the false impression of resources as being static rather than the dynamic, humanly-responsive phenomena they are.

Zimmerman brings out an additional misunderstanding of the term in the frequent failure to realize that for a resource to exist there must be a resistance or reaction working against its utilization. (25) Demands placed by individuals on the asset, which at a particular point in time occurs in a finite amount, create a resource. As such, the term has connotations of scarcity as parties vie for its use, or in certain extreme cases its disuse.

In view of these misconceptions, what a resource actually is becomes more evident. Resources infer value judgments by humans as they express wants or desires as means of attaining ends. Although there is a finite amount of a resource available at any particular point in time, the concept of a resource is a dynamic one changing with those human appraisals of wants and desires. An illustration of this point is the example of the Amazon Basin's rubber trees. The development of the vulcanization process created a use for the otherwise valueless, isolated rubber trees of the Amazon River Basin. Rubber producing firms competed for the right to utilize this resource in order to produce the highly demanded rubber products. The demand for the trees continued to increase until it was discovered that the tree could be produced much cheaper and made more accessible to the processors if the species were grown on plantations far removed from the Amazon River Basin. As a result, the transportation costs of securing these trees precluded their use, and the trees completed the cycle by once again becoming disattached from human appraisal. The point of this example is that the resource base is not fixed, but varies with changes in technology and the demands of society.

Zimmerman summarizes his search for an acceptable definition of resource by stating: "the word 'resource' does not refer to a thing or a substance but to a function which a thing or a substance may perform or to an operation in which it may take part, namely, the function or operation of attaining a given end such as satisfying a want." (25, p. 7)

Based on the criteria above, the subsurface area of certain localities must be considered a resource function. The qualification of "certain localities" is made because it is only in those areas where there exist demands by competing users for underground space that the definition holds. In these areas some degree of scarcity exists, and, as a result, individuals must assign values for its various uses to which it should be designated.

That underground space is a resource in certain instances has been established. It should be pointed out that this is not the only reason for developing a public policy concerning its use. There are potential hazards associated with underground space utilization which, in the public interest, demand regulatory controls to at least minimize, if not totally eliminate, their effects.

For example, in the case of DWWD, there are documented cases of well failure occurring. The Hammermill Paper Company in Erie, Pennsylvania, experienced well failure with one of its wells which resulted in the release into Lake Erie of 150,000 gallons of spent sulfite liquor per day for a three week period. (3) Another deep well at the Rocky Mountain Arsenal in Denver encountered problems as the pressure by which the wastes were injected forced open fissures in surrounding granite formations resulting in surface vibrations. (3)

It should be desired that the regulatory controls of the DWWD public policy not overemphasize the potential harms involved. If DWWD were totally prohibited, there would certainly be created opportunity costs to society in the form of non-use of a resource. Any regulations governing deep well use should be flexible enough to evaluate the potential risks on a case by case basis versus the potential benefits to be realized in using the method.

Since what constitutes a resource is a function of human values and technology, it is conceivable that natural materials having no present economic value might become useful in the future. Hence, it is difficult to predict the future role underground space will play as a resource. For example, brackish groundwater is currently being used to a very limited extent, however water shortages in certain areas coupled with advances in desalination technology may give such saline water positive economic significance. Recent trends suggest that the greatest demand for subsurface space will exist at the shallower depths. If this area should become used up, the increased demand may cause greater depths to be utilized. All of these factors point to a need for governing, guiding, and regulating underground space utilization.

## Cost Components of DWWD

To facilitate discussion of costs, the deep well disposal system can be divided into distinct sub-systems. The first of these is that of the treatment facility. Though some injection systems may require no pretreatment of wastes, this appears to be the exception rather than the rule as pretreatment generally results in a more problem free operation. When pretreatment is employed in a DWWD operation, it is utilized to a much lesser degree than in surface treatment alternatives. The primary objective of pretreatment is to remove suspended solids which may clog the injection tubing. In contrast, surface treatment facilities concentrate not only on suspended solids, but also on BOD, nitrogen, and phosphorous removal, as well as reducing effluent toxicity.

Cost components of the treatment facility involve such equipment as initial and final flow equalization basins as well as any physical and chemical treatment apparatus required to prepare the waste for injection. The degree to which these facilities are required are a function of the type of waste to be injected. As a result of the practically infinite waste possibilities with regard to composition and toxicity, any cost estimate of the treatment facility required is at best crude. A general idea of the components required in pretreatment is given in Figure 1, a shcematic inventory of a "typical" pretreatment facility treating the "typical" waste. Once again, prior to cost estimating this facility, engineering decisions are necessary with regard to the size of the equipment. These decisions are based upon desired throughput capacity, fluid retention time, chemical reaction time, and such related factors, all of which are a function of the complexity and variability of the waste.

A second distinct sub-system of a DWWD plan is that of the pumping element. Very few wells operate simply by the force of gravity, and therefore employ artificial pressure in the form of pumps. The pumps drive the well at pressures ranging from a hundred to several thousand pounds per square inch. The primary cost component of this sub-process is the pump itself with minor related equipment furnishing the remainder of the expense. The cost of the injection pumps is based

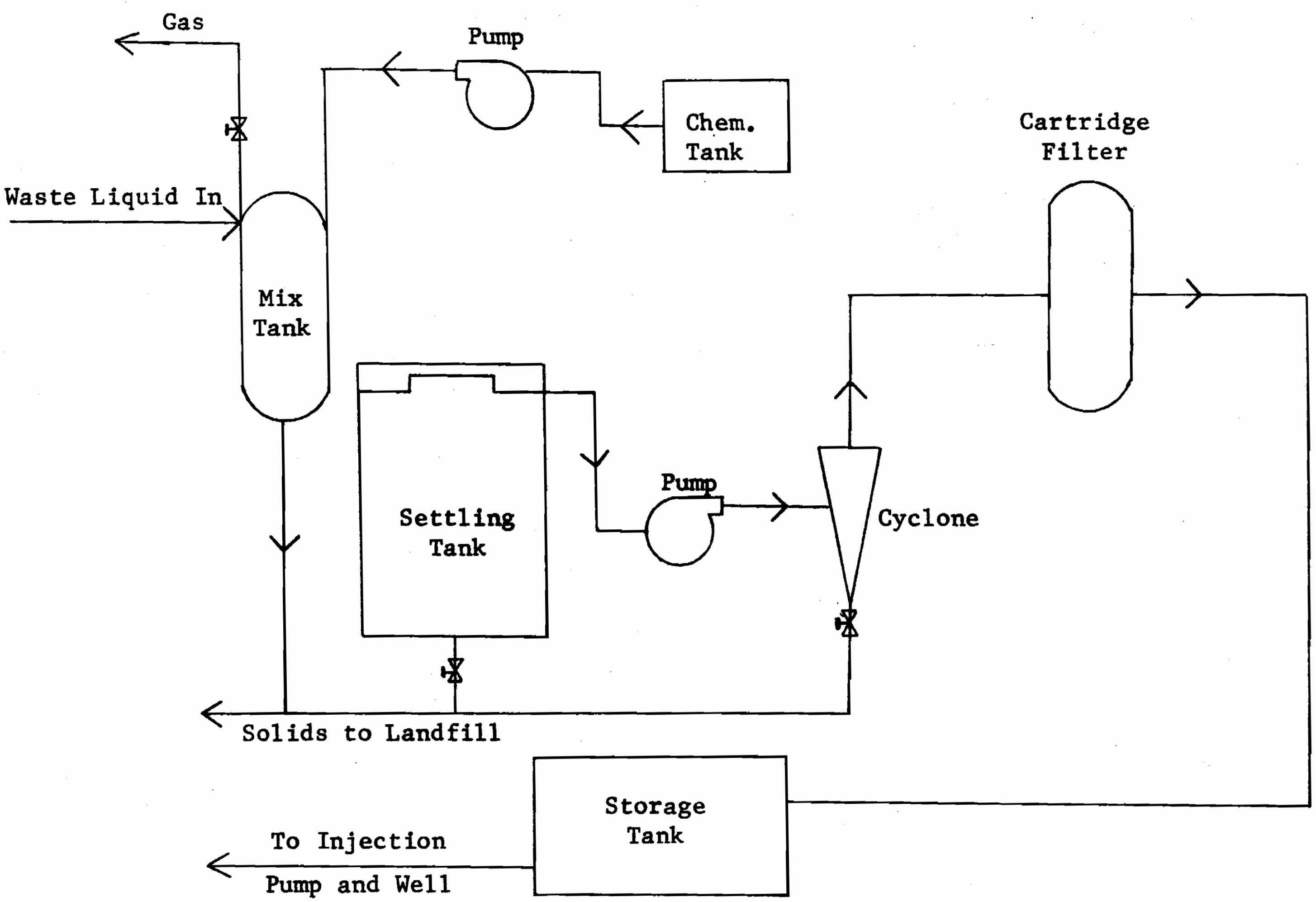

Figure 1. Schematic Diagram of a "Typical" Pretreatment Facility.

Source: David M. Grubbs and Charles D. Haynes, Design and Cost of Liquid-Waste Disposal Systems, Report 692, (University of Alabama: Natural Resources Center, December 1969), p. 8.

on the desired horsepower which in turn is a function of the required operating pressure. The cost of operation is directly related to the cost of electrical power as dictated by the energy requirements.

The distribution phase of the DWWD operation is simply a centralized pumping facility and a high pressure delivery system which carries the waste to the wellheads. Related items to be considered as costs in this category include pipe cost, right-of-way cost, and cost of installation.

The deep well itself can be categorized as a separate system and is defined as the apparatus which transports the waste from the surface to the reservoir disposal zone. It is a very complex structure having numerous individual cost components. The first and major expense involved in this category is that of drilling costs. Down hole component cost including that of drilling are a function of desired well diameter. Other components of the well apparatus include the wellhead and its connections and valvings, plastic preventive lining for the injection conduit, injectivity tests, and others. Figure 2 is helpful in concepualizing these components and the deep well itself.

Closely related to the well is the cost associated with the disposal zone. Energy requirements to disperse the desired waste flow into the injection stratum is the major financial outlay involved here. This cost is more of an operating cost to be incurred over the life of the well's operation than an initial capital investment, and hence leads to a second major grouping of DWWD costs, operation and maintenance fees. These costs include in addition to energy cost requirements, labor costs, workover expenses, and interest on working capital.

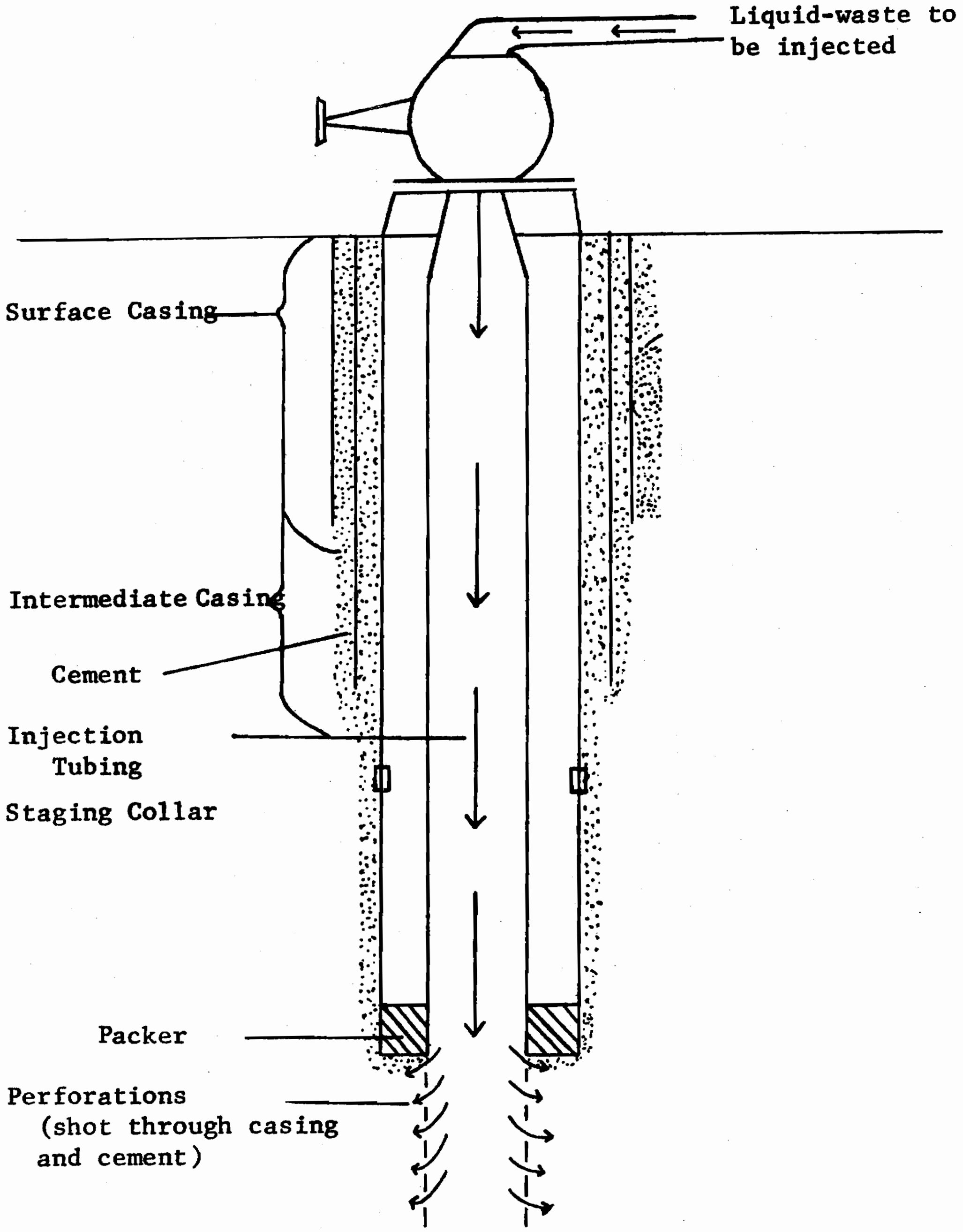

Figure 2. Schematic Diagram of a Deep Well.

Source: Adapted from Albert Bradford and David M. Evans, "Under the Rug," <u>Environment</u> 11, (October 1969), p. 6.

Just as the characteristics of the waste stream determine the degree of treatment and sizing of well equipment, the operating costs are also a function of that waste stream. Table 1 illustrates the cost responses of operating and capital cost for various operating procedures, specifically flow rate and operating pressure. Operating costs are referred to as unit costs in Table 1, and in this example include annual operation costs, maintenance costs, workover expenses, labor costs, power costs, and interest in the working capital.

A major operating expense not mentioned above is that incurred when a well monitoring program is employed. In many cases a strict monitoring program is required by the regulatory agency in charge to prevent damage to adjacent underground resources and to assure the public that the well is functioning safely and effectively. Though the equipment required for DWWD monitoring is more technologically advanced and expensive than that required for surface treatment, monitoring a DWWD installation has some importance economic implications which must not be ignored.

Since environmentally safe operation is so safely tied to effective well operation, DWWD manages to shift the responsibility as well as the cost of monitoring from the public agency to the private firm. For example, to insure equal compliance between a deep well user and a firm employing surface treatment and subsequent surface discharge in meeting pollution standards, the regulatory body would be much more burdened in keeping the surface discharger within the limits of the law. A spot check of effluent discharge must suffice in most cases of surface disposal thus leaving much time for the firm to adjust pollu-

## TABLE 1

## SUMMARY OF CAPITAL AND OPERATING COSTS FOR A SINGLE INJECTION WELL

| Flow Rate gallons/day | Operating Pressure (psi) | Capital Cost ($1000) | Unit Cost ($/1000 gallons) |
|---|---|---|---|
| 100,000 | 0 | 195.7 | 0.847 |
| | 200 | 197.3 | 0.858 |
| | 400 | 198.1 | 0.870 |
| | 600 | 198.9 | 0.881 |
| | 800 | 199.7 | 0.892 |
| | 1000 | 200.3 | 0.902 |
| | 1200 | 200.9 | 0.913 |
| | 1400 | 201.5 | 0.924 |
| 200,000 | 0 | 204.7 | 0.521 |
| | 200 | 207.1 | 0.532 |
| | 400 | 208.7 | 0.543 |
| | 600 | 209.9 | 0.554 |
| | 800 | 211.1 | 0.565 |
| | 1000 | 212.3 | 0.574 |
| | 1200 | 213.4 | 0.586 |
| | 1400 | 214.4 | 0.596 |
| 400,000 | 0 | 215.6 | 0.340 |
| | 200 | 219.5 | 0.351 |
| | 400 | 220.0 | 0.362 |
| | 600 | 224.2 | 0.373 |
| | 800 | 226.3 | 0.383 |
| | 1000 | 228.2 | 0.393 |
| | 1200 | 230.4 | 0.404 |
| | 1400 | 232.8 | 0.414 |
| 600,000 | 0 | 220.9 | 0.271 |
| | 200 | 228.3 | 0.283 |
| | 400 | 231.6 | 0.294 |
| | 600 | 234.7 | 0.304 |
| | 800 | 237.9 | 0.315 |
| | 1000 | 241.4 | 0.325 |
| | 1200 | 244.8 | 0.336 |
| | 1400 | 248.3 | 0.346 |
| 800,000 | 0 | 226.8 | 0.232 |
| | 200 | 235.6 | 0.244 |
| | 400 | 239.6 | 0.254 |
| | 600 | 243.7 | 0.265 |

TABLE 1.--Continued

| Flow Rate gallons/day | Operating Pressure (psi) | Capital Cost ($1000) | Unit Cost ($/1000 gallons) |
|---|---|---|---|
| | 800 | 248.4 | 0.275 |
| | 1000 | 253.0 | 0.286 |
| | 1200 | 257.5 | 0.296 |
| | 1400 | 261.9 | 0.307 |
| 1,000,000 | 0 | 231.7 | 0.207 |
| | 200 | 241.3 | 0.219 |
| | 400 | 246.4 | 0.229 |
| | 600 | 252.2 | 0.240 |
| | 800 | 257.9 | 0.250 |
| | 1000 | 263.5 | 0.261 |
| | 1200 | 269.0 | 0.271 |
| | 1400 | 274.3 | 0.282 |

Source: Joseph F. Malina, Jr. and Joe C. Moseley, III, "The Cost of Injection Wells for Industrial Waste Disposal," Proceedings of the 26th Industrial Waste Conference, May 4, 5, and 6, 1971, Part II, Engineering Extension Series No. 140, (Purdue University), p. 1057.

tion releases to periods of non-enforcement. Conversely, DWWD makes "cheating" more difficult since the granting of a disposal well permit by a regulatory agency also, in effect, approves or stipulates the well's limitations such as operating pressure and injection rate. Then, to assure continued smooth well operation, the firm itself must keep a close check on the well's functioning. Monitoring is self imposed. These implications of well monitoring do create a direct cost to the firm; but at the same time are visually offset by social benefits, although not realized by the cost bearer, accruing in the form of less expensive enforcement of the law. Perhaps this may be one of the determinants of society encouraging or rejecting this method of waste management.

A firm involved in the selection of a waste management objective must consider yet another category of costs where DWWD is concerned. These are a group of indirect costs a firm faces in which no tangible DWWD equipment is involved. Entailed are such costs as those incurred during the permit obtaining process, possible legal actions brought by adjacent landowners, or possibly higher insurance premiums resulting from employing a system subject to a higher degree of risk with regard to its safe operation than the previously employed system.

All of these cost categories must be taken into account by the private firm if an accurate cost comparison is to be made, and a subsequent waste management choice is to be made. The life expectancy of the proposed project must also be considered in weighing alternatives. The time of replacement is essential in determining the pay out period of a proposed waste management scheme. It is conceivable that DWWD could gain a cost advantage in this regard. Barring strict enforcement of subsurface environmental quality standards, ideal geologic conditions could permit extremely long injection resulting in a very long pay out period. The issue of whether the use of deep well waste disposal is economically cheapter than surface alternatives must avoid broad generalizations, however, and be determined on a case by case basis.

## Social Costs and Benefits

The evidence suggests, to date, that where an economic analysis has been employed either by the firm desiring to employ DWWD or the public agency granting DWWD permits, considerations have been limited to the narrowly defined direct costs incurred by a firm as discussed in the previous section. It is evident that knowledge of the direct costs and benefits to the individual firm of using deep well waste disposal rather than alternative surface waste disposal systems is rather meager. This is a direct result of the novelty of DWWD as well as the industry's reluctance to releast cost data. By comparison, however, the questions regarding the nature, magnitude, and distribution of indirect costs and benefits from a societal view have seldom been raised.

Societal effects arise out of the inefficiencies of the market system. One person's behavior results in a cost or a benefit to others while the creator of the cost is not forced to pay for it nor is the creator of the benefit completely rewarded for it. (1) The market simply fails to account for these social costs and social benefits, hence they exist externally to the firm's decision making activity. If, in fact, DWWD is a feasible utilization of the underground space resource, then these effects must be considered along with the well defined direct costs. A just public policy concerning DWWD in terms of optimal social welfare can then be developed, and subsequently this policy can evolve into the private firm's decision making process.

For instance, it may be that a firm which switches from surface waste disposal to DWWD will create benefits to other surface users, even though this may not enter into his decision to use DWWD. External benefits created are incidental to him. If significant benefits are created in this process, however, it might be deemed socially desirable to encourage DWWD. Numerous policy alternatives are possible under such circumstances such as publicly subsidizing the users of DWWD or barring the use of other alternatives.

Conceive of the situation where a high volume water consuming industry utilizes the local river as a dumping grounds of its effluent. The local citizenry decides to pressure the firm to clean up its operation; and after exploring possible alternatives, the firm settles on DWWD as the "best" solution to its problem. Now, several months after the deep well has become operative, a noticeable improvement in the river's water quality is apparent. The city further decides to open a municipal marina, permit fishing, and operate a swimming beach on the once stench ridden waters. Furthermore, the local firm's corporation partner, located 50 miles downstreat indicates that its waste disposal costs have been sharply reduced. As a result of the local firm no longer releasing effluent into the river, the stream's assimilative capacity has increased to the point of permitting the downstream user to dump effluent of much lesser treatment, but yet remain below the stream standards. These benefits were created because of the industry's decision to use DWWD, but in all probability they did not enter into that decision. These benefits are rather abstract in nature and as such difficult to measure. Attempts to quantify them requires considerable information on economic, social, and physical factors of the situation being debated.

Another hypothetical example might be useful in illustrating these issues of social costs and benefits. Let us assume an industrial firm produces chemical waste which can be discharged into surface water after receiving high level treatment. A certain amount of pollutants remain after treatment and is permissible according to established water quality standards. If it so happens that DWWD, with some degree of pretreatment, is acceptable to the relevant regulatory agency, the firm may wish to consider this method. Next, assume an economic analysis of costs of alternative disposal systems shows DWWD to be slightly less expensive than the next best surface disposal alternative. Other things equal, we assume he will choose the subsurface disposal method and thereby minimize his direct costs of waste disposal. The pertinent question now becomes: have all costs and benefits entered into this decision? If not, why not and what type of losses and gains have been omitted?

As is true in many environmental quality considerations, there appears to be no automatic method of insuring that all costs and benefits are taken into account. This may result from the fact that while the market system works quite well in allocating private goods, in most situations, under existing institutional arrangements, it is not adequate to take account of all environmental damages or benefits. As a result of this lack of compensation characteristic, the entrepreneur may have no incentive to favorably affect social welfare by either creating public benefits or reducing public damages. Although they are far from perfect and have been soundly criticized on a number of grounds, quality standards are an attempt to narrow the divergence between private and public benefits and costs.

On the other hand, there are, at least potentially, social costs involved in using DWWD. Identification of DWWD related social costs are limited by our knowledge of exactly what eventually happens to the injected wastes and its effect on the underground materials and by the unforeseen future demand for underground space by other users. There are, however, some potential social costs which are obvious and cannot be ignored. From a natural resource point of view, possible negative implications (social costs) of using underground space for waste disposal are: (a) foreclosure of future opportunities for the extraction of minerals, (b) preventing development of subsurface reservoirs for fresh water or gas storage, (c) effects on potential utilization of brackish water, (d) contamination of potable groundwater resources, and (e) effected surface water uses as a result of reduced streamflow.

The existence of these unaccounted for damages and benefits emphasizes the inefficiencies of the market system in allocating the use of resources. It has been argued that the social costs and benefits cannot be considered in monetary terms, the market's unit of measurement, because they are at best vague and unquantifiable. Counter arguments claim nothing is unquantifiable, but rather the problem is one of inexperience in dealing with them. Underlying the issue of quantifying social effects is the matter of property and property rights. Prior to attaching dollar values to these effects, it must be determined specifically who is effected and to what extent, who owns the space, who is liable and to what extent for damages, and the cost of recovering damages. Such criteria is often site specific; varying widely among localities as it is determined in legal deliberations.

Assuming that these factors are determinable, one method available to arrive at magnitudes of the social costs and benefits involved in a particular case is to employ the opportunity cost concept of the resource(s) in question. The opportunity cost concept is defined as the social value foregone by moving the resource from one activity into an alternative use. (15) For example, in the case of recreational use of surface water, an industry releasing permissible levels of effluent into surface waters may be diminishing the resource's usefulness by discouraging numerous water based recreational activities. The firm has created an opportunity cost manifested in society's search for substitutable activities such as the cost of a two week Carribean cruise to remove ones annual water based recreational urge. Likewise, if a substantial water quality improvement is realized by discontinuing effluent discharge into surface waters, employing DWWD would create opportunity "gains." Foregone recreational uses could take place when the water quality improvement would be sufficient to permit such uses. The latter possibility has, in fact, been realized.

An EPA composed Environmental Impact Statement concerning methods of treated wastewater disposal says of DWWD: "diversion of wastewaters from surface water to deep wells will substantially and immediately improve the quality of those surface waters and will contribute to the long-term enhancement of surface water quality." (20, p. 13)

Employing this type of analysis permits one to arrive at a net social benefit, either positive or negative, which in conjunction with the direct cost of employing a specific DWWD plan permits a rational decision to result. Such information would also be valuable to public interest oriented regulatory agencies some of which, to date, have approved DWWD as a temporary last resort if no other method is feasible. The latter philosophy suggests an almost infinite value be placed on the preservation of a resource, underground space. Undoubtedly, there are few, if any, resource uses upon which we would place an almost infinite value. Infinitely valuing the preservation of a resource fails to consider the social cost of its "non-use."

Regardless of the method chosen to deal with social effects, the quantification process is in need of refinement. Proponents of the opportunity cost theory feel that a "willingness to pay" scheme can be implemented to achieve the actual dollar figure being sought. The characteristics of the services in question, however, cause individuals to understate their true personal value. Since the service can be shared by one more person at no additional cost, the individual may elect to give no value to the service when interviewed. He is then able to participate, if the activity is offered, at no personal expense--a "free rider."

Economically speaking, this is the primary characteristic of a collective good. Because the use of these goods or services by an individual does not preclude their use by others, their aggregate demand must be arrived at by vertically, rather than horizontally, summing the individual demand curves. The area under the total demand curve then represents the total benefits to be accrued as a result of the good. Conversely, the total cost curve of a collective good is a horizontal line, the costs are constant regardless of the number of users. In the case of a pure collective good, an economic efficiency evaluation can then be made concerning the decision of whether or not to offer it for consumption. If the benefit to cost ratio exceeds one, then the good should be offered for consumption; if not, it should not be offered.

Although DWWD is primarily a private good, the theory of collective goods still has some pertinent implications concerning it. For example, if the benefits of the public goods created via DWWD exceed the costs of the public disbenefits, then it may be desirable to encourage deep well use by subsidizing the firm in some way. However, since the marginal cost of supplying a collective good is zero, it follows that the price charged for realizing the benefits should be zero. This will allow the consumer to use the good to the fullest extent possible. A means of solving this dilemma would be to implement a taxing scheme whereby payment would not effect the amount of the good or service consumed. (1)

Problems in dealing with social costs and benefits are extremely complex. Nevertheless, from a social welfare standpoint and a subsequent economically efficient allocation of resource usage, they must be accounted for; even if a mere mentioning of their existence is all that is deemed possible. Perhaps the initial step to be taken in persuading the private firm to consider social costs and benefits in its decision making process would be to incorporate an economic efficiency aspect into the regulatory agency's permit granting procedure. If a firm must show that its selection of a waste management plan is an economically efficient one in terms of both direct and indirect costs and gains, then no doubt the second part effects will become internalized in the firm's operation. The Environmental Protection Agency's proposed amendments to the Federal Water Pollution Control Act requiring a cost effectiveness analysis on waste treatment management systems is a step in this direction. One pertinent section of the proposed amendments is:

> f. Cost-Effective Analysis Procedures. (1) Method of Analysis. The resources costs shall be evaluated through the use of opportunity costs. For those resources that can be expressed in monetary terms, the interest (discount) rate established in section (f) (5) will be used. Monetary costs shall be calculated in terms of present worth values or equivalent annual values over the planning period as defined in section (f) (2). Non-monetary factors (e.g., social and environmental) shall be accounted for descriptively in the analysis in order to determine their significance and impact.
>
> The most effective alternative shall be the waste treatment management system determined from the analysis to have the lowest present worth and/or equivalent annual value without overriding adverse non-monetary costs and to realize at least identical minimum benefits in terms of applicable Federal, State, and local standards for effluent quality, water quality, water reuse and/or land and subsurface disposal. (8, p. 17736)

Care must be taken by regulatory agencies in dealing with societal effects with particular regard to their distribution implications.

Knowledge of the specific segment of society being effected either directly or indirectly is essential not only for an economically efficient decision with regard to resource use, but also for assuring an equitable allocation. Failure to involve a sizable enough geographical area in the analysis may result in an omission of some of the gains and losses. Such a tendency strongly encourages a regional environmental management framework as a basis for evaluating deep well waste disposal system proposals.

# CHAPTER IV

## REVIEW OF EXISTING OPERATIONS AND POTENTIAL FOR EXPANSION OF DWWD USE

Chapter IV is concerned with discussing the economics of industrial and municipal use of deep well waste disposal, specifically the direct capital requirement for installing and operating the system. A firm faced with altering its waste management practices to either align its operation with environmental regulations or perhaps reduce its production costs turns to an economic analysis as means of evaluating alternative courses of action. Likewise, the cost effectiveness analysis to be implemented on the selection and development of any waste treatment management system which will receive Federal funding, as required by the Federal Water Pollution Control Act Amendments of 1972, points to the increased importance to public agencies of an economic evaluation. This chapter focuses on two methods of arriving at a dollar figure cost for a proposed DWWD system: (a) through the employment of cost models, and (b) by estimating the cost on the basis of data obtained from wells already in operation. Attempts are also made in this chapter to place operating costs of DWWD in perspective with regard to other methods. Finally, the industrial potential for DWWD use in the Mid and South Atlantic states is investigated.

## Economics of Industrial DWWD Users

The Federal Water Quality Administration estimated, in 1968, that an annual investment of a third of a billion dollars would be necessary to meet the minimum water quality standards of that year. The primary iron and steel industry alone realized expenditures of $115 million in 1969, while the overall industrial capital outlay for pollution control equipment increased 36.1 percent from 1968 to 1969. (12)

A survey conducted by The Conference Board RECORD concerning capital investment in pollution control facilities in 17 manufacturing firms yields equally significant findings. Of particular interest is Table 2. As expected, there appears to be a direct correlation between the size of the company by total assets and expenditures for pollution control facilities. More important, however, is the column indicating percentage change from 1968 to 69 and 1969 to 70. The accompanying data show that the smaller asset sized firms, classes I, II, and III, are experiencing the greatest financial effects, with respect to their ability to pay, in meeting either new environmental quality laws, increased citizen and governmental pressure, or a greater social responsibility. Regardless of the reason for these sizable increases in capital outlays, the smaller scale firm facing such sudden rises in its production costs may be forced out of existence.

These firms are in need of accurate economic data in order to evaluate the various alternatives confronting it. Where DWWD is an alternative, one method of arriving at a dollar figure cost for a proposed system is through the use of models designed for that specific

### TABLE 2

### CAPITAL EXPENDITURES FOR POLLUTION CONTROL BY ASSET SIZE 1968, 1969, 1970

| Asset Size Class | Number of Companies 1968 | 1969 | 1970 | % Change 68-69 | % Change 69-70 |
|---|---|---|---|---|---|
| I. ($10-$50 million) | 21 | 25 | 28 | 19.0 | 12.0 |
| II. ($50-$100 million) | 38 | 43 | 44 | 13.2 | 2.3 |
| III. ($100-$250 million) | 61 | 66 | 76 | 8.2 | 15.2 |
| IV. ($250 million-$1 billion) | 75 | 83 | 89 | 10.7 | 7.2 |
| V. ($1 billion & over) | 33 | 34 | 34 | 3.0 | 0 |
| Total | 228 | 251 | 271 | 10.1 | 8.0 |

Source: Leonard Lund, "Industry's Current Pollution Control Costs," The Conference Board RECORD, (April 1971), p. 40.

TABLE 2--Continued

| Asset Size Class | | Expenditures (In $000's | | | % Change 68-69 | % Change 69-70 |
|---|---|---|---|---|---|---|
| | | 1968 Actual | 1969 Actual | 1970 Anticipated | | |
| I. | ($10-$50 million) | $ 1,476 | $ 3,005 | $ 3,057 | 103.6 | 1.7 |
| II. | ($50-$100 million) | 3,867 | 6,321 | 12,733 | 63.5 | 101.4 |
| III. | ($100-$250 million) | 9,887 | 25,502 | 65,025 | 157.9 | 155.0 |
| IV. | ($250 million-$1 billion) | 86,347 | 129,258 | 138,982 | 49.7 | 7.5 |
| V. | ($1 billion & over) | 187,908 | 229,928 | 267,382 | 22.4 | 16.3 |
| | Total | 289,485 | 394,014 | 487,179 | 36.1 | 23.6 |

Source: Leonard Lund, "Industry's Current Pollution Control Costs," The Conference Board RECORD, (April 1971), p. 40.

purpose. These models attempt to predict the total cost as well as operating costs of a DWWD installation given certain engineering, geological, and economic factors. Two of the most prominent models are Design and Cost of Liquid-Waste Disposal Systems, referred to as the Alabama study, by Charles D. Haynes and David M. Grubbs, and Relationships Between Selected Physical Parameters and Cost Responses for the Deep-Well Disposal of Aqueous Industrial Wastes, more commonly known as the Texas model, by Joe C. Moseley, III and Joseph F. Malina, Jr. (9, 13)

The Alabama study developed data by considering three basic topics. First, the physical and engineering limitations in the design of the entire system including pretreatment are considered. The assumption is made that DWWD is an ultimate disposal, and as such, any pretreatment of the wastes should be much less complex than a corresponding facility for surface treatment alone. Haynes and Grubbs point out that this aspect is a dominant economic factor in the concept of deep well waste disposal. The second topic occupies the greatest part of the discussion and deals specifically with the capital investments of the treatment plant, the pipeline from the plant to the wellhead, and the well itself. Cost data are furnished in the form of two dimensional graphs from which the cost of each component (by size) can be obtained. The costs of all components can then be summed to arrive at an estimate of the investment for the entire system. The model presents the treatment plant as entailing very few variables, simple in concept, with the operation and maintenance cost being a function of the volume of waste treated, the size of suspended solids to be removed, the corresponding power requirements, and volume of chemicals used. The volume of the waste treated also serves to determine the cost of the pipeline. The concept of disposal well cost becomes somewhat complicated as numerous variables with respect to the geology of the area and the characteristics of the firm enter into consideration. The study bases well costs on such factors as well depth, physical properties of the disposal stratum, mechanical limitations of the well design and equipment, and management decisions related to the well itself. The Alabama study is concluded with the development of a computer program which permits a high degree of flexibility in designing and estimating the cost of DWWD systems. Even though the costs in the program have been developed with regard to the geology of Alabama, it is applicable to any area by simply modifying the costs pertaining to drilling costs for any location. If the firm employing this computer program is aware of the specific volume of waste and its chemical qualities, the program will determine by a process of trial and error the physical parameters required of the disposal zone. In this way a feasibility study may be made in a matter of minutes for a particular geologic or geographic locality.

Mosely and Malina's Texas model applies oild field data obtained thru experience towards the development of DWWD-related costs. Since historical cost data were used, the Building Cost Index was employed to adjust the figures for the impact of inflation. As the title implies, the objective of the Texas model was the development and presentation of data dealing with quantitative relationships between physical parameters and costs responses for the deep-well disposal of liquid industrial wastes. However, because of the lack of correlation with actual industrial injection wells, certain limitations of the model must be realized. These limitations are: (a) the physical characteristics of the model well are based on one particular design; however, well design may vary widely in actual practice, (b) many "idealizing" assumptions concerning the geologic characteristics of the disposal reservoir must be made, (c) the costs of specific components may be lacking, (d) the test cases were based on many assumptions and many parameters were held constant for the test, (e) most of the results are presented in typical two dimensional plots, but one must remember that there are many interrelationships not expressed in this type of plot, and (f) no attempt has been made to directly correlate the cost responses generated with those of actual operating wells. (13, pp. 4-5)

A major difference in the Alabama study and the Texas model is the latter's dealing with the pretreatment facilities. Moseley and Malina do not attempt to estimate the cost of pretreatment as they feel that due to the complex nature and wide variability of wastes, as well as the variable geologic conditions, any prediction of the necessary pretreatment scheme is impossible without some specific knowledge of the waste and the receiving formation. Hence, any attempt to estimate the cost of such an operation would be at best a very rought and possibly misleading effort.

The following conclusions adequately summarizes the findings of the Texas model: (13, pp. 157-159)

1. The technological skills necessary to design, install, and operate deep-well disposal systems have been developed by the petroleum production industry. Experience and knowledge gained from the design and operation of waterflood systems and brine disposal wells are particularly applicable.

2. Approximations of the costs of this disposal may be made by extrapolating economic data from the oil industry and combining it with other available information. Values obtained by this method show reasonable agreement with cost figures for industrial wastewater injection operations which have appeared in the literature.

3. Sufficient differences exist in the physical systems used and in the economics involved between production of petroleum and the deep-well disposal of liquid industrial wastes to justify further investigation of the problems involved.

4. The minimum unit cost of deep-well injection appears to be 0.25 dollars to 0.40 dollars per thousand gallons of waste. These figures include amortization of the initial capital investment and minimum preinjection treatment expense.

5. The capital cost of such systems appears to vary from 0.30 dollars per thousand gallons per day for a 10 million gallons per day system to over 2.00 dollars per thousand gallons per day for a 0.10 million gallons per day system.

6. The cost of the pre-injection treatment required to insure compatibility between the waste and the formation fluids may increase the cost of the operation considerably. It may vary widely, depending on the particular combination of waste and reservoir; hence, it is impossible to predict this cost to any degree of accuracy without specific knowledge of the fluid and formation.

7. Formation parameters including permeability, porosity, and effective height determine if a given stratum will accept enough to make it acceptable as a disposal zone. The formation properties dictate the number of wells of a given design that are required to handle the waste.

8. The physical design variables which exert the most influence on disposal costs are casinghead operating pressure, well diameter, and injection rate.

9. It is possible to develop certain relationships between variables which could be very useful in determining the optimum design for such a system. That is, mathematical analysis, namely the techniques of operations research may be readily applied to models of this nature.

10. The results developed in this study are intended only to establish the general relationships between the variables involved. In this sense, they are "relatively" quantitative rather than "absolutely" quantitative, and certain assumptions made in this study merit reevaluation. The basic model used in this study should be correlated with field data on operating wells, and certain background data should be closely examined.

If the assumptions and resultant model limitations are kept in mind throughout the analysis, beneficial cost estimates may be made. It appears DWWD simulation models can furnish reliable predictions to decision making units. These models also avoid the problem of uncooperativeness in furnishing cost data on the part of the existing well operators, a problem often encountered in the second method of cost estimation discussed next.

The cost of a proposed DWWD installation may also be derived by employing data obtained from wells already in operation. This type of ex post faco analysis estimates the cost of the proposed deep well by adjusting previous cost figures given such factors as desired well size, type of waste to be injected, and disposal stratum characteristics. Problems arise in attempting this type of estimation from the numerous variables requiring adjustment, the high degree of reluctance of the private firm to furnish cost data, and the relatively few injection wells in operation upon which such estimates could be based. In the process of conducting a survey of firms employing DWWD, questionnaire response to actual monetary inquiries was very limited to the point of being nonexistent in most cases. (24) Even though the questionnaire assured that any data furnished would be used in the strictest confidence, the usual reason for the firm's refusal was that such production information could not be divulged. When a firm did provide a dollar figure response, the amount was in such gross form and in total disregard of questionnaire detail that it was of very little value. For example, the figure of $200,000 for the financing of a DWWD operation fails to say whether that amount is the initial capital investment, annual operating expense, cost of the complete system or merely one of its components. Consulting engineering firms, often involved in DWWD feasibility studies, also prefer not to divulge specific cost data; electing to protect the business-client relationship. This situation is remedied somewhat when firms receiving governments' funds for the construction of waste treatment facilities are contacted. These firms are required to make public vouchers of all related purchases and services where matching funds are involved. Unfortunately, the frequency of Federally funded DWWD projects is not great enough to confidently estimate the cost of proposed systems.

Employing this method of estimation also encounters the problem of costs for a pretreatment facility. The cost of pretreatment is dependent upon (a) the pH of the waste, (b) the tendency of the waste to form precipitates at some pH ranges, (c) the size and amounts of suspended solids, (d) the corrosiveness of the waste, and (e) the physical and chemical characteristics of the disposal formation. Therefore, if an accurate estimate of the surface equipment is to take place, site specific geologic data and an analysis of the waste are required. Likewise, the completion costs of the well are directly related to the desired well depth. Complications arise here as not only the cost per foot rises with the depth of the well, but also drilling and completion rates vary throughout the nation. (13)

The basis for attempting to estimate the cost of a proposed injection well system, that being a cost comparison, may be destroyed if a firm decides to install an injection well and yet employ previously existing surface treatment facilities. Such behavior would obviously erase the need for a cost comparison as the original practice would be the least cost alternative. Such action is taken to either align the operation with future environmental standards or to avoid their effect.

The economic data concerning initial investment and operating cost of industrial deep wells are at best sketchy. Likewise, cost comparison with DWWD as an alternative are not all-conclusive in pointing to one method as "the least cost alternative." Nevertheless, the cost data that are available together with the social cost and benefit implications brought out in Chapter III are helpful in economically placing DWWD in perspective as a liquid waste management alternative.

Erle C. Donaldson, in conjunction with the U. S. Department of Interior's Bureau of Mines, surveyed fifteen companies operating DWWD systems in 1964, compiling his results in <u>Subsurface Disposal of Industrial Wastes in the United States</u>. (23) Donaldson found cost information available on 8 of the 15 wells with the total cost of the system the only economic data being supplied. These costs ranged from

$30,000 where no surface equipment was required to $1,400,000 for a 12,000 feet well with a very extensive pretreatment facility. (23) The author generalizes a typical budget of an injection system in Table 3 for given favorable physical conditions and the accompanying engineering specifications.

An iron processing firm in the Midwest faced with industrial acid sludge accumulation made the switch to DWWD in 1965. In this case study, deep well disposal has been credited with reducing sludge accumulation by 70 percent. (10) Table 4 provides an operating cost comparison (dollars/month) between DWWD and the previously used lime neutralization facilities. It should be noticed that the large difference in labor costs is due to the highly automated nature of the injection system. In general, the waste injection wells require only the part-time attention of plant operators to keep track of their operating efficiency. The labor required by the deep well primarily involves the repair and maintenance of acid piping, pumps, filters, valves, and other items. Also, in this particular cost comparison, nothing is shown to credit the well with savings in land use, so essential to sludge disposal. Data from Table 4 indicate the annual operating cost for surface treatment to be $395,664 while the DWWD value is $62,184, a $333,480 difference in favor of the latter.

The capital cost of a DWWD system, in certain cases, greatly exceeds the outlay required for surface facilities. These differences often times, however, are more than compensated by deep well waste disposal's lower operating expenses. In one instance, the capital investment required for a deep well was $160,000 greater than a comparable

TABLE 3

"TYPICAL" BUDGET OF AN INJECTION WELL GIVEN CERTAIN ENGINEERING SPECIFICATIONS

| Well Characteristics and Components | Engineering Specifications and Costs |
|---|---|
| Well Specifications: | |
| Depth of well | 3,000 feet |
| Surface casing, 200 feet | 10½ inch (outside diameter) |
| Injection casing, 3,000 feet | 7 inch (outside diameter) |
| Tubing, 3,000 feet | 2-2/3 inch (outside diameter) |
| Completion method | Casing perforations at disposal zone |
| Capital Costs: | |
| Drilling costs: Drilling of hole, drilling mud, coring, cementing, perforating, logging, drill stem test, and well stimulation | $ 30,000 |
| Materials: Surface casing, injection casing, tubing, and wellhead | 20,000 |
| Testing: Analysis of waste, core, and brine; injectivity surveys | 5,000 |
| Engineering and consulting | 15,000 |
| Surface equipment | 125,000 |
| Monitor well - 1,000 feet deep | 5,000 |
| Total | $200,000 |

Source: United States Department of the Interior, Bureau of Mines, Subsurface Disposal of Industrial Wastes in the United States, Info. Cir. 8212, p. 9.

## TABLE 4

## COMPARATIVE OPERATING COSTS FOR WASTE-ACID DISPOSAL OF TWO SYSTEMS

| Item | Method | |
|---|---|---|
| | Neutralization | Deep-Well |
| | -----dollars per month------ | |
| Labor (including benefits) | 3,214 | 875 |
| Repair and Maintenance | 10,807 | 2,312 |
| Utilities (electricity, steam, water) | 4,654 | 600 |
| Lime | 9,295 | 0 |
| Supplies | 910 | 197 |
| Services | 832 | 291 |
| Technical and Administrative | 3,260 | 907 |
| Total | 32,972 | 5,182 |

Source: Adapted from C. D. Hartman, "Deep-well Disposal of Steel Mill Waste," Journal of Water Pollution Control Federation, Vol. 40 (January 1968), p. 100.

surface installation, but the well operated at an annual cost of $126,000 less. (7) Tables 5 and 6 illustrates the wide variability in costs of different deep well waste disposal systems. The data presented in Table 5 is from a well drilled in 1960, in New Mexico. The total cost of $562,000 includes the cost for well completion of $260,400. Conversely, a 1969 completed well in Amarillo, Texas, shows a capital requirement of $149,796 (Table 6). Although it is not certain what causes this difference, it could be attributable to such things as differences in injection rates, well depths, or drilling site costs. Once again, the difficulty of cost estimation without a thorough analysis of local variables is apparent.

What little industrial DWWD cost data are available does seem to indicate that there is a cost advantage to those presently employing an injection well system. In light of the recent "energy awareness" the relatively smaller operating cost of DWWD may cast the method into an even more important role as a waste management possibility. The evidence should not be taken, however, as all-conclusive in suggesting that DWWD is "the best" alternative in solving liquid waste problems. Broad generalizations favoring it in every decision making process where it is involved must be avoided. Specific site analysis is essential before any meaningful conclusions can be made.

## Economics of Municipal DWWD Users

Deep well waste disposal is rapidly gaining popularity in certain regions as a means of disposing treated municipal wastes. As regulatory agencies demand more complete removal of certain wastewater com-

TABLE 5

DETAILS OF COSTS FOR AN INJECTION SYSTEM CONSTRUCTED IN NEW MEXICO IN 1960

| Item | Cost |
|---|---|
| Drilling and completion costs: | |
| Rig transportation and location preparation | $ 13,400 |
| Drilling and coring of 7-7/8 in. hole, 2,066 ft. | 73,200 |
| Drill-stem tests, swabbing, and logging | 28,800 |
| Reaming operations | 12,500 |
| Casing (surface and injection) | 53,000 |
| Perforating and fracturing | 35,600 |
| Plastic liner | 21,200 |
| Stainless steel liner | 19,400 |
| Acidizing | 3,300 |
| Total | $260,400 |
| Testing costs: | |
| Analyses of core, water, logs, and drill-stem tests | $ 15,300 |
| Pump-out test | 15,700 |
| Consulting, spinner surveys after 90 days of operation | 73,400 |
| Total | $104,400 |
| Cost of surface installations: | |
| Decanter | $ 20,900 |
| Filter plant | 98,700 |
| Pipeline, 7,400 ft. of rubber-lined 12-in. pipe | 73,000 |
| Freshwater-monitoring well. 628 ft. deep | 4,600 |
| Total | $197,200 |
| Total Cost of Disposal System | $562,000 |

Source: Erle C. Donaldson, "Injection Wells and Operations Today," Underground Waste Management and Environmental Implications, edited by T. D. Cook (Menasha, Wisconsin: The Collegiate Press), 1972, p. 44.

## TABLE 6

## DETAILS OF COSTS FOR AN INJECTION WELL COMPLETED IN TEXAS PANHANDLE IN 1969

| Item | Cost |
|---|---|
| Casing, 16 in. OD, 730 ft. | $ 6,770 |
| Casing, 10-3/4 in. OD, 1,070 ft. (alloy) | 6,530 |
| Casing, 10-3/4 in. OD, 3,980 ft. | 21,700 |
| Casing sub | 1,000 |
| Casinghead | 850 |
| Fittings | 800 |
| Rotary rigup | 3,150 |
| Rotary day work with pipe | 35,200 |
| Rotary day work without pipe | 4,200 |
| Completion unit | 2,100 |
| 16 in. casing equipment | 1,150 |
| 10-3/4 in. casing equipment | 2,600 |
| Engineer - stake location | 100 |
| Mud and chemicals | 8,000 |
| Cement | 12,000 |
| Cement services | 2,600 |
| Drill bits | 9,000 |
| Perforating | 4,600 |
| Logging | 3,000 |
| Treating services | 6,000 |
| Tool rental | 12,000 |
| Fuel for completion unit | 150 |
| Water hauling | 1,400 |
| Bulldozer | 1,400 |
| Trucking | 2,000 |
| Welder | 200 |
| Supervision | 700 |
| Car mileage | 250 |
| District expense | 260 |
| Vacation allowance | 86 |
| Total | $149,796 |

Source: Erle C. Donaldson, "Injection Wells and Operations Today," Underground Waste Management and Environmental Implications, edited by T. D. Cook (Menasha, Wisconsin: The Collegiate Press), 1972, p. 44.

ponents, municipal authorities have been forced to investigate new alternatives that are more economically feasible in meeting the requirements. Implementing a DWWD system in such a manner actually circumvents the problem of stricter effluent quality standards since the waste stream being injected has received no additional treatment. The Environmental Protection Agency has permitted this type of action as DWWD will "under proper construction and operation practices, effectively separate from man pathogens surviving the treatment process and other residual pollutants." (20, p. 13) Although the waste stream still contains surviving microorganisms, they will be subjected to the following environmental changes: (20, p. 188)

a. drastic pressure changes such as from less than 10 to approximately 1300 pounds per square inch in 10 minutes,

b. anaerobic conditions will exist in a few weeks as free oxygen in the fluid is depleted,

c. sunlight will be absent,

d. reduction in temperature, and

e. suspended solid particles, with some of the remaining bacteria will tend to settle on the floors of the caverns in the injection zone.

The rate of survival of pathogens experiencing these environmental extremes will be minimal.

By diverting wastewaters from surface waters, DWWD will substantially and immediately improve the quality of those surface waters, and will contribute to the long term enhancement of surface water quality. (20) The EPA has also suggested the possibility of storing domestic wastewaters in this manner, under controlled conditions, and possibly retrieving them during droughts for use as a source of freshwater irrigation, for prevention of saltwater intrusion into surface canals, or for other uses which would justify costs of reclaiming the stored water. At the time of retrieval an evaluation for possible additional treatment would be made. (20) It must be noted that at the date of this writing, no such attempts have been made.

Benefits of municipal wastewater disposal via deep wells are difficult to account for in a cost comparison feasibility study. They are more in the nature of the social benefits discussed on pages 34 to 42. Unfortunately, the availability of direct cost data concerning domestic DWWD use are just as limited as in the case on industrial deep well use.

The State of Florida has been particularly instrumental in considering the use of injection wells for disposing of municipal wastes. Not only does there exist in the state suitable subsurface geology for the method, but the state as a whole is witnessing a population growth which calls for increased public services such as waste treatment facilities. The Gainesville-Alachua County area of the state exemplifies this problem. The governing bodies of the area recently embarked on the task of composing a Master Plan in hopes of arriving at a feasible alternative to their present waste handling facility whose capacity has been exceeded. The eight alternatives considered were: discharge into the Haile Sink, drainage well disposal, DWWD, percolation pond disposal, spray irrigation disposal, modified advanced waste treatment, complete advanced waste treatment-Tahoe method, and complete advanced waste treatment-Gainesville method. Table 7 presents the cost of municipal DWWD relative to the other seven alternatives in this case. Item 3 in the table, Injection Well Disposal, designates DWWD as referred to in this study. In this particular situation DWWD was not recommended in the Master Plan as the solution to the area's problem, as it was felt that the modified advanced waste treatment alternative was a better suited choice.

Just as in the case of industrial DWWD employment, this method cannot be generalized as the clear-cut best alternative. Objective evaluations must be made always considering site specific characteristics.

## Potential Industrial Use of DWWD in the Mid and South Atlantic States

As explained in the acknowledgements, the original project funded by the National Science Foundation and granted to the Virginia Water Resources Center geographically focuses on the States of Delaware, Maryland, West Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, and the eastern halves of Kentucky and Tennessee. In order to determine the potential role DWWD could play as an industrial waste management tool in the study area, it is first necessary to identify the present and potential users of the method.

According to a deep well census of 1972, eighteen industrial wells are located within the bounds of the study region. Since fourteen of these wells are operated by a single industrial group, the chemical related manufacturers, meaningful conclusions with regard to

TABLE 7

COMPARATIVE COSTS OF EIGHT WASTE MANAGEMENT ALTERNATIVES FOR THE GAINESVILLE-ALACHUA COUNTY AREA OF FLORIDA

| Plan | Construction Cost | Annual Cost ($1000) | | |
|---|---|---|---|---|
| | | Capital | Operating | Total |
| Haile Sink Disposal | $4,440,000 | $315 | $246 | $ 561 |
| Drainage Well Disposal | 4,550,000 | 323 | 246 | 569 |
| Injection Well Disposal | 4,730,000 | 336 | 186 | 522 |
| Percolation Pond Disposal | 5,050,000 | 358 | 246 | 604 |
| Spray Irrigation Disposal | 6,550,000 | 465 | 246 | 711 |
| Modified Advanced Waste Treatment | 5,440,000 | 386 | 312 | 698 |
| Complete AWT-Tahoe | 7,670,000 | 544 | 715 | 1,259 |
| Complete AWT-Gainesville | 8,070,000 | 573 | 709 | 1,282 |

Source: Supplemental Engineering Report on Lake Kanapaha Wastewater Treatment Plan for Gainesville/Alachua County. Regulatory Water and Sewer Utilities Board. Project No. 110-71-91. Black, Crow, and Eidsness, Inc., October, 1972.

the identification of potential users cannot be drawn from the existing wells.

A more complete analysis can be conducted by first determining the types of wastes suitable for injection, and then relating these substances to the manufacturing processes from which they originate. Subsurface Disposal Corporation of Houston, an injection well specialist, provided a list of wastes presently being injected. This information, together with well data from the 246 wells surveyed in the 1972 census (24), serve to identify the suitable waste types. Industrial processes producing these wastes are obtained from various references, especially <u>Liquid Waste of Industry-Theories, Practices and Treatment</u> by Nelson L. Nemerow, which provides a list of industries and the types of waste produced by each. (17) These sets of data, waste types currently being injected and industrial practices producing these wastes, are combined to achieve the identification. For a uniform basis of comparison, the Standard Industrial Classification Codes are employed. Using this coding, 168 out of a possible 422 4-digit industry numbers can be classified as present or potential employers of DWWD. These industries fall under the major manufacturing groups (2-digit SIC) as presented in Table 8.

The concentration and location of the DWWD industries (4-digit SIC numbers) are obtained from County Business Patterns 1971. These volumes are well suited for the task since they contain tables listing types of industry by SIC code, by state, by county, and by number and size of reporting units. These data have then been transferred to the accompanying map in terms of frequency of occurrence (Figure 3). It

TABLE 8

MAJOR MANUFACTURING GROUPS AS PRESENT OR POTENTIAL DWWD USERS

| SIC No. | Major Manufacturing Group |
|---|---|
| 19 | Ordnance and Accessories |
| 20 | Food and Kindred Products |
| 22 | Textile Mill Products |
| 24 | Lumber and Wood Products, Except Furniture |
| 26 | Paper and Allied Products |
| 27 | Printing, Publishing, and Allied Products |
| 28 | Chemical and Products |
| 29 | Petroleum Refining and Related Industries |
| 30 | Rubber and Miscellaneous Plastic Products |
| 31 | Leather and Leather Products |
| 33 | Primary Metal Industries |
| 34 | Fabricated Metal Products, Except Ordnance, Machinery, and Transportation Equipment |
| 37 | Transportation Equipment |
| 39 | Miscellaneous Manufacturing Industries |

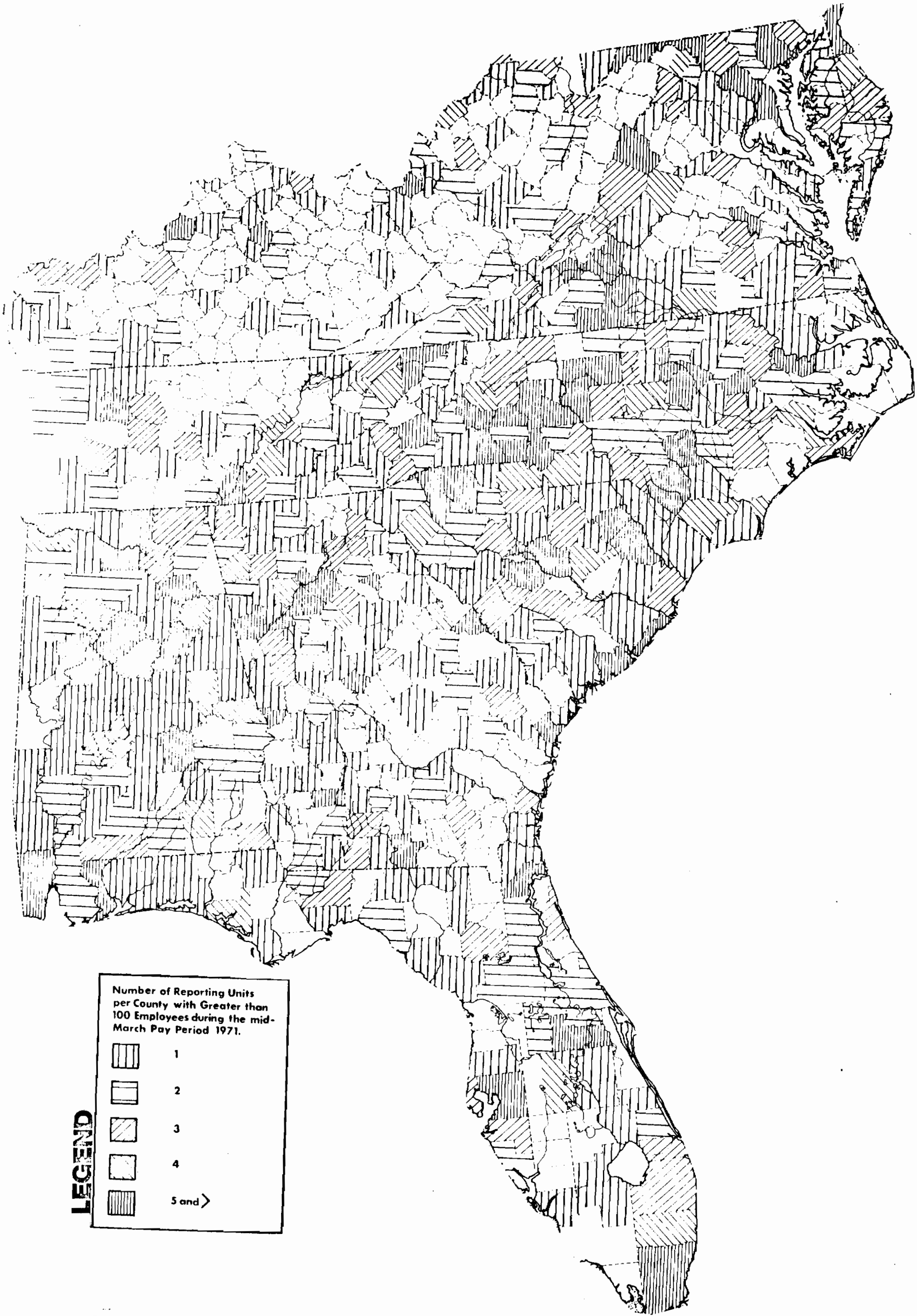

Figure 3. Density of Present and Potential Users of DWWD.

should be noted that the employment size of the reporting industry was also considered in deciding whether or not particular firms should be considered a DWWD user or not. For a DWWD industry to have been counted on the frequency, it must have had at least one reporting unit with greater than 100 employees during the mid-March pay period 1971. This limit was chosen with hopes of eliminating from the analysis those firms too small to utilize their own waste management facility.

Although city locations are not indicated on the map, the areas having the greatest economic potential for employing DWWD are in counties containing or adjacent to the metropolitan centers. It should be noted, however, that the potential for employing deep well waste disposal as shown on the accompanying map says nothing of perhaps the most limiting factor in determining feasibility, the subsurface geology. DWWD might be the least cost alternative in a particular case as well as being legally permissible, but unless the proper physical conditions exist at the site there will be no deep well. It might so happen that areas identified as having the greatest industrial potential, as indicated on the map, are totally lacking in physical suitability for injection sites. Ideally, the results of this geographical analysis should be correlated with a county-based geological analysis to outline specific zones of the Mid and South Atlantic region which are both geologically and economically capable of employing DWWD.

Unlike an economic analysis, however, certain generalizations concerning geological suitability for DWWD use can be made. The findings from the physical aspect of the original NSF funded DWWD project indicate that "good" physical potential exists in the Appalachian Plateau geologic province. Geographically, this area encompasses the western most part of the study area in a strip running the length of the study area from north to south. Although not as extensive, the Atlantic Coastal Plain area also shows "good" potential for injection well use. Areas indicated to possess "poor" potential for DWWD employment are the Piedmont and Blue Ridge Provinces. Oversimplified, these areas are located between the two highly favorable geologic provinces of the study area. These generalized geologic findings can now be correlated with the frequency map if a generalized industrial-geological feasibility for DWWD area is desired.

It is conceivable that although an area may not at this time show potential for deep well use with regard to suitable industrial locations, it may in fact be able to attract industries by possessing both favorable DWWD-geologic characteristics and regulations governing its use. This possibility, of course, rests on public acceptance of deep well use as well as other waste management alternatives being cast in disfavor for various reasons.

# CHAPTER V

# SUMMARY AND CONCLUSIONS

This final chapter summarizes the study and briefly states the implications of these findings. The purpose of this study was to conduct a preliminary investigation of the potential of deep well waste disposal as a waste management tool. The analysis focused on identifying and examining economic concepts and issues relevant to the utilization and regulation of the method. An attempt was also made to evaluate the current and potential state of DWWD from an industrial basis in the designated study area, the Mid and South Atlantic states.

The overall feasibility of employing DWWD is based on a combination of three general factors. These can be identified as physical, legal-institutional, and economic. It is difficult to rate the factors in terms of importance as any one can be limiting enough to prevent the implementation of a deep well operation. Physical feasibility is concerned with the composition of the waste to be injected and also the subsurface geology of the surrounding area. The nature of the DWWD process narrowly dictates the geological requirements for an environmentally secure system. Simplified, a suitable geology is one possessing confining subsurface strata at depths below the occurrence of potable groundwater and other extractable natural resources. The legal aspect involves the public policy and regulatory controls governing DWWD use. Regulation at various levels of government exists in the forms of specific statutes enacted solely for the purpose of DWWD control, modification of existing subsurface usage regulations to include DWWD, or simply a complete absence of any mention of the method. Third, the economics of deep well usage, the concentration of this study, is not only concerned with determining if the employer of such a system can finance it, but perhaps more importantly whether the allocation of resources to this form of waste management is an efficient and equitable one from an overall environmental and societal point of view.

Attempts to estimate the direct cost a firm will encounter by installing a deep well waste disposal system have met with limited success. Two methods of cost estimating DWWD discussed in the analysis are through the use of models designed for that purpose and deriving cost estimates by adjusting previously existing cost figures to align them with site specific characteristics. Problems are encountered in employing the latter technique with the numerous variables requiring adjustment, the reluctance on the part of the private firm to furnish cost data on existing wells, and the relatively few injection wells in operation upon which such estimates could be based. DWWD cost estimating models are better suited for the task, particularly the Alabama study and the Texas model which are summarized in this study. These models predict the total cost of an injection well installation given certain engineering, geological, and economic factors.

Two readily identifiable cost categories of any method of waste treatment are the capital cost and the operating and maintenance fees. Capital components of an injection well system include those expenses encountered in constructing the facility such as the pretreatment plant, the pumping system, and the well itself. The operating and maintenance fees cover the energy requirements for both pretreatment and operation of the well, workover expenses, labor costs, interest on initial investment, and costs of monitoring the disposal apparatus. The latter outlay is especially interesting from a societal viewpoint as it relieves the public agency of a major portion of the regulatory responsibility and effectively shifts much of the cost involved to the private firm. This point must be considered as a social advantage of employing DWWD even though it forces a cost upon the party using the method. A third cost category, though a bit more obscure, are the indirect outlays resulting from legal confrontations, changes in insurance premiums, and the permit obtaining process.

With respect to these direct costs, it appears that based on the limited data available from existing wells, in some cases initial capital outlays for DWWD systems are somewhat greater than those for surface treatment facilities. Perhaps this stems from deep well systems often employing a part of the original surface treatment facility for purposes of pretreatment. Hence, there is an outlay requirement for this component in addition to the well itself. A direct cost advantage does seem to exist in favor of DWWD with regard to the operating and maintenance fees. Both energy and labor requirements appear to be less for the operation of a deep well. Demands for labor exist primarily in well monitoring and thus insuring problem free operation. Generally this can be carried out by a single individual checking various gauges. In light of the present energy situation, the relatively smaller energy requirements for DWWD may increase the importance of this cost factor.

It should be emphasized that broad generalizations of direct cost advantages that one type of disposal holds over others must be avoided. The high number of site specific variables prevent anything but a case to case evaluation of alternatives in deriving a least cost choice.

Although much more difficult to quantify than the direct costs, the social costs and benefits of DWWD present a readily identifiable cost advantage, from an overall societal viewpoint, to this method over surface treatment alternatives. There have been documented cases of well failure resulting in damage to the surrounding environment; however, a closely monitored well which insures proper functioning or alerts the operator to any problems avoids the complications of well failure. Hence, the major social cost of deep well waste disposal is one of risk or potential harm. Another cost of this type to consider is the preclusion of uses of underground space as dictated by unforeseen future demand for the area. Even this cost is potential in nature.

In contrast, the social benefits to be gained from DWWD are more tangible. Additional recreational use of surface water, reduced land use for waste treatment, aesthetic benefits, and a lesser energy requirement are examples of DWWD-related social benefits. To date, these factors have not entered into the private firms decision of which waste management alternative to employ. This stems from the fact that they are not readily quantifiable in terms of dollars and cents, the market's unit of measurement. An efficient allocation of resources to waste treatment, however, depends on the accounting of all benefits and costs whether direct or indirect, quantifiable or unquantifiable.

This characteristic of DWWD costs and benefits indicates the need for a comprehensive regulatory policy which in some manner forces the private firm to consider social effects in their decision making processes concerning various waste management alternatives. The cost effectiveness analysis requirement of the Federal Water Pollution Control Act Amendments is a beginning in this direction.

It is conceivable should the existence of social benefits from using deep well waste disposal be in excess of the social costs created that society may wish to encourage this form of waste management. Since, to day anyway, the firm is unable to recover compensation for the creation of these benefits, society in some manner subsidize these systems. Such action would alert the firm to society's position on the issue and thereby close the now open feedback mechanism between society and the firm.

The geographical analysis of DWWD-using industries indicates the greatest economic potential for employing the method in the Mid and South Atlantic states to exist in areas surrounding metropolitan centers. This seems plausible since the highest concentration of manufacturers occur in the cities and immediately adjacent urban areas.

Should the use of DWWD for domestic wastewater increase in popularity, then any locality possessing its own sewerage system would have an "economic potential" to employ deep well waste disposal.

In the final analysis, the decision to employ DWWD must be made on an individual basis. The industrial firm, municipality, or other governmental organization must weigh many factors of the physical, legal-institutional and economic aspects as dictated by the location of the proposed system. It is very possible that the social advantages of DWWD could be the determining factor in favoring this waste management practice.

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# A PRELIMINARY INVESTIGATION OF THE POTENTIAL OF DEEP WELL WASTE DISPOSAL

by

James Charles Vogelsang

## (ABSTRACT)

The 1972 amendments to the Federal Water Pollution Control Act provide for major changes to reduce and eventually eliminate water pollution by 1985. In contrast, projections indicate that the volume of wastes generated by population and economic growth in the near future will be very large and the cost of treating it by standard methods will be extremely high. Hence, all possible systems and methods of waste disposal must be considered and ways of reducing the amount of waste discharges sought.

In attempting to reach the goal of zero waste discharges, one alternative which must be considered in certain situations is the employment of deep well waste disposal (DWWD). This method accomplishes long term isolation of highly toxic liquid industrial wastes in confined subsurface geologic strata. This study undertakes a preliminary investigation of the potential of DWWD as a waste management tool.

The analysis is conducted from an economic standpoint with the relevant economic concepts and issues being identified and examined as they apply to both users and regulators of the method as well as the

general public. The direct cost for the system and its operation was discussed with particular attention paid to its derivation. Numerous site specific variables prevent generalizations concerning the cost of DWWD relative to surface treatment methods. On occasions, however, the method appears to have a greater initial capital outlay requirement but a much less operating and maintenance cost than alternative forms of wastewater management achieving the same effect.

The social costs and benefits of deep well waste disposal were viewed in detail. Suggestions were made as how society might compensate the firm for the creation of social benefits in excess of social costs, and how they may be internalized into the firm's decision making process.

Finally, the industrial potential for employing DWWD in the study area, designated as the Mid and South Atlantic states, is derived and discussed.