PERSPECTIVE ON THE REGULATION OF UNDERGROUND INJECTION OF WASTEWATERS

A monograph outlining the status of subsurface disposal of industrial wastewater, the questions it provokes with respect to public policy and regulations, and suggested procedures to satisfy administrative needs, geologic evaluation and technical requirements, specifically as related to circumstances in the Ohio River Valley.

PART I - Public Policy, Legislative and Legal Aspects
by Edward J. Cleary

PART II - Administrative Guidelines and Evaluation Criteria
by Don L. Warner

An appraisal sponsored by the

OHIO RIVER VALLEY WATER SANITATION COMMISSION

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Ohio River Valley Water Sanitation Commission
414 Walnut Street, Cincinnati, Ohio 45202

OHIO RIVER VALLEY
WATER SANITATION COMMISSION
414 WALNUT STREET, CINCINNATI, OHIO 45202

TO: The Chairman and Members of the Commission

This "Perspective on the Regulation of Underground Injection of Wastewaters" may be said to have had its origin in a memorandum drafted by Edward J. Cleary shortly before he relinquished the post of executive director of ORSANCO in October 1967. He questioned whether public policy and other issues concerning the growing practice of deep-well disposal were being adequately evaluated and proposed Commission review of the situation. The Commission directed the staff to develop a monograph that might serve as a basis for its further deliberations.

Accordingly, I assigned execution of this project to Dr. Cleary who continues to serve the Commission as a consultant. He invited the collaboration of Don L. Warner, a specialist in the geological and technical aspects of injection-well practice, who until recently was chief of the earth-sciences section of the Ohio River Basin Office of the Federal Water Pollution Control Administration. Dr. Warner is now associate professor of geological engineering at the University of Missouri.

Much of Dr. Warner's contribution to this two-part monograph was developed during his employment on the staff of FWPCA, Department of the Interior, which is one of the three federal departments that hold membership on ORSANCO. Since the Interior department has not at this time established a specific policy on underground injection, the section written by Dr. Warner should not be interpreted as reflecting Interior policy, nor should the recommendations be interpreted as representing opinions of the FWPCA.

However, it might be noted that shortly after an advance draft of this document was submitted to the FWPCA for review, the Secretary of the Interior on December 17, 1969, issued a press statement regarding underground waste injection, saying among other things: "We must review existing regulations and start collecting the kind of environmental data needed to assess the level of risk, and consider ways of organizing Federal, state and industrial efforts to solve this growing problem."

This monograph may be regarded as providing a frame of reference for such an inquiry, and I commend the recommendations advanced for this purpose.

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Robert K. Horton
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C O N T E N T S

Part II - Tables (continued)

SYNOPSIS OF FINDINGS AND RECOMMENDATIONS

The eight states represented on the Ohio River Valley Water Sanitation Commission (ORSANCO) concluded it would be of mutual interest to appraise policies, procedures and other matters allied to the practice of subsurface disposal. As a basis for such a review the staff of ORSANCO was directed to develop a monograph that would offer perspective and guidelines on the regulation of underground injection of wastewaters. This document is intended to fulfill that assignment.

The monograph is presented in two parts, each of which has been individually authored. The first section provides background on public policy issues associated with environmental factors and subsurface-resources stewardship, and it embraces consideration of legislative and legal aspects. Part II discusses administrative procedures, geological evaluation and technical criteria relating to injection-well practice, specifically with respect to circumstances in the Ohio Valley.

Jointly shared by the authors is the conclusion that the regulation of underground injection and the criteria for evaluating proposals merits comprehensive assessment. To this end suggestions on the conduct and scope of such an undertaking have been developed. These suggestions stem from the following findings.

Findings set forth in Part I

Within recent years industry managers have exhibited increasing interest in the use of injection wells for the disposition of wastewaters. This situation may be attributed to: (a) A response to more aggressive enforcement of laws pertaining to surface water pollution; and (b) the availability of improved technology for injecting liquids underground, which offers the promise of a low-cost alternative to other methods of disposal.

Nationwide, the installation of well systems for industrial wastes has been accelerating. Only 6 systems were in use ten years ago; in 1963 the number had increased to 35; today the estimate is 150. Within the ORSANCO states a total of 33 installations have been made.

From a social standpoint there is growing concern that wastewater injection may be proceeding with greater vigor than the assessment of public policy issues and the adequacy of regulatory procedures associated with this practice.

Professional concern reflects limitations on the extent of knowledge of underground conditions and how they will be influenced by the pumpage of fluids under pressure. A case in point with respect to potential environment hazard is the conjecture that a deep-well disposal system near

Denver may have triggered earth tremors in the area. It has also been asserted that extension of wastewater injection hinges on more definitive estimates of the availability of underground storage space and the prospects of its exhaustibility; involved here is the social issue of preemption of limited space.

Additionally, concern is being expressed regarding not only the adequacy of existing legislation in some states for effective regulation, but the difficulties confronting regulatory agencies in marshalling sufficiently experienced personnel to deal with the complex and often novel aspects of subsurface disposal.

From a legal standpoint concern exists with respect to questions of underground trespass and the definition of subsurface "public" waters.

Because of the unknowns and uncertainties associated with underground wastewater storage the basic public policy issue to be confronted is this: Under what circumstances should society find it reasonable to trade-off the potential imposition of environmental risk for the benefits that may be advanced in behalf of injection-well installations?

Allied to this policy issue is the questions: What constraints should be imposed on the installation and operation of deep-well injection systems to safeguard future utility of underground strata for the extraction of oil, gas and other mineral resources or for subsurface water supply development?

And finally: Are regulatory agencies adequately fortified with legislative directives and staff for appropriate evaluation of the geohydrological, the technological and the public-interest aspects of injection-well proposals?

Concerning legislation and policy, the situation may be portrayed in this fashion. No state is known to have legislation that denies the installation of wastewater injection systems. However, nine states subscribe to a policy of either rejecting applications or discouraging them. The remaining states permit the practice, but only three (Ohio, West Virginia and Texas) have specific legislation pertaining to the regulation of industrial wastewater injection.

There is no specific federal legislation on deep-well disposal. However, in matters relating to disposal of radioactive wastes a license must be obtained from the Atomic Energy Commission. The Federal Water Pollution Control Administration, which reviews disposal activities at federal facilities, presumably could influence choice and design of injection systems.

<u>Findings set forth in Part II</u>

All aspects of the planning, construction, operation and abandonment of waste-injection systems should be embraced in the regulatory process. Decisions and requirements thus must include appraisal of wastewater characteristics, geology and subsurface hydrology, well construction and testing methods, surface and standby facilities, materials of construction, operational practices and abandonment procedures.

Ohio and West Virginia are among the three states in the nation that have adopted specific legislation pertaining to industrial-waste injection. The New York State Department of Health has enunciated a last resort" policy concerning use of injection wells; the state has also classified groundwater resources, one result of which is to limit the aquifers that can be used for disposal purposes.

Indiana, Illinois, Kentucky and Pennsylvania permit the installation of disposal wells and have regulated their use through existing laws and regulations· Illinois has defined one area of the state as "off limits" for injection. Although Virginia has not yet received any applications for subsurface injection, it expects to process proposals under present regulatory authority.

Only small areas of the Ohio Valley would appear to be eliminated or significantly limited for waste injection on the basis of the most general consideration of the rock units that are present, their geologic structure, and the groundwater circumstances. Precambrian crystalline rocks crop out at the surface in most of the Virginia portion of the Ohio Valley, eliminating that area for wastewater injection. In the remainder of the Virginia portion of the Ohio Valley and parts of southeastern West Virginia, Kentucky and Illinois the possibilities for deep-well waste injection are limited by geologic structure or the lack of saline water-bearing strata.

Outside of the areas mentioned, in the greater portion of the Ohio Valley, deep-well disposal is not immediately ruled out or greatly restricted by the general geologic and hydrologic criteria that have been applied. Locally, subsurface injection may or may not be technically feasible depending on the results of detailed geologic and hydrologic studies. Information and judgment for evaluating the local geologic and hydrologic circumstances falls within the purview of state and federal agencies that deal with underground natural resources and geology.

A significant restrictive factor is likely to be the volume of wastewater to be dealt with, because any fluid injected into the subsurface must displace another that is already there. For this reason only very limited quantities of wastes should be regarded as eligible for subsurface disposal. This places a responsibility on the regulatory agency to insist, and the applicant to assure, that all possible means will be employed to minimize the amounts of fluid to be injected.

Subsurface-well installation procedures and construction materials developed by the petroleum industry possess high capability of providing the desired protection of potable groundwater and mineral resources if properly used. The variety of possible construction methods and materials denies generalizations concerning their application, except to say that they must be compatible with the wastewater characteristics, the operating program, and the subsurface conditions.

Operational restrictions of major significance relate to injection rates and volumes, and they are interdependent. Operating pressures should be specified at some level below that at which hydraulic fracturing or formation parting occurs, that restriction, in turn, will limit the injection rate. Injection rates may be specified at a lower limit than that established by pressure constraints in order to control the total amount of fluid that eventually will be injected. Continuous records of wastewater volumes and injection pressures should be kept. Monitoring of conditions at the injection interval or other intervals above or below the injection horizon may be a desirable requirement in some cases.

With respect to requirements for abandonment of an injection system, it is suggested that wells be completely plugged with cement and that a permanent monument be constructed at the well site.

Recommendations for a comprehensive assessment

The prevailing situation with respect to injection-well practice as reflected by viewpoints and findings set forth in this monograph invites comprehensive assessment. The eight states signatory to the Ohio Valley compact could regard such an undertaking to be of regional significance and thus suitable for advancement under the aegis of their interstate agency. In so doing they would be following a familiar pattern of cooperative effort, the mechanism for which offers opportunities to enlist participation of a variety of qualified individuals from state and federal agencies and long-established ORSANCO advisory committees.

It is recommended, therefore, that the commissioners of ORSANCO entertain the creation of an ad hoc expert committee to develop public policy guidelines, regulatory procedures and evaluation criteria pertaining to the practice of underground injection of industrial wastewaters in the Ohio Valley. Specific questions that should be addressed by the committee include:

1. On the basis of theoretical considerations and practical experience what might be an estimate of the risk probabilities of wastewater injection with respect to: (a) environmental hazards and (b) impairment of utility of the underground and future extraction of its mineral resources?

2. Under what circumstances and conditions should society find it reasonable to trade off the potential imposition of risk?

3. What limitations and safeguards should be imposed to minimize environmental risks and provide protection for groundwater, oil, gas and other underground resources? This question embraces consideration of:

   a. Are there specific horizons that should be ruled out, regionally or locally, for deep disposal and are there others that may be conditionally regarded as suitable for such use?

b. What requirements should be specified concerning well construction, logging, and testing procedures?

c. What constraints should be placed on formation treatment methods?

d. What operational requirements should prevail?

e. Where and when should monitoring provisions be required?

f. What conditions should be imposed on the abandonment of wells with respect to plugging, site identification and assumption of responsibility for future difficulties.

4. What categories of wastewaters produced by industries in the Ohio Valley could be favorably regarded for injection and what justifications can be advanced for their disposal underground?

5. What is the nature and scope of investigations and research that should be initiated to remedy deficiencies in information for the evaluation of injection-well proposals?

6. Should ORSANCO be charged with the duty of establishing and maintaining a registry of data on each well drilled and tested in the compact district for the purpose of providing a central file for such installations in the Ohio Valley and disseminating such information for reference needs?

Background information and discussion relevant to these questions is detailed in the text that accompanies this synopsis.

PART I -- BACKGROUND AND POLICY ISSUES

Increasing installation of underground injection systems for the disposition of industrial wastewaters provokes an assessment of public policy issues concerning this practice and adequacy of its regulation. At least, this was the conclusion of the Ohio River Valley Water Sanitation Commission and the motivation for sponsoring a monograph on the subject.

The eight states who are represented on the Commission, with one exception thus far (Virginia) have been confronted with making decisions on applications for injection-well installations. In their continuing effort to sharpen judgment on such matters it was their desire to have a review of the situation that would embrace consideration of the environmental, geological, technological and administrative aspects of underground injection.

Accordingly, this two-part monograph has been designed to:

Provide perspective on the status of underground injection practice and the social concerns and policy issues that relate to it; and

Offer regulatory guidelines and criteria for evaluating the location, design, construction and operation of injection wells, specifically with respect to geological and other circumstances in the Ohio Valley.

Overall direction and preparation of Part I of the monograph, was undertaken by Edward J. Cleary, consultant to ORSANCO. The second part was developed by Don L. Warner, formerly chief of earth sciences section Ohio Basin Region, Federal Water Pollution Control Administration, and now associate professor of geological engineering, University of Missouri. Dr. Warner's collaboration does not imply endorsement of the views set forth either by the FWPCA or the Department of the Interior, which has not yet established any policy regarding underground disposal.

As a matter of perspective, it should he noted that the injection of liquids in subsurface strata is not a new concept. This technique has been employed for half a century by the petroleum industry for two purposes -- to increase crude oil production by water-flooding or re-pressuring of oil strata, and as a means for returning to the underground the salt water normally associated with oil extraction.

What is new, relatively, is the application of injection-well technology for underground storage of a variety of industrial wastewaters. The distinction to be made is this: Where salt water is injected into the stratigraphic zone from which it originated this merely returns to the subsurface a liquid that had been originally accommodated and confined;

these latter conditions, of course, do not apply with respect to injection of extraneous wastewaters. Consequently, to cite oil-field brine disposal experience as the precedent to justify extension of underground injection for other liquid wastes is not altogether relevant.

Regardless of relevance, the fact is that underground disposition of industrial wastes has had considerable advocacy as a more convenient and cheaper way of dealing with the pollution problem than the employment of other alternatives. And resort to this technique has become increasingly attractive as a result of more stringent requirements for surface water pollution control being imposed by governmental jurisdictions.

Thus we find that today the number of industrial-waste injection systems in the United States is estimated to be 150 as contrasted with 35 in 1963, and only 6 some ten years earlier. (These figures are exclusive of oil-field brine disposal installations, estimated to total more than 40,000). In the ORSANCO district 15 industrial systems have been installed, and 18 more are located within the borders of the ORSANCO states but outside the interstate compact district.

Virtually all types and significant quantities of industrial wastewaters are now being pumped underground.(1) They include alkalies, acids, chromates, nitrates, phosphates and sulfites, a variety of organic materials, such as alcohols, ketones, phenols, cyanides and chlorinated hydrocarbons, as well as radioactive wastes. More than half of the well systems have been installed by chemical, petrochemical and pharmaceutical industries, the wastes from which often include toxic and refractory contaminants. Quantities injected through well systems vary from 50 to 800 gallons per minute, with the majority of installations handling 200-400 gpm.

Social Concerns and Strategies

While underground injection of liquid wastes is proving to be economically attractive to individual producers, from a social standpoint broad extension of this practice could be regarded as one of the least satisfactory of the available options for pollution control. Limited experiences suggest that it is premature for proponents of this practice to postulate that injection wells offer "a complete and final solution to the disposal problem."

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(1) Warner, Don L., "Deep-wells for Industrial Waste Injection in the United States - Summary of Data," Bull. WP-20-10, Dept. of Interior, FWPCA, Cincinnati, Ohio.

Questionable, also, is the propriety of affiliating the term "disposal" with this technique. Actually, injected liquids are only being committed to storage, often with uncertainty as to the ultimate confinement limits of the storage zone. There is little evidence to suggest that conditions underground are conducive to the degradation or dilution of most pollutants to the point where they might be regarded as becoming innocuous. Two exceptions are radioactive wastes containing short-lived isotopes and acids that are readily neutralized in limestone or dolomite rock formations.

One of the earliest advocates of caution was Dr. Harold A. Thomas, Jr., professor of sanitary engineering at Harvard University. In 1962 he expressed the view(1) that while injection-well installations appeared capable of providing economies in disposal of wastewaters there were also hazards and uncertainties to be weighed in the national interest. He pointed to limitations of knowledge of geological formations and their hydraulic connections, and the element of risk this introduced in deciding on the feasibility of an installation as well as in future attempts to reverse the injection process should things get out of hand.

Noting that many underground aquifers and other geological formations may underlie two or more states and be connected directly or indirectly with interstate surface waters, Professor Thomas proposed the establishment of a national registry of deep injection wells. Its objectives would be: (1) the collection and dissemination of data that would be useful in identifying and utilizing safely those underground strata suitable for wastewaters of various types; and (2) provide an expanding body of experience to be used in framing legislation as the need arises. Although laudable efforts in compiling such information have since been undertaken by the Federal Water Pollution Control Administration as well as the Interstate Oil Compact Commission, much remains to be done to satisfy the objectives envisioned by Professor Thomas.

Basic questions -- Because of the unknowns associated with underground wastewater storage the pervading public policy issue that asserts itself is this: Under what circumstances should society find it reasonable to tradeoff long-range potentialities of environmental risk for short-term economic gains or other benefits that may be advanced in behalf of injection-well installations?

Allied to this policy issue is the question: To what extent might the proliferation of deep-well injection systems impair potential utility of underground strata for the future extraction of groundwater and mineral resources or for the development of subsurface reservoirs for water supply and other purposes?

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(1) Set forth in a memorandum prepared for the subcommittee on waste disposal of the Committee on Sanitary Engineering and Environment, National Research Council, May 9, 1962.

And finally: Are regulatory agencies adequately fortified with legislative directives and staff for appropriate evaluation of the geohydrological, the technological and the public-interest aspects of injection-well proposals?

Uncertainties and risk -- With respect to the first issue -- probabilities of environmental risk -- at this point in time such an assessment is inhibited by sparsity of geohydrological knowledge and limited operating experiences. "It is not easy," cautions one operator of an injection system,(1) to determine or evaluate events occurring about a mile underground in an environment about which little data is available."

The uncertainties that exist have prompted recommendations for greater research effort. For example, it has been reported(2) that the hydrodynamics of underground formations are not well enough understood to permit injection as it has been practiced thus far. One cause for concern relates to subsurface pressurization by injection, which could result in the rupture of strata at the periphery of a rock formation many miles away. Another concern stems from growing advocacy of deliberate hydraulic fracturing as a means for increasing the intake rate of injection wells.

Recent developments in Alabama(3) suggest both the scope and the cost of undertaking appropriate exploration and research before decisions are made regarding underground waste disposal. Here the Reichhold Chemicals, Inc., will drill a 5,500 ft. test well at its Tuscaloosa plant to develop data on the porosity, confinement potentialities, compatibility characteristics and other conditions that may be relevant to waste injection "with complete safety to the total environment."

The company has allocated $675,000 for this research project, which will be conducted under supervision of the Alabama Geological Survey. The latter agency has received a grant of $314,500 from the Federal Water Pollution Control Administration for this purpose.

While this project does not represent the only occasion where industry has made a substantial investment in pre-injection studies, it does reflect something new in federal funding assistance and state direction of research on underground disposal installations.

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(1) Elliot, A. M., "Subsurface Waste Disposal Problems," Industrial Water and Waste Conference, University of Texas, June 1, 1967.

(2) Sheldrick, Michael G., "Deep-well Disposal: Are Safeguards Being Ignored?" Chemical Engineering, April 7, 1969, pp. 74-78.

(3) Research Drilling Project for Waste Disposal, Clean Air and Water News, Nov. 21, 1969, pp. 14-15; published by Commerce Clearing House, Inc., Chicago, Illinois.

Meantime, it might be noted that the U. S. Geological Survey and Maryland are contemplating a cooperative research program on factors relating to deep-well disposal in that state.

Examples of risk -- Experiences with two deep-well injection systems -- one at the Rocky Mountain Arsenal 10 miles northeast of Denver, and another at the Hammermill Paper Co. plant in Erie, Pa. -- have focussed attention on environmental and operational risks.

At the Arsenal installation wastes were pumped into a fractured-gneiss rock zone at a depth of 12,040 ft. Shortly after the operation began in March 1962 the Denver area became subject to a series of earth tremors, which were previously uncommon. Injection of wastes continued intermittently for some five years when the operation was halted because of a growing conviction among some geologists that this might be causing the disturbance.

A Denver consulting geologist has theorized that the injected fluids reduced friction in faulted rock zones, which in turn led to slippage and thus triggered the quakes. Other scientists question this hypothesis holding to the view that all areas are eqrthquake-prone and it could be only coincidental that the period of tremors in Denver followed operation of the well.

Suggestions that the Arsenal well might be pumped out to avoid possibilities of a catastrophic quake have been countered with the argument that such action could precipitate the event which it seeks to prevent. Whatever the merits of the various judgments being made, the fact is that much undertainty exists with respect to what can happen underground. And once something unfavorable does happen that could be attributed to the injection of wastewaters, it would be very difficult, if not impossible, to reverse the process.

Operational-risk probabilities are illuminated by failure of an injection well at the Hammermill Paper Co. on the shore of Lake Erie. Here a 1,610 ft. deep-well was installed in 1964 to dispose of some 2.5 mgd of spent sulfite liquor along with other waste residues. Utilizing pressures up to 1,300 psi, the liquids were pumped into a dolomite formation. On April 14, 1968, the top of the well blew off with such force that equipment was reported to be thrown 30 ft. in the air. This was followed by a gusher of waste liquids that flowed into Lake Erie at the rate of some 200 gallons per minute for several days before the well could be capped.

The Hammermill failure was attributed to corrosion of a joint in the injection tube. As a result the pressurized liquid stored beneath the ground gained entry into the annulus of the well and thus escaped to the surface. This series of events was attributed to "technological shortcomings" by a spokesman for the company.

Two questions of obvious public concern arise from this incident, namely: What assurances can be obtained from installers and operators of injection wells concerning the technological sufficiency of their systems; and, in addition, what should be the requirements to incorporate fail-safe provisions in a system?

Guidelines pertaining to technological sufficiency are offered in Part II of this report. In dealing with the question of fail-safe provisions perhaps the only response is for regulatory authorities to insist on the availability of alternate disposal facilities. This is called for in Kentucky requirements. And recently in Indiana approval of a deep-well system for ammonium-chloride carried the stipulation that stand-by equipment must be available to evaporate the wastewater discharge in the event the well should fail.(1)

A company specializing in the installation of wells advocates the following(2): If the volume of waste to be disposed of is large and other conditions prevent the use of surface equipment for storage of the produced waste, a stand-by well may be the most practical or economical solution to the problem of maintaining continuous disposal capability. Generally, the stand-by well or a second injection well is completed similar to the primary injection well. The economics of a stand-by injection well versus surface emergency storage facilities determines the feasibility of such a well to solve a disposal problem.

A more recent incident pointing to the importance of stand-by disposal capability has to do with initial operating difficulties with a new injection system at Mansfield, Ohio(3). Here the Empire-Reeves Steel Division drilled a 5,000 ft. well into the Mt. Simon formation for the disposition of spent steel-pickle liquor containing ferric sulfate with about 5 percent of sulfuric acid.

Injection started November 22, 1968, at an average pressure of about 1,100 psi. The pumping rate was about 20,000 gallons per day on an intermittent basis related to demand. On January 19, 1969, an alarm system on the well indicated a malfunction. Injection was stopped and the company resorted to partial neutralization of the spent pickle liquor and discharge to the stream in accordance with requirements existing prior to construction of the well system. Starting March 15, the spent pickle liquor was transported to an abandoned strip mine where it was neutralized with lime before discharge in accordance with an established procedure.

The repairs to the well were completed on April 7 although testing was continued using spent pickle liquor until April 24. Injection was resumed on April 24, 1969, and continued without interruption except for a scheduled shutdown for preventive maintenance in July, 1969, during a mill vacation shutdown.

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(1) Minutes of the Indiana Stream Pollution Control Board, May 20, 1969, p. 19, recording action on approval of application of the Indiana General Corp., of Valpariso, Indiana.

(2) Slagle, K. A. and Stogner, J. M., "Oil Fields Yield New Deep-well Disposal Technique," Water and Sewage Works, June 1969, pp. 238-244.

(3) Personal communication from George H. Eagle, chief engineer, Ohio State Health Department, Nov. 18, 1969.

Utility of the underground -- From the viewpoint of natural-resources stewardship there are reasons to exhibit caution in countenancing subsurface storage of contaminated liquids. It has been contended that proliferation of the use of the underground for wastewater injection could imperil potable groundwater resources as well as limit, if not foreclose, future opportunities for: (a) the extraction of minerals; (b) for the development of subsurface reservoirs for purposes such as freshwater or natural gas storage; and (c) for the potential utilization of brackish groundwaters.

A widely voiced objection to injection wells hinges on the possible hazards of contaminating potable groundwater resources. This concern is most vehemently expressed in cases where approval has been given for the disposition of liquids containing constituents that would be toxic to humans in the concentrations that occur in the wastewater. Examples include highly radioactive materials and residues from insecticide manufacutre. But concern does not end with materials that constitute a threat to health. It embraces any of the substances that might impair groundwater quality.

Another basis for objecting to subsurface storage rests on the risk this may pose for contaminating existing mineral resources. Envisioned in this connection are the environmental hazards that could emanate from the intermingling of an injected radioactive waste with oil or gas deposits. Industrial wastewaters other than those containing radioactivity offer the potential of depreciating the value of mineral deposits. Indeed, this potentiality has been explicitly recognized in new legislation in West Virginia where coal operators are given a strong voice with respect to approval of proposals for deep well installations. In Ohio, the initial criterion for screening an injection-well application is a determination of whether the installation would present the risk of causing wastage or contamination of oil and gas in the earth.

Meantime, utility of the underground for storage of potable water supplies is assuming new dimensions. Among the advantages cited is the elimination of evaporation losses that are associated with open-storage projects. In addition, ground storage permits land that otherwise would be usurped for reservoirs to be used for other purposes. Such storage could be accommodated in saline-water aquifers of the type being used for waste disposal as well as in freshwater aquifers. In fact, storage in saline aquifers has already been practiced in Israel and research toward this end is being carried out in this country.

In situations where heretofore minor concern might have been exhibited if industrial-wastes were to be injected into brackish-water aquifers, a change of view is becoming evident. For example, it is reported that Illinois now regards brackish water with a salt content of some 5,000 ppm that underlies 2,500 sq. miles of the state as a future potential source of water supply that should be protected. This decision reflects confidence that advances in the desalinization of sea water will make it eminently practical to produce potable water at acceptable costs from brackish sources, such as those in Illinois, which are 1/6 as salty as the ocean.

The U. S. Geological Survey has suggested that saline groundwater, which can be found in quantity at some depth under nearly two-thirds of the United States, may be one of the nation's valuable resources of the future. Today it is regarded as worse than worthless -- a "misery" to well drillers.(1)

Adequacy of regulation -- There is growing recognition in states permitting installation of industrial-waste injection systems -- and this includes most of them -- that existing regulatory procedures leave something to be desired. Among the deficiencies cited are: (a) Inadequacy of legislative guidelines and technological criteria; (b) poorly defined jurisdictional linkage among agencies traditionally involved with underground resources and those concerned with pollution contro; and (c) staff unfamiliarity with the complex and often novel aspects of subsurface injection practice.

In states where applications are approved by health or water-pollution control agencies the fortification of staff capabilities to deal with the evaluation of proposed installations and the detailing of safeguards associated with their operation poses difficult problems. As pointed out in a recent report(2) of the Interstate Oil Compact Commission: 'The complex number of skills necessary for full evaluation of a tentative program (of deep-well injection of wastes) is such that no one agency normally would have all the qualified personnel and research facilities for a proper study."

In many states the number of applications received thus far simply has not warranted recruitment of the specialized scientific and engineering personnel that might otherwise be regarded as appropriate. And even under the most favorable circumstances of staff sufficiency, experience with industrial-waste injection is only now reaching the stage where it is becoming feasible to establish criteria for evaluation of proposals. Finally, additional and vital constraints on adequate evaluation are often imposed by the paucity of geologic and hydrologic information at sites under consideration.

Further complications in regulatory practice may be encountered in states where administrative authority is lodged in an agency concerned primarily with oil, gas and mineral extraction. Such agencies are not necessarily oriented to provide appropriate cognizance of the public health and water-resources implications of subsurface waste disposal.

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(1) Anon. "Salty Groundwater Has Vast Potential," Clean Air and Water News, May 29, 1969, p. 2, Commerce Clearing House, Inc., Chicago.

(2) Subsurface Disposal of Industrial Wastes. A study conducted by the Research Committee, Interstate Oil Compact Commission, June 1968, P. O. Box 53127, Oklahoma City, Oklahoma 73105.

Legislative Status of Regulation

The foregoing comments invite additional discussion of the conduct of regulation and development of legislation to improve it.

As matters now stand, the exercise of jurisdiction over the installation and operation of injection systems is basically the responsibilitty of individual states. There is no specific federal legislation regarding deep-well disposal. However, where radioactive wastes are to be dealt with a license must be obtained from the Atomic Energy Commission. The Federal Water Pollution Control Administration, which is charged with review of plans for waste disposal at all federal facilities, presumably could influence choice and design of injection systems.

Information from two surveys[1,2] published in 1938 and supplemented with more recent inquiries on state legislation and policies regarding subsurface disposal, offers a basis for the following portrayal of the present situation:

No state is known to have legislation that denies the installation of wastewater injection systems. However, nine states subscribe to a policy of either rejecting applications (Arizona, Idaho, New Jersey and Wisconsin) or discouraging them (Alaska, South Carolina, South Dakota and New York). New York, for example, recently declared that its policy will be one of regarding liquid-waste injection as a "last resort" after all other methods have been evaluated.

Present policy in the remaining states (among which information from five is not available) is to permit the practice of subsurface disposal. However, only three states -- Ohio, West Virginia and Texas -- have specific legislation pertaining to the regulation of industrial wastewater injection. Regulations applied in other states apparently stem from a patchwork of legislation, some of which relates to the protection of groundwater aquifers or to the installation of salt water injection wells.

As of 1967, industrial wastewater injection systems were being operated in 16 states. From a survey[3] made by the Federal Water Pollution Control Administration at that time the greatest number, 32, was in Texas. Louisiana had 24 and Michigan 21. It is believed that today injection wells have been installed in at least 21 states.

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(1) Walker, Wm. R., and Stewart, Ronald C., "Deep-well Disposal of Wastes," Jour. Sanitary Engineering Div. of ASCE, Oct. 1968, pp. 945-966.

(2) Subsurface Disposal of Industrial Wastes. A study conducted by the Research Committee, Interstate Oil Compact Commission, June 1968.

(3) Warner, Don, Deep-wells for Industrial Waste Injection in the United States - Summary of Data, Bull. WP-20-10, Dept. of the Interior, FWPCA, Cincinnati, Ohio, November 1967.

From information compiled in 1969 for the states signatory to the Ohio River Valley Water Sanitation Compact the distribution and number of wells that have been constructed is as follows: Indiana, 9; Pennsylvania, 5; Ohio, 6; Illinois, 4; West Virginia, 4; New York, 4; and Kentucky, 1.

Ohio legislation -- The Ohio law, which became effective in June of 1967, makes it mandatory to obtain a permit for the use or installation of any well or borehole "for the production, extraction or injection of any gas or liquid mineral, excluding potable water to be used as such, but including natural or artificial brines and oil-field waters, sewage and any liquid used in or resulting from any process or industry, manufacture, trade, business or agriculture."

An application for a permit in Ohio must be filed with the chief of the division of oil and gas. He is vested with responsibility first of determining whether the proposed injection system would present an unreasonable risk of causing wastage or contamination of oil and gas in the earth.

If he concludes such a risk does not exist he then transmits copies of the application to the water pollution control board, director of health, chief of geological survey, chief of division of water and, if so required (by another section of the law), to the chief of the division of mines.

Each of these entities is then required to make a determination as to whether or not the proposal is acceptable or on what basis approval should be qualified. Thereupon "the chief of the division of oil and gas shall issue a liquid disposal permit with such conditions as may be necessary to protect health, safety, or the conservation of natural resources, including all conditions appended by the water pollution control board and the department of health."

Additionally, "the chief may order that a liquid disposal permit be suspended and that operations cease if he determines that the well is being operated in violation of law, regulation, order or condition of the permit." And he is empowered to take similar action "if he has reasonable cause to believe that the permit would not have been issued if information available at the time of suspension had been available at the time a determination was made by one of the agencies acting under authority of this section."

Among the virtues of the Ohio statute is the explicit manner in which it sets forth jurisdictional linkage among administrative agencies for review of proposals and the determination of conditions for approval. This facilitates cognizance of individual agency responsibilities and the enlistment of a variety of staff competencies. Also of merit are the provisions for suspension of a permit.

The Ohio legislation was passed as an emergency measure. Necessity for prompt enactment was postulated on the declaration that the legislation "will enable industries which have a present need to dispose of untreatable waste materials to dispose of them safely underground and thus avoid pollution of the rivers and streams of the state."

From the standpoint of delineating public policy, there are two postulates in this declaration that might be circumscribed. The first has to do with the matter of "untreatable" waste materials. Virtually all waste materials are treatable -- at a cost. In fact, one of the earliest permits issued for underground disposal under the new legislation in Ohio, as will be described, was for wastewater already being treated by one method and amenable to treatment by several other methods in a manner to avoid stream pollution.

The second postulate -- that waste materials can be placed "safely underground" -- would likewise benefit from qualification. As was pointed out earlier, it appears premature on the basis of existing scientific information and operating experiences to fully embrace such a conclusion. Indeed, it is the view of a study committee of the Interstate Oil Compact Commission, previously cited, that: "A majority of the decisions leading to the approval of a disposal program (by industrial waste injection) are based on opinion rather than fact;" and it cautions that "some of the problems which might be created could be far worse than the one being corrected."

Among the first industries in Ohio to gain approval of a deep-well wastewater installation under the new law was the Vistron division plant of Standard Oil Co. of Ohio. As described in a recent publication(1), Vistron had been incinerating a waste stream from its Lima acrylonitrile plant, at an operating cost of $600,000 a year. Studies undertaken by the company concluded that underground disposition of the wastes could be accomplished at an estimated operating cost of only $100,000. It was the cheapest of a half-dozen alternative disposal methods investigated.

Approval was obtained for an injection system in the 200 ft. thick Mt. Simon sandstone stratum, which lies about 3,000 ft. below the Lima area. Feasibility studies by the company indicated that the 20 percent porosity characteristic of the sandstone could be regarded as providing substantial storage capacity, and the permeability was considered suitable for effective lateral dispersion of the waste liquids. The latter contain organic products such as acetonitrile and complex organic cyanides, as well as catalyst solids and up to 10 percent of ammonium sulfate.

It might be concluded from the published information on the Vistron installation that this decision to utilize underground injection was motivated primarily by economic considerations rather than by existence of a need to deal with an "untreatable" waste.

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(1) Anon. "Deepwell Injection is Effective for Waste Disposal," Environ. Science and Technology, June 1968, pp. 406-410.

West Virginia legislation -- Two new legislative acts in West Virginia giving cognizance to regulation of industrial-waste injection systems went into effect on July 1, 1969. One amendment to that part of the state code governing water pollution (Chap. 20-5A) makes it unlawful to operate, plug or abandon any underground injection well without a permit from the chief of the division of water resources of the Department of Natural Resources. Another amendment to Chapter 22 of the code vests extensive powers of control over the installation and abandonment of industrial-waste injection wells with the deputy director for oil and gas of the Department of Mines.

The latter amendment specifies what kind of geological and technical information must be supplied to the deputy director to obtain a permit from the Department of Mines. It also requires the applicant to furnish the same information for the chief of the division of water resources as well as to each coal operator in the area in the event the proposed well is known to be underlain by workable coal deposits.

Additional details on the content of these amendments are given in Part II of this monograph. Because the legislation has just gone into effect little can be said at this time concerning the manner of its administration.

Policy in New York -- One of the states that has been probing for an appropriate basis on which to rule concerning applications for injection-well systems is New York. On May 29, 1969, the division of pure waters of the New York State Department of Health issued a statement of policy which, among other things, said:

> "The injection of liquid wastes by deep wells is considered a last resort after all other methods have been evaluated; it is a method for gaining long-term storage rather than treatment. The applicant must demonstrate that this method (1) is the optimal approach, and (2) has the least effect to the total environment."

What may be regarded as significant with respect to public policy is the declaration that applications for deep-well disposal will be considered only 'as a last resort after all other methods have been evaluated." In brief, the New York authorities have concluded that use of the underground is the least satisfactory option for control of water pollution.

What will command attention, of course, is the manner in which this policy is implemented. For example, what criteria must be devised to evaluate an applicant's demonstration "that this method (1) is the optimal approach, and (2) has the least effect to the total environment?" As detailed throughout this monograph, these are matters that thus far have not been adequately scrutinized.

New Institutional Arrangements

In a recent and provocative assessment of underground disposal[1] Arthur M. Piper, research geologist (retired) of the U. S. Geological Survey, concludes that the time has come to consider creation of a new institutional vehicle for the regulation of wastewater injection.

Mr. Piper's proposal is premised on two propositions: (1) the general public should have the inalienable rights to be spared harm from, and to reap the benefit of accrued experience with, deep-well injection; and (2) few, if any, state agencies currently have the staff skills, centralized authority and financial resources to assure these general-public rights. Accordingly, Mr. Piper advances the need for new institutional arrangements, the structure and functions of which he outlines as follows.

Establishment of a government agency or commission, or a public corporation, either designated from among existing institutions or newly created for the purpose, which would be vested with exclusive authority and responsibility to: (a) delineate provinces and stratigraphic zones suitable for injection; and (b) maintain a continuing record of waste storage in the several provinces and zones -- both capacity occupied and capacity unused, along with volumes, chemical characteristics and concentration of wastes injected. As required, such institutions might exist in en echelon scope -- nationwide, single state or major province, subprovince, and local zone. Staff capability and financial support, both commensurate with responsibility, would be presumed at each echelon. Each subprovince or local zone would constitute a hydrodynamic whole and would be administered as a whole; if any such unit had parts in more than one state, a single jurisdiction would be negotiated or otherwise arranged.

Each of these governmental or public entities would: (a) construct injection facilities and offer waste-storage service at a suitable fee or, alternatively; (b) license a private agency or an association of such agencies to construct and operate an injection facility for its exclusive use. The fee charged for injection service might be scaled according to volume, concentration, and compatibility of the waste delivered to the public agency. Such a policy would create incentive for the waste producer to minimize his demand on the space available for waste storage. The license would require full disclosure of all information originating with the waste producer as required for orderly long-term management of the injection province or zone. The license might also grant to the private agency or association the prerogative of exploring and delineating a suitable injection zone or zones.

Among its prerogatives, the public agency would be authorized to:

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(1) Arthur M. Piper, "Disposal of Liquid Wastes by Injection Underground -- Neither Myth nor Millenium." Presented at annual meeting of the American Institute of Chemical Engineers, Nov. 16-20, 1969, Washington, D. C.

(a) So regulate the construction and casing of injection wells that wastes are excluded, completely and permanently, from the zone between the land surface and the injection zone into which they are released:

(b) Promulgate and enforce "safe" injection pressures and rates of injection -- these should be variable, as hydrodynamic conditions might require;

(c) Prescribe an aggregate volume of waste permitted to be injected into a particular province, subprovince, or zone;

(d) Require any waste to be treated before injection, as may be necessary to render it chemically compatible or stable;

(e) Prohibit injection of chemically incompatible or excessively noxious wastes;

(f) Declare any province, subprovince, or zone to be "off limits" to injection, either permanently or temporarily, as may be necessary to achieve or maintain suitable hydrodynamic and geochemical balances;

(g) As warranted, reserve any particular zone or subzone for a declared resource-management purpose -- for example, as a source of fresh water by desalination, or as a storage area for gas;

(h) Preserve the integrity of the confining layer above any designated waste-injection zone, by requiring that all wells or other openings drilled into that layer for any purpose be adequately cased, and plugged if abandoned;

(i) Continually search for alternative and economically competitive methods of waste handling, to the ends of minimizing encroachment on the land-surface environment while prolonging capacity for injection underground.

Mr. Piper points out that in the concept he has suggested, the public agency having only a local jurisdiction would, in principle, act as an agency of one particular state, possibly in the form of a utility or conservancy district. To implement the concept fully would require legislation establishing the proper Federal role and approaching a uniform state role, both roles to encompass the full scope of technical and management problems discussed or implied.

Legal Liabilities and Constraints

The law pertaining to underground waters has been broadly characterized by one practitioner(1) as vague, uncertain and inadequate. He points out

(1) Kreiger, James H., "The Law of the Underground," Civil Engineering, March 1964, pp. 52-53.

that: "Because what goes on beneath the surface of the earth cannot be seen, it is difficult to comprehend the problems of the underground, let alone fashion meaningful and enforceable rules to govern subsurface activities."

Two areas of litigation that may be associated with injection wells involve the contamination of groundwaters, and interference with the recovery of valuable mineral resources. Legal proceedings for the adjudication of such matters have embraced the doctrines of trespass, negligence, nuisance and strict liability. An informative account of the manner in which these doctrines have been interpreted and applied is provided by Walker and Stewart[1] from which the following commentary is derived.

<u>Trespass</u> -- The "unauthorized entry on the land or invasion of the property right of another,' is a definition of trespass. In cases of alleged subsurface trespass, recovery is allowed only when the plaintiff can demonstrate that damages were sustained, and can identify the offending party. Although trespass is considered in some jurisdictions to offer a possible basis for dealing with subsurface pollution, its utilization is believed to be limited. Knowledge of the flow of percolating waters is uncertain, and the diffusion of waste contaminants through the ground is not easily defined. Thus the basic elements of trespass -- possession and intentional act -- are difficult to establish.

<u>Negligence</u> -- Cited as perhaps one of the most widely accepted bases for relief in cases involving the contamination of percolating waters is negligence. Failure to exercise reasonable care constitutes the tort of negligence. Whether or not a defendant has been negligent is a jury question, which is resolved on the facts of the case. The burden of proof usually rests on the plaintiff.

However, in cases of negligence where the defendant has complete and absolute control of that which causes the damage, the principle of <u>res ipsa loquitur</u> (namely, "the thing speaks for itself") would apply. In such situations the defendant would be subject to the responsibility of showing that reasonable care was exercised. It is suggested that this procedural concept could have application to deep-well injection. If a system is designed so that pollution could not be expected to occur, but in fact does, the courts might shift the burden of proving negligence from the plaintiff.

<u>Nuisance</u> -- Any conduct that interferes unreasonably and substantially with the enjoyment and possession of land may offer a cause for action under the doctrine. In applying this test to subsurface litigation the courts have reasoned that the owner of land is entitled to use of the underground water in its natural state and adjoining land owners have no right to limit this use. Thus, if an injected waste alters the natural state of an underground water a condition of nuisance exists.

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(1) Walker, Wm. R., and Stewart, Ronald C., "Deepwell Disposal of Wastes," <u>Jour</u>. Sanitary Engineering Div., Amer. Soc. of Civil Engineers, October, 1968, pp. 945-968.

The distinction between nuisance and negligence is defined in this manner: Negligence is a failure to employ the degree of care required under the particular circumstances involved; a condition of nuisance, on the other hand, does not rest on the degree of care used, but on the degree of interference that occurs even with the best of care.

Strict liability -- The doctrine of strict liability contends that fault is not a prerequisite for liability. Thus a defendant may be held responsible even though he has in no way acted materially to cause resulting damage. The doctrine has found expression in situations where the inherent hazards associated with an enterprise, although conducted with every possible precaution, threatens others with risk or danger. Strict liability has been imposed on such activities as blasting and drilling of oil wells. It is concluded that applicability of this principle to deep-well injection enterprises will depend on judicial determination of whether such an activity is inherently dangerous. The deep-well operation at the Rocky Mountain Arsenal, which was described earlier, would appear to offer an example where liability for earthquake damage might possibly be asserted if it should be conclusively determined that the tremors in the Denver area were the result of fluid injection.

A final means for legal restraint in cases involving pollution from a deep-well injection system would be to establish violation of a specific statute. The power of a state to promulgate statutes to control activities declared to be a menace to public health apparently is absolute. Thus, violation of a statute prohibiting the pollution of underground waters would serve to establish either negligence or liability as a basis for legal action.

Walker and Stewart conclude their analysis of liability for polluting percolating waters by citing several cases declaring the principle of damnum absque injuria (loss or damage without violation of legal right). They point out that regardless of on what basis relief is sought, several jurisdictions have supported the proposition that to gain recovery negligence must be shown. What this means is that in the absence of determination of negligence there is no liability for damage if the act causing it was a lawful one. In brief, these courts recognized existence of injury but denied recovery, whereas the same set of facts in jurisdictions recognizing the right of action based on nuisance or trespass would permit recovery.

Further considerations -- Additional insights on legal aspects are provided by Talbot(1). Pointing out that one element of concern when injection systems are considered is the matter of subsurface trespass, he then poses the question: Is it in fact trespass and a cause for damages if waste injected under one property migrates in the subsurface to another property owner's holdings?

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(1) Talbot, J. S., "Some Basic Factors in the Consideration and Installation of Deep Well Disposal Systems," Water and Sewage Works, Reference Number, 1968, pp. R213-R219.

In general, he says, the courts have held that such invasion is not ...ie for damages unless the plaintiff is able to show he has in fact been ...ured and further can show reasonably who caused the injury. For ex...mple, if a company operating an injection well, and due to its own neg...igence including improper design and construction of the well causes ...ooding of a coal mine, the well owner would likely be required to pay ...mages to the mine owner.

Mr. Talbot urges clarification by legislative and regulatory bodies of the definition of subsurface 'public" waters. If public waters are ...strued to include those saline underground waters containing valuable elements such as bromine, iodine, chlorine and magnesium this could intro...uce a conflict with longstanding statute and common law declarations. The latter hold that the owner of property owns everything it contains "to the center of the earth." Or it might conflict with the law of capture, which maintains that liquids from the subsurface belong to him who is able to reduce them to possession.

In summary, it would appear that legal liabilities and constraints associated with injection-well practice are rather formidable. Viewed within the context of existing judicial doctrines the owner of a well could be subject to litigation based on allegations of negligence, creation of a nuisance, violation of public-health statutes prohibiting pollution of groundwater, or possibly trespass.

The Setting for Assessment

Up to this point the discussion has sought to frame the setting for an appraisal of injection-well practice and its social implications. From this it may be concluded that public policy issues have received only limited consideration. Furthermore, evaluation procedures and regulatory restraints that now exist often may leave something to be desired.

The prevailing situation invokes rigorous examination. The issues transcend those associated with technologic and economic optimality. They involve the broader and more subtle aspects of social optimality.

Questions to be examined -- Among the specific questions that lay claim for attention are these:

1. Do regulatory agencies have access to -- or means of acquiring -- adequate geologic, hydrologic and technologic information for evaluating the long-range feasibility of injection-well applications?

2. Where information is inadequate what is the nature and scope of investigations and research that should be initiated to remedy these deficiencies?

1. On the basis of existing information is it possible to broadly delineate areas that appear to be (a) favorable for the practice of injection; (b) utterly unsuitable; and (c) questionable pending more detailed examination?

2. Are there reasons other than convenience and economic preferment that can be advanced to justify subsurface disposal and how valid are these reasons?

3. On the basis of theoretical considerations and practical experience what are the risk probabilities of wastewater injection causing: (a) environmental hazards; and (b) impairment of utility of the underground and future extraction of its mineral resources?

4. In view of the unknowns presently associated with the practice of subsurface injection under what circumstances and conditions should society find it reasonable to trade off probabilities of risk?

Positions and attitudes -- While a majority of states permit the practice only three of them -- Ohio, West Virginia and Texas -- have specific legislation pertaining to injection of industrial wastewaters. Thus it might be conjectured that most states either are in the dubious position of having confidence in the adequacy of existing regulations or have not yet assessed their situation.

Thus far the Federal government has not essayed an activist role in the delineation of policy pertaining to deep-well disposal. But there are indications that this stance is not destined to remain static. For example, the U. S. Geological Survey has become increasingly vocal in expressing concern over the possibilities of creating an unsolvable problem for the future by indiscriminate "sweeping of our wastes underground." Some weeks after this monograph was completed and an advance copy made available to the Federal Water Pollution Control Administration for review, the Secretary of the Interior issued a news release that said, among other things:

> "For years we have been pouring unwanted, and sometimes noxious, wastes deep into the ground with relatively random and cursory restrictions based upon fragmented geologic knowledge. All prudence dictates that we attack this problem systematically before it gets out of hand."

The news release stated that the Secretary had ordered the Geological Survey to carry out a research program. Undoubtedly one of the policy questions that will be examined is: Should federal legislation be broadened to deal with prevention of groundwater as well as surface-water pollution and thus provide a basis for regulating injection-well systems?

Four years ago the predecessor agency of the Federal Water Pollution Control Administration published what may be regarded as the first definitive account of deep-well injection practice in the United States.(1) The author of that bulletin, Dr. Warner, who has written the following Part II of this monograph said in 1965: " . . . deep-well injection of liquid wastes is thought to be technically feasible in many areas of the country and, if properly planned and implemented, is not likely to be harmful to natural resources." His view was premised on having available adequate knowledge of the geologic, hydrologic and engineering aspects of deep-well disposal, and it reflected experiences with the practice up to that time.

Upon re-examination, Dr. Warner believes that his earlier conclusion is valid today. The few instances of environmental damage that have resulted and the operational difficulties that have occurred reinforce his caveat that injection systems must not only be planned and constructed with the greatest care but operated with utmost skill and vigilance.

Presumably considerable time may elapse while social policy and other issues are being debated. Meanwhile, many state agencies will be involved with decisions on the approval of injection-well installations. Part II of this monograph offers guidelines for this purpose. It outlines hydrogeologic and technologic criteria for evaluating proposals, along with some recommendations on administrative procedures. In addition, it includes a description of major geological characteristics of the Ohio Valley region with reference to their suitability for wastewater injection.

(1) Warner, Don L., "Deepwell Injection of Liquid Waste," Public Health Service Publication 999-WP-21, Division of Water Supply and Pollution Control, U. S. Dept. of Health, Education and Welfare, Cincinnati, Ohio, April 1965.

Regulation

PART II -- ADMINISTRATIVE GUIDELINES AND EVALUATION CRITERIA

Regulation of the installation and operation of injection-well systems involves consideration of procedures that will satisfy administrative needs, geologic evaluation and technical requirements. It is the purpose of this Part II of the memorandum to discuss these matters with specific reference to conditions that prevail in the region of the states signatory to the Ohio River Valley Water Sanitation Compact. Attention will first be directed to administrative considerations.

ADMINISTRATIVE CONSIDERATIONS

Six steps are identified as essential in the administration of a regulatory program for deep-well wastewater disposal.[1] They are:

1. Preliminary assessment by the applicant of the geology and geohydrology at the proposed well site and the suitability of the wastes for ~~disposal.~~ injection These initial studies should be made in consultation with the appropriate state agencies, as described later.

2. Preparation by the applicant of an application for injection a permit to drill and test ~~or convert~~ a well for underground waste ~~disposal.~~ This application requires an extensive report that documents all details of the proposed disposal plan ~~as~~ (outlined in Appendix A-1). Granting of this permit only allows the applicant to drill and test a well. It does not convey permission for waste disposal.

3. Drilling and evaluation of the test well under surveillance of the state and submission of the well samples and logs and test information to the state along with a well completion report (Appendix A-2).

4. Request by the applicant for approval to ~~dispose of~~ inject wastes into the drilled well. [An example of the application for underground waste disposal is included as (Appendix A-3).]

5. Operation of the system under ~~supervision~~ regulation of the state. [~~An example of a form~~ for submitting operating information is included] ~~as~~ (Appendix A-4).

6. Abandonment of the well by the operator ~~with the approval and under the supervision of the state~~ in accordance with state regulations. Supervision ~~regulation~~. Examples of an application for a permit to plug and abandon an injection well and a final abandonment report are included ~~as~~ (Appendixes A-5 and A-6).

None of the ORSANCO states employ precisely the procedures outlined in steps 1 through 6, but all of the states that have existing wells have proceeded generally in the manner outlined. Procedure employed by the individual ORSANCO states is described as follows:

[1] Throughout Part II, the term waste is meant to imply industrial wastewater.

UGIWW

ILLINOIS

Authority for regulation of underground waste disposal is invested in both the Sanitary Water Board and the Department of Mines and Minerals. Permits are required from both agencies, a permit for construction of a waste disposal facility from the Sanitary Water Board and a well drilling permit from the Department of Mines and Minerals. A $1,000 bond to insure proper plugging of the well upon abandonment must be submitted to the State Mining Board prior to commencement of drilling.

In addition to the drilling permit, an application to use the well for waste disposal must also be submitted to the Department of Mines and Minerals, before or after drilling of the well. A requirement for this permit is notification by the applicant to oil and gas and coal mine operators within one-half mile of the well site that application is being made for a disposal well permit. If objection is made, a hearing may be held.

It has been the practice of the Sanitary Water Board to visit the construction site at the times that water samples are obtained, well logs run, and injection tests made. A well completion report must be filed with the Department of Mines and Minerals within 30 days after completion of the well, and well logs and generally rock and water samples are supplied to the State Geological Survey.

Upon abandonment of a disposal well, it must be plugged as directed by the Department of Mines and Minerals and an affidavit to this effect submitted to that agency.

INDIANA

Indiana Stream Pollution Control Law, Section 10 of Chapter 214, Acts of 1943 as amended, requires that all plans and specifications for water pollution control facilities be approved by the Stream Pollution Control Board. A 1957 amendment (Sec. 16) gives the authority to prevent and control pollution of groundwater. It is on the basis of this authority that the pollution control board requires approval of all deep-well disposal systems in the state.

The board does not have specific construction or operating requirements for deep-well industrial waste disposal systems. Each project is reviewed as an individual case.

The Indiana Department of Natural Resources, Geological Survey, is consulted by the pollution control board concerning the geological aspects of each project.

KENTUCKY

Applications for subsurface waste disposal in Kentucky are acted upon by the Water Pollution Control Commission of the State Department of Health, division of environmental health. The commission solicits the advice of the State Geological Survey and the division of oil and gas, State Department of Mines and Minerals. Specific regulations have not been formally adopted by the commission but the following information must be submitted in support of an application before a permit would be issued.

A process "flow sheet" and description of the plant's operations.

A detailed explanation of the plant's operations which result in a waste effluent.

A breakdown of the substances and quantities that will be contained in the waste stream.

A geological report describing the local and regional geology. If possible, the zone of influence of the well must be defined.

Information on wells previously drilled in the influence zone, their location and condition.

The storage capacity of the disposal formation, the maximum injection rates and pressure.

Information regarding the treatment facilities required to render the waste waters compatible with the disposal formation waters.

Type of monitoring system or systems that will be provided.

A plan showing a stand-by or alternate disposal system.

The type of construction which will be applicable to completion of the disposal well.

The commission requires that a permit to drill a well be obtained from the division of oil and gas and submitted along with the above information. Performance bonds are required during the life of the well.

NEW YORK

New York presently does not have specific laws or regulations governing deep-well industrial waste disposal. However, the following statement of policy has been developed by the New York Department of Health to guide those who seek permission to dispose of waste by subsurface injection:

The injection of liquid wastes by deep wells is considered a last resort after all other methods have been evaluated; it is a method for gaining long-term storage rather than treatment. The applicant must demonstrate that this method (1) is the optimal approach, and (2) has the least effect on the total environment.

fresh groundwaters and potential mineral resources, which may be subject to ... development, must be protected against any adverse effect by the disposal ... wastes into the subsurface.

It is incumbent upon the applicant to obtain a competent geologist and a ...sional engineer for the necessary studies, design and preparation of re... and plans. This should include, but not be limited to the environmental, ...nomical and technical implications.

Continuous injection at critical input (hydraulic parting) pressures is pro...ited and will not be approved.

A permit must be issued prior to the construction and operation of any dis...al of wastes through deep well injection.

Concurrence must be obtained from the division of oil and gas of the Conser... Department and the office of the state geologist of the Education Department.

Permits are required from both the New York State Department of Health and ...division of oil and gas. The health department requires a permit for the ...struction of a waste disposal system. Permits to drill, reopen, plug back, or ...vert deep wells are required by the division of oil and gas. A $1,000 bond is ... required to insure proper surface restoration and well plugging. These and ...er requirements of the division of oil and gas apply.

A fact of importance in New York is that the groundwaters, including saline ..., have been classified according to usage, based on quality. Fresh ground...ters are defined as those having a chloride content equal to or less than ... mg/l or a total dissolved solids content equal to or less than 1,000 mg/l. ...ine water is defined as exceeding these limits. Saline groundwaters are ...ified as GSA or GSB. GSA waters are those best used as a source of potable ...eral water, for conversion to potable water, or as raw material for chemical ...ufacture. GSB waters are those saline waters having a chloride content in ...ess of 1,000 mg/l or a total dissolved solids content of over 2,000 mg/l, the ...ifers of which may be used for disposal of wastes.

...

Prior to 1967, Ohio did not, by policy, permit the subsurface injection of ...tes other than oil-field brines. During 1967, the Ohio legislature enacted ...es in the state oil and gas code to incorporate specific wording pertaining ... industrial-waste disposal wells. Regulatory authority is in the division of ...and gas of the Department of Natural Resources. Applications for a permit ...e a well for waste disposal must, however, also be approved by the Water ...tion Control Board, the Department of Health, and the Geological Survey. ...e proposed well is in a coal-bearing area the division of mines must also ... approval. Denial of approval by agencies other than the division of oil ... gas can be appealed.

Rules and regulations specifically governing industrial-waste disposal wells ...e not been developed. Applications for a permit are handled individually.

...ments for construction and abandonment procedures as applied to oil, gas, ...brine disposal wells in Ohio generally also apply to industrial-waste injec-... wells. Such requirements include obtaining a permit to drill, reopen, deepen, ...back, or rework a well, posting of a surety bond, providing a well completion ... and such rock samples and well logs as may be requested, and maintaining a ...ord of the volume of fluid injected and the pressures experienced.

...SYLVANIA

Grover Emrich

In Pennsylvania, the Sanitary Water Board regulates the subterranean disposal ...astes. The Department of Health is the board's enforcement agent. Application ... permit to dispose of wastes by deep-well injection is made on the board's ...lication form relative to treatment or discharge of industrial wastes. The ...'s Department of Mines and Mineral Industries regulates certain aspects of well ...struction and abandonment in areas underlain by workable coal seams.

No specific rules, regulations, or procedures have been developed by the ...nitary Water Board. Each disposal well is regulated as an individual case.

...RGINIA

In Virginia, the State Water Control Board has jurisdiction over underground ...aters and, therefore, apparently the authority to regulate deep-well waste dis-...osal. It is not yet known whether the requirements established by other state ...encies are applicable. This has not been resolved because no applications for ...bsurface disposal have been received.

It is anticipated that any application for deep-well waste disposal would ...enerally follow the same format as is now required for facilities disposing of waste to surface waters. In the evaluation of proposals, supervision of con-struction and operation and other technical matters, the board presumably would ...raw upon the services of other state and federal agencies as consultants.

...EST VIRGINIA

Chapter 20, Article 5-A of West Virginia Code empowers the chief of the division of water resources of the Department of Natural Resources to require the submission of plans, specifications, and other data relative to, and inspect the construction and operation of any activity in connection with water pollution control. The law further requires all persons directly or indirectly discharging or disposing of treated or untreated wastes into any waters or underground strata of the state to file with the division of water resources such information as the chief may require in a form prescribed by him.

In addition to these general powers, the law as amended in 1969, specifically states that "it shall be unlawful for any person, unless he holds a permit therefore from the department, which is in full force and effect, to:"

"Operate any disposal well for the injection or reinjection underground of any industrial wastes, including, but not limited to liquids or gases, or convert any well into such a disposal well or plug or abandon any such disposal well."

In addition to the power vested with the division of Water Resources, the deputy director for oil and gas of the Department of Mines has extensive powers of control over the construction and abandonment of industrial-waste injection-wells as conveyed by 1969 amendments to Chapter 22 of the Code of West Virginia.

This portion of the West Virginia Code states that:
Section 22-4-2b: Before drilling a well for industrial waste injection, the well operator must submit a plat showing the tract and all adjacent tracts and the names of owners, and the proposed well location.

The operator must also provide the following information on the plat or by way of attachment thereto to the department in the manner and form prescribed by the department's rules and regulations:

(a) The location of all wells, abandoned or otherwise located within the area to be affected;

(b) where available, the casing records of all such wells;

(c) where available, the drilling log of all such wells;

(d) the maximum pressure to be introduced;

(e) the geological formation into which such liquid or pressure is to be introduced;

(f) a general description of the liquids to be introduced;

(g) the location of all water-bearing horizons above and below the geological formation into which such pressure, liquid or waste is to be introduced; and

(h) such other information as the deputy director by rule and regulation may require.

In the event a proposed well is known to be underlain by workable coal deposits, all of the above information must be forwarded to each coal operator operating inside or within 500 feet adjacent to the tract involved. This information must also be supplied to the chief of the division of water resources. If no objection is made by a coal operator, by the Department of Mines, or the division of water resources within 30 days, a permit is issued to the applicant, subject to the bonding provisions of the code. A bond of $1,000 per well or a blanket bond of $10,000 is required.

If objections to the application are raised by any affected coal operator, the chief of the division of water resources, or by the Department of Mines, there is provision for a hearing, and if such objections cannot be resolved there further provision for the applicant to appeal to the county circuit court.

On the other hand, if a permit should be granted over the objections of a coal operator or the chief of the division of water resources, either of them may appeal such a decision to the county circuit court and, if necessary, to the supreme court of appeals.

The laws additionally provide for protective casing to be left in during the life of the well, for the proper installation of fresh water casing, and for the adherence to specified plugging and abandonment procedures.

TECHNICAL CONSIDERATIONS

Procedure in the ORSANCO district for complying with the state requirements for waste injection wells have been outlined. Attention will now be focussed on technical aspects to be considered in preparing and evaluating waste injection proposals and in regulating the construction, operation and abandonment of injection systems. The discussion is intended to be useful to those preparing proposals as well as to those who are charged with their evaluation.

The discussion of technical considerations is strongly oriented toward the regional geologic conditions in the Ohio Valley and all other aspects receive less extensive treatment. This is because the writer (Warner, 1965) previously reviewed the engineering aspects of deep-well injection that apply generally, and rather than to be repetitive, the reader is referred to the earlier publication.

The geologic discussion is not extensively referenced, but rather, the reader is advised to seek assistance from the appropriate state, federal and interstate agencies and private consultants in obtaining more detailed information. It should be noted that state agencies in Illinois and New York have published papers dealing with the geologic aspects of subsurface disposal in those states. (Bergstrom, 1968; Kreidler, 1967). A description of the possibilities of subsurface industrial waste disposal in New York has also been published by McCann and others (1968).

CHARACTERISTICS OF UNTREATED WASTES

A foremost consideration in evaluating the feasibility of deep-well injection is the character of the untreated wastewater. In Table 1 are listed the factors that are pertinent.

Waste volumes should be small. No arbitrary limit can be specified, but quantities greater than a few hundred gallons per minute are generally too great for injection into a single well in the Ohio Valley. Review of industrial processes may reveal possibilities for minimizing the volume of wastes for injection through such means as improved waste management practices or by exclusion of waste streams that can be handled by other means.

For example, Armco Steel Corporation of Middletown, Ohio, originally contemplated injecting 700 gpm of concentrated spent-pickling liquor along with dilute rinse water from pickling operations into a well. Testing of the first well, which was drilled in 1967, indicated that only the concentrated pickling liquor could be economically injected. The remaining dilute rinse water will be treated by neutralization and other processes.

TABLE 1 -- Factors to be Considered in Evaluating the Suitability of Untreated Wastes for Deep-Well Disposal

A. Volume

B. Physical Characteristics

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

C. Chemical Characteristics

1. Chemical constituents
2. pH
3. Chemical stability
4. Reactivity

   a. With system components
   b. With formation waters
   c. With formation minerals

5. Toxicity

D. Biological Characteristics

Waste liquids with a high content of dissolved inorganic solids are among the most commonly considered feasible for injection disposal. Industries have also favored injection of waste liquids containing organic or inorganic chemicals that are objectionable in trace amounts in surface waters, as well as highly concentrated organic chemicals that are resistant to biological degradation.

Wastes containing suspended solids as the major contaminants are not normally suitable for injection. However, wastes of this type are being injected, without prefiltration, into a highly porous and permeable limestone formation by the Dow Chemical Company at Midland, Michigan.

Commonly mentioned problems related to waste characteristics are listed in Table 2. Examples of the occurrence of some of these problems and methods used for solving them are included in the description of existing wells.

TABLE 2 -- Operational Problems Related To Waste Character

Problem of Concern	Means of Evaluating	Means of Controlling Undesirable Effects
REACTION		
Wastes and formation minerals	Laboratory tests and observation of system	Preinjection waste treatment
Wastes and formation water	Laboratory tests	Preinjection waste treatment or a buffer zone
Autoreaction of waste at formation temperature and pressure	Laboratory tests	Preinjection waste treatment
Wastes and system components	Laboratory tests and observation of system	Preinjection waste treatment, addition of corrosion inhibitors to waste, and use of corrosion-resistant materials
MICROORGANISMS	Laboratory tests and observation of system	Preinjection waste treatment and addition of biocides
SUSPENDED SOLIDS	Laboratory tests and observation of system	Preinjection waste treatment or formation treatment
ENTRAINED OR DISSOLVED GASES	Laboratory tests and observation of system	Chemical or mechanical degasification

GEOLOGY AND GROUNDWATER HYDROLOGY

The suitability of a particular site within the ORSANCO drainage district for deep-well waste injection depends, among other things, upon the geology and the hydrology of underground waters at the site and in the vicinity.

Examination of a site begins at the regional level, then is narrowed to the vicinity of the site and finally focuses upon the immediate site itself. Outlined in Table 3 are factors to be considered in site evaluation.

Only regional geologic and hydrologic framework for the ORSANCO district can be outlined in this memorandum. It is not practical to attempt to report on such a large geographic area in sufficient detail to provide an analysis of the local geology. Such analysis must be made for each proposed injection system unless an existing installation is so closely located as to provide this information.

Water pollution control agencies may not always have the information or the personnel to adequately develop and evaluate the geologic aspects of injection proposals. Each of the ORSANCO states does, however, have agencies with geologic information on file and staffed with men trained in the geologic fields to assist in the development and evaluation of proposals.

TABLE 3 -- Factors For Consideration In The Geologic And Hydrologic Evaluation Of A Site For Deep-Well Waste Injection

I. Regional geologic and hydrologic framework
   A. Structural geology
   B. Stratigraphic geology
   C. Groundwater geology
   D. Mineral resources
   E. Seismisity
   F. Hydrodynamics

II. Local geology and geohydrology
   A. Structural geology
   B. Geologic description of sedimentary rock units
      1. General rock types and characteristics
      2. Detailed description of potential injection horizons and confining beds
         a. Lithology
         b. Thickness and vertical and lateral distribution
         c. Porosity (type and distribution as well as amount)
         d. Permeability (same as c)
         e. Chemical characteristics of reservoir fluids

TABLE 3 (Continued)

3. Groundwater aquifers at the site and in the vicinity
   a. Thickness
   b. General character
   c. Amount of use and potential for use

4. Mineral resources and their occurrence at the well site and in the immediate area
   a. Oil and gas (including past, present and possible future development)
   b. Coal (as in a)
   c. Brines (as in a)
   d. Other (as in a)

Physiography and General Geology -- The physiography of the Ohio Valley area is not of much direct consequence in considering deep underground disposal, however, the physiographic provinces shown in Fig. 1 reflect to a large degree the underlying geologic features that are important. In Table 4 are listed the physiographic units of the Ohio Valley and vicinity with a description of their characteristics, principal rock units, and general geologic structure. The descriptions in Table 4 and Fig. 1, 2, and 3 show the close relationship between the physiographic units and the geologic features. For example, the boundaries of the Blue Ridge physiographic province, the Valley and Ridge province, and the Coastal Plain province are essentially the same as boundaries of geologic features shown in Fig. 3, and it is therefore convenient to discuss them as geologic units.

Consolidated rocks within the Ohio River drainage basin range in age from Precambrian to Tertiary; Precambrian rocks are the oldest and Tertiary the youngest (Fig. 2). These consolidated rocks are overlain by unconsolidated Quaternary age glacial deposits in the northern part of the basin and by alluvium in the major stream valleys. A few feet of soil usually masks these geologic deposits at the immediate surface. Precambrian igneous and metamorphic rocks lie beneath the covering of younger sedimentary rocks everywhere in the Ohio basin and because they are essentially nonporous and impermeable form the so-called "basement." Precambrian rocks lie at the surface in the bulge that extends from the southeast side of the basin into the Appalachian Mountains of West Virginia, Virginia and North Carolina.

Physiographic Units of the Ohio Valley and Their Characteristics

Physiographic Unit	General Physiographic Characteristics	Principal Rock Units	General Geologic Structure
1. Appalachian Highlands Division			
a. Piedmont Province	Rolling hills, gentle slopes, low to moderate relief	Paleozoic, metamorphic and igneous crystalline rocks	Intense faulting and folding and intrusion by igneous rocks
b. Blue Ridge Province	Mountains, steep slopes, deep valleys, moderate to high relief	Precambrian and Paleozoic metamorphic and igneous rocks	As in a.
c. Valley and Ridge Province	Ridges with steep slopes and moderate to high relief. Broad valleys with areas of low rounded hills. Valley and ridge pattern controlled by geologic structure	Sedimentary rocks of Cambrian through Pennsylvanian ages. Total thickness 25,000 to 40,000 feet	Sedimentary rock beds are everywhere tilted and folded into prominent anticlines and synclines and are cut by many large faults
d. Appalachian Plateaus Province	Dissected plateaus, steep slopes, moderate to strong relief. Drainage pattern is random	Sandstone and shale with coal, limestone and conglomerate of Devonian through Permian age, but primary Pennsylvanian and Mississippian. Older sedimentary rocks are not exposed. Total thickness of sedimentary rocks ranges from 5,000 feet in west to 20,000 feet in east	Considerable folding and faulting along the boundary of the Valley and Ridge province. Nearly flat lying beds further west with more gentle folds and few faults

Table 4 -- Physiographic Units of the [illegible] Valley and Their Characteristics

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1. Appalachian Highlands Division			
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d. Appalachian Plateaus Province	Dissected plateaus, steep slopes, moderate to strong relief. Drainage pattern is random	Sandstone and shale with coal, limestone and conglomerate of Devonian through Permian age, but primary Pennsylvanian and Mississippian. Older sedimentary rocks are not exposed. Total thickness of sedimentary rocks ranges from 5,000 feet in west to 20,000 feet in east	Considerable folding and faulting along the boundary of the Valley and Ridge province. Nearly flat lying beds further west with more gentle folds and few faults

Table 4 -- Physiographic Units of the Ohio Valley and Their Characteristics (cont.)

Physiographic Unit	General Physiographic Characteristics	Principal Rock Units	General Geologic Structure
2. Interior Plains Division			
a. Central Lowlands Province	Gentle slopes, low to moderate relief, random drainage pattern	Sedimentary rocks of all types but limestone and shale predominate. Exposed rocks are of Ordovician to Pennsylvanian age. Quaternary age glacial deposits may cover bedrock. Total thickness of sedimentary rock 3,000 to 5,000 feet	Beds nearly flat-lying with broad arches and basins. Little faulting except in Kentucky River and Rough Creek fault zones
b. Interior low Plateaus Province	As in a.	As in a. except no glacial deposits	
3. Atlantic Plain Division			
a. Coastal Plain Province	Low hills, flood plain and delta low to moderate relief	Poorly consolidated Cretaceous and Tertiary sedimentary rocks, may be overlain by Quaternary alluvium. The thickness increases southward from a few hundred feet in the north	Cretaceous and Tertiary sedimentary beds dip gently to the south and unconformably Precambrian rocks

The configuration of the Precambrian basement in the Ohio basin is shown in Fig. 4, which is a contour map of that surface with sea level as a datum. The total thickness of the sedimentary rock cover at any point can readily be estimated by subtracting the altitude of the Precambrian surface as determined from Fig. 4 from the altitude of the land surface, which can be obtained from a topographic map.

The total thickness of sedimentary rocks ranges from zero in the area of exposed Precambrian rocks to a maximum of about 30,000 ft. in the northeastern portion of the Ohio Valley. A minimum amount of 2,000 to 3,000 ft. of sedimentary rocks is necessary, in most circumstances, to provide a satisfactory environment for waste disposal.

Structural Geology -- Structural geology for the purpose of this report means the folding, faulting and fracturing of rocks and the geographic distribution of these features. Such features comprise part of the geologic environment and affect the subsurface hydrology and thus affect the waste disposal potential.

Major structural geologic features of the Ohio Valley and surrounding area are shown in Fig. 3. Major synclinal basins or downwarps of the crust are the Appalachian basin and the Illinois basin. Small portions of the Michigan basin and the Mississippi embayment are also within the Ohio Valley. The Cincinnati arch and its continuations, the Kankakee and Waverly arches to the north and the Nashville dome to the south are major uplifts separating the basins. The outcrop of crystalline rocks that forms the core of the Appalachian Mountain ranges (Blue Ridge province) represents a major anticlinal fold that bounds the Appalachian basin on the southeast.

Each of the major folds has many smaller ones superimposed upon it. The southeastern portion of the Appalachian basin is, in particular, complexly deformed by many smaller folds as indicated in Fig. 3.

A zone of very intense and complex folding, faulting and fracturing ranging from a few miles up to about 80 miles in width borders the northeast-southwest trending crystalline core of the Appalachian Mountains from the Alabama-Georgia border north into Canada. As has been mentioned, this zone coincides with the so-called Valley and Ridge physiographic province and will be referred to by that name. Other areas of relatively intense rock deformation are the faulted and fractured Rough Creek and Kentucky River fault zones.

Blue Ridge Province

Rocks of the Blue Ridge province are complexly deformed Paleozoic and Precambrian metamorphic and igneous rocks that provide no opportunity for deep disposal and the area will, therefore, not be discussed further.

Valley and Ridge Province

The Valley and Ridge province is a classic geologic area because of the abundance of structural features. Almost everywhere, the rocks have been tilted at moderate to steep angles and in places completely overturned. Anticlines, synclines, and large faults are abundant.

The intensity of rock deformation in the Valley and Ridge province decreases from southwest to northeast. Intense faulting characterizes the province in Tennessee, but faults become less abundant northeastward and are largely replaced by sharp narrow synclines and anticlines in central Virginia. In northeast Pennsylvania, the folds have flattened and they die out completely in southern New York, where the Valley and Ridge province narrows and passes into the Appalachian plateaus.

A vertical thickness of as much as 40,000 ft. of sedimentary rocks is believed to underlie portions of the Valley and Ridge province. In spite of this enormous thickness of sedimentary rocks, the structural complexity of the province makes it a relatively poor geologic area for underground waste injection. However, the area is not equally deformed throughout its extent and subsurface injection may be permissible locally.

Appalachian Plateaus

The Appalachian Plateaus are formed by relatively flat-lying, deeply dissected Mississippian and Pennsylvanian age strata that lie within a broad downwarp that includes most of the Appalachian basin as shown in Fig. 3. The boundary between the Appalachian Plateaus and the Valley and Ridge province is at the border of the erosionally resistant Pennsylvanian sediments, which form an escarpment that rises abruptly above the topographic level of the Valley and Ridge province to the east.

As was described, deformation within the Valley and Ridge province decreases toward the northwest. It does not end, however, at the boundary of the Appalachian Plateaus, but continues to decrease in intensity, the folds becoming broader and more gentle and faulting less prevalent. Support for this concept has been found in recent years, through more detailed geologic studies and through deep drilling for oil and gas, that show that the intensity of folding and the prevalence of faulting may be much greater beneath the surface in portions of the plateau area than is apparent at the surface. This is true in the complexly folded area shown in Fig. 3 that occupies much of the Appalachian basin.

Another structurally complex area of the Appalachian Plateaus province is the Kentucky River fault zone. This zone consists of a number of normal faults that have displacements of as much as 600 ft. This zone is a continuation of the Rough Creek fault zone that is discussed later.

Structural geologic conditions alone do not appear to preclude subsurface waste injection within most of the Appalachian Plateaus province. Areas where structural conditions may limit use of the subsurface are in the Kentucky River fault zone and perhaps in the deeper zones of the complexly folded area adjacent to the Valley and Ridge province.

Interior Provinces

The various interior physiographic provinces that contain all of the pertinent geologic features west of the Appalachian basin have a somewhat similar geologic character. The sedimentary rocks have been broadly raised and lowered to form arches, domes and basins. In the basins the sediments are thicker and Pennsylvanian and Mississippian age rocks lie at the surface, whereas the sedimentary cover over the uplifts is thinner and older rocks are exposed. The basins and arches have undergone several periods of deformation and they have had some smaller folds and faults superposed on them. The various major structural geologic features of the interior provinces are discussed below.

Cincinnati Arch -- The Cincinnati arch and its continuations separate the Appalachian basin from the Michigan and Illinois basins. Near Cincinnati, Ordovician rocks lie nearly flat on its crest and about 4,000 ft. of Ordovician and Cambrian sedimentary rocks cover the Precambrian basement. These sediments dip gently northwest and southeast from the crest of the arch beneath progressively younger beds. Sediments are about 2,000 ft. thick over the crest of the Findlay arch and about 5,000 ft. thick over the Nashville dome. The sediments are not generally disturbed by faulting of much consequence, except in the area of the Kentucky River fault zone. Minor folds trend northwest across the main structure of the Nashville dome on its southside and may reflect the presence of fractures at depth.

Illinois Basin -- The Illinois basin (Fig. 3) is an oval area containing a thickness of 12,000 to 14,000 ft. of sedimentary rocks at its center. The basin is a relatively gentle downwarp and beds dip toward the center of the basin at rates of one degree or less, except where local deformation has caused greater tilting.

The Illinois basin is divided into two parts by the southward trending anticlinal ridge (LaSalle anticline) that extends through much of the length of the basin. The location of this feature is reflected by the southward indenting of the structure contours in Fig. 5. Subsidiary folds and faults associated with the LaSalle anticline and other unrelated folds and faults complicate the structure of the Illinois basin.

Rough Creek Fault Zone -- In southern Illinois, western Kentucky, and adjacent areas, the Paleozoic rocks are extensively disturbed by faulting in a 175-mile long area. A series of east-west trending faults along the north border of this area form the Rough Creek fault zone (Figs. 3 and 5). A series of northeast trending faults that lie south of the Rough Creek zone and, in part, cut across it are included in the faulted area shown in Fig. 3. Faults in this disturbed zone have displacements of up to 3,500 ft. In the southern part of the area faults contain veins of the mineral fluorite and numerous bodies of igneous intrusive rocks have invaded the sedimentary beds.

To the east, in Kentucky, the Rough Creek zone breaks up into discontinuous ...tures. Further east along the same trend the previously mentioned Kentucky ... fault zone occurs as a continuation of this disturbed belt.

... Features of Interior Provinces -- Because so little of the Ohio Valley ... involved, the Michigan basin and the Mississippi embayment will not be ...ssed in detail.

The area of the Ohio basin that is underlain by the Mississippi embayment ... considered to offer little possibility for underground disposal because the ...er rocks that contain potential disposal intervals are likely to be disturbed ... the same type of structural features that occur in the fault zone immediately ... the north.

The Illinois basin is a generally favorable area for deep-well disposal, ...ce it is underlain by a relatively thick sequence of sedimentary rocks with ...tentially suitable injection intervals.

The anticlinal area between the Illinois and Appalachian basins is also ...nerally favorable within the Ohio Valley. Sedimentary rock sequences are, ...wever, thinner in the interbasin areas and the number of potential injection ...tervals is thus limited.

The major fault zones that have been mentioned are not necessarily entirely ...nsuitable for underground disposal but their suitability is greatly limited because of their structural geologic complexity and because injection zones and ...confining beds are offset by faults and perhaps extensively fractured.

Stratigraphic Geology -- A satisfactory injection horizon may be defined as one with sufficient porosity, permeability, and areal extent to accept injected fluids at safe pressures without hazard to natural resources. Thick sequences of sedimentary rock usually contain sandstones, limestones, or dolomites with these characteristics. Such rocks are fluid-saturated in the subsurface and, below the present level of fresh water circulation, contain saline water in the pores. This interstitial saline water is not suitable for most purposes and only occasionally contains enough dissolved minerals to be commercially valuable.

It is generally desirable for shale or other impermeable confining strata to overlie and underlie the injection horizon to prevent the vertical escape of injected waste. Absolute confinement may not always be essential, as sufficient protection may be provided by a series of thick permeable formations that can safely accommodate the relatively small volumes of waste liquids involved.

As previously mentioned, the total thickness of sedimentary rocks in the Valley ranges from zero to a maximum of about 30,000 ft. These sediments in age from Cambrian to Tertiary. Rocks of interest for underground dis- al are from Cambrian to Pennsylvanian in age.

In Fig. 10 are shown the relationships of some of these sedimentary rocks a cross section that extends from eastern Illinois to western Pennsylvania; Fig. 11 are shown similar relations from northwest to southeast Ohio. These cross sections are shown to provide some concept of the regional distribution be found among some of the rock units of the Ohio Valley. It is informative realize, for example, that the Trenton Limestone is found in the subsurface roughout virtually the entire Ohio Valley area and beyond. This point is fur- er illustrated by Fig. 5, which is a contour map on the top of the Trenton estone.

Other geologic units such as the Mt. Simon Sandstone are also widely distri- uted and are recognized by the same name. On the other hand, many of the geo- gic units are only locally recognizable and their names are only locally applied. e original cross sections from which Figs. 9 and 10 were constructed provide ex- ples of much more detailed correlations of some of the geologic units found in the subsurface in the Ohio Valley. In Table 5 is listed the terminology used for rock units in West Virginia. The variability in terminology indicated in this table offers an example of the problems involved in understanding and discussing subsurface geology on a regional basis.

Indicated in Figs. 5, 6, 10 and 11 are the depths at which the various geo- logic horizons occur. It is clear, for example, from Figs. 5 and 10 that forma- tions of Ordovician and Cambrian age are too deeply buried to be of interest as disposal horizons in the central parts of the Illinois and Appalachian basins.

Other useful cross sections and structure contour maps are available from the geological surveys of the various states and from the U. S. Geological Survey. This information, supplemented by the data from nearby wells, makes it possible for a qualified geologist to predict with reasonable accuracy the geologic con- ditions to be encountered in much of the Ohio Valley.

For purposes of deep waste injection, it is convenient to discuss the sedi- mentary rock units of the Ohio Valley in different groupings than are ordinarily used in geologic reports. The groupings used in this study are shown in Fig. 12. The Cambrian-Ordovician, Silurian-Devonian, and Mississippian-Pennsylvanian se- quences contain the majority of the potential injection horizons whereas the Devonian and Ordovician shale sequences are primarily useful as confining units. The top of the basement sequence of crystalline igneous and metamorphic rocks defines the lower limit of possible injection zones. Cretaceous and Tertiary rocks are present only in a very small portion of the southwest corner of the area and are, therefore, not discussed. Each of the other sequences is described below.

GEOLOGIC SYSTEMS		TERMINOLOGY USED IN WEST VIRGINIA GEOLOGICAL SURVEY COUNTY REPORTS	TERMINOLOGY REVISED PRESENT USAGE (WOODWARD)	OIL AND GAS SANDS (DRILLERS' TERMS)
PERMIAN		DUNKARD		
CARBONIFEROUS	PENNSYLVANIAN	MONONGAHELA		CARROLL
		CONEMAUGH		MINSHALL MURPHY MOUNDSVILLE LITTLE DUNKARD (1ST COW RUN) BIG DUNKARD
		ALLEGHENY		BURNING SPRINGS GAS LOWER GAS HORSE NECK
		POTTSVILLE		2 ND COW RUN SALT SANDS (1 ST, 2 ND, 3 RD)
		UNCONFORMITY		
	MISSISSIPPIAN	MAUCH CHUNK		PRINCETON RAVENCLIFF MAXTON LOWER MAXTON LITTLE LIME
		GREENBRIER		BLUE MONDAY BIG LIME KEENER BIG INJUN
		POCONO		SQUAW WEIR BEREA
DEVONIAN	UPPER	CATSKILL	HAMPSHIRE FM. ("BROWN SHALE")	GANTZ FIFTY-FOOT THIRTY-FOOT GORDON STRAY GORDON FOURTH FIFTH BAYARD
		CHEMUNG	CHEMUNG FM. ("BROWN SHALE")	
		PORTAGE	BRALLIER SH. ("BROWN SHALE")	ELIZABETH WARREN FIRST WARREN SECOND CLARENDON OR TIONA SPEECHLEY BALLTOWN OR CHERRY GROVE RILEY BENSON ELK OR PORTER
		GENESEE	HARRELL SH. ("BROWN SHALE")	
		UNCONFORMITY		
	MIDDLE		TULLY LS. ("BROWN SHALE")	
		HAMILTON	HAMILTON FM. ("BROWN SHALE")	KANE ?
		MARCELLUS	MARCELLUS SH. ("BROWN SHALE")	GAS IN OHIO, KY. AND SOUTHERN W.VA.
		HUNTERSVILLE (ONONDAGA GROUP)	ONONDAGA LS. / HUNTERSVILLE CHERT / NEEDMORE SH.	CORNIFEROUS (HUNTERSVILLE CHERT) YIELDS SOME GAS IN PENNA. AND NORTHERN W.VA.
	LOWER	ORISKANY	ORISKANY SS	ORISKANY SAND IMPORTANT GAS SAND IN MD., N.Y., OHIO, PENNA., AND W.VA.
		SHRIVER (HELDERBERG GROUP)	PORT JERVIS LS. PORT EWEN LS.	
		HELDERBERG (HELDERBERG GROUP)	BECRAFT LS. NEW SCOTLAND LS. COEYMANS LS. DISCONFORMITY KEYSER LS.	HELDERBERG HAS YIELDED SMALL VOLUMES OF GAS FROM SEVERAL WELLS IN PENNA. AND W.VA. BIG LIME OF OHIO
SILURIAN		BOSSARDVILLE (CAYUGAN (SALINA) SERIES)	TONOLOWAY LS. (BLOOMSBURG FACIES)	
		RONDOUT (CAYUGAN (SALINA) SERIES)	WILLS CREEK FM. (BLOOMSBURG FACIES)	NEWBURG GAS SAND IN OHIO AND W.VA. SHOWS OF OIL IN W. PENNA.
		BLOOMSBURG (CAYUGAN (SALINA) SERIES)	WILLIAMSPORT SS. (BLOOMSBURG FACIES)	LOCKPORT DOLOMITE YIELDS OIL IN KY. GAS AND OIL IN OHIO AND GAS IN SW. W.VA.
		NIAGARA (NIAGARAN SERIES)	MC KENZIE FM. (LOCKPORT OF N.Y.) (BLOOMSBURG FACIES)	KEEFER SANDSTONE (BIG SIX SAND OF SW. W.VA.) YIELDS GAS IN E. KY., OHIO, AND SW. W.VA.
		CLINTON (NIAGARAN SERIES)	ROCHESTER SH. KEEFER SS. ROSE HILL FM.	CLINTON SAND OF OHIO YIELDS GAS IN N.Y., OHIO AND W.VA. YIELDS SOME OIL IN KY. AND CENTRAL OHIO
		WHITE MEDINA	TUSCARORA SS. (CLINCH OF VA. & TENN.)	
		UNCONFORMITY		
ORDOVICIAN	UPPER	RED MEDINA	JUNIATA FM. (QUEENSTON SH. OF N.Y.) (SEQUATCHIE OF VA.)	
		GRAY MEDINA	OSWEGO SS. (RICHMOND OF OHIO)	
		MARTINSBURG	REEDSVILLE SH. UPPER TRENTON LS.	TRENTON YIELDS OIL IN N.Y., ONTARIO PENINSULA, SE. MICH., NW. OHIO, S. CENTRAL KY., NE. TENN., AND SW. VA. SHOWS OF OIL AND GAS IN DEEP WELLS IN PENNA., OHIO AND W.VA.
	MIDDLE	CHAMBERSBURG	MIDDLE TRENTON LS. LOWER TRENTON LS. BLACK RIVER LS.	
		STONES RIVER	CHAZY LS.	PRODUCES OIL IN S. CENTRAL KY. ST PETER YIELDS OIL AND GAS IN W. OHIO AND GAS IN E. KY.
		UNCONFORMITY		
	LOWER	BEEKMANTOWN	BEEKMANTOWN LS. CHEPULTEPEC LS.	"ST PETER" SS. OR "ROSE RUN" SS. NOT PRODUCTIVE AS YET OIL FOUND IN KNOX DOLOMITE IN E. KY.
CAMBRIAN	UPPER	CONOCOCHEAGUE LS.	CONOCOCHEAGUE LS.	TREMPEALEAU YIELDS OIL AND GAS IN OHIO
	MIDDLE	ELBROOK LS.	ELBROOK LS.	
	LOWER	WAYNESBORO FM.	WAYNESBORO FM.	EXPOSED ONLY IN BERKELEY AND JEFFERSON COUNTIES
		TOMSTOWN LS.	TOMSTOWN LS.	
		ANTIETAM SS.	ANTIETAM SS.	
		HARPERS SH.	HARPERS SH.	
		WEVERTON SS.	WEVERTON SS.	
		LOUDOUN SS.	LOUDOUN SS.	NOT EXPOSED IN W.VA.
		UNCONFORMITY		
PRE-CAMBRIAN CRYSTALLINES				

TABLE 5
Generalized Stratigraphic Column--West Virginia and Adjacent Areas
(From Latimer, 1968)

Basement Sequence

The basement sequence consists of igneous and metamorphic rocks that usually have virtually no permeability and porosity and do not, therefore, contain potential injection intervals. Basement-sequence rocks in the Ohio Valley and vicinity are of Precambrian and Lower Paleozoic age. Within the Ohio Valley, basement rocks are probably entirely of Precambrian age in the subsurface and include only a few Cambrian age metamorphic rocks in the area of basement exposure in the southeast side of the area (Fig. 2).

Igneous and metamorphic crystalline rocks normally have virtually no injection potential and drilling ceases soon after passing into them. However, injection at the Rocky Mountain Arsenal near Denver, Colorado, was entirely into fractured and sheared Precambrian crystalline rocks during the operation of that well from 1962-66. It has also been reported that a part of the liquid injected into the deeper of the two injection wells at Hammermill Paper Company, Erie, Pennsylvania, has gone into fractured or sheared Precambrian rocks. The presence of zones of permeability was not anticipated prior to drilling of the two wells mentioned and basement rocks cannot be considered as having potential for injection disposal in the Ohio Valley except in rare instances.

Cambrian-Ordovician Sequence

Rocks of the Cambrian-Ordovician sequence overlie basement rocks in the Ohio Valley in all but the small area of Virginia and North Carolina where basement rocks are exposed (Fig. 2). Cambrian rocks are exposed only in that area of the Valley and Ridge province immediately adjacent to the exposed basement rocks. In the remainder of the Ohio Valley, the oldest exposed rocks are Ordovocian and a minimum of about 3,000 ft. of Cambrian-Ordovician sedimentary strata cover Precambrian rocks. Throughout much of the valley these basal sediments provide the only available injection intervals because overlying rocks have been removed by erosion. Rock types in the Cambrian-Ordovician sequence include limestone, dolomite, shale and sandstone, generally in about that order of relative abundance.

The Trenton Limestone and equivalent rocks lie at the top of the sequence. Contours on the top of the Trenton are shown in Fig. 5. In areas where the top of the Trenton lies more than about 5,000 ft. below sea level, the basal Cambrian-Ordovician sequence is too deep to be of practical interest for disposal purposes in most cases, although it is still well within drilling reach.

A generalized stratigraphic section of the Cambrian-Ordovician sequence from a deep well in Cattaraugus County, New York, is shown in the following tabulation.

Generalized Sequence of Trenton and Older Rocks from a Deep Oil Well in Northwestern Cattaraugus County, New York (From Flagler, 1966)

Rock Unit Age	Rock Unit Name	Thickness (ft.)	Character
Ordovician	Trenton-Black River Groups	780	limestone and dolomite
Cambrian	Little Falls Formation	19	gray to green dolomite
	Theresa Formation	653	dolomite, sandy dolomite and sandstone
	Potsdam Formation	173	sandstone with streaks of dolomite and shale
Precambrian	Basement Sequence		gneiss

Rock unit names in the section are ones used in New York and immediately adjacent areas, except for the Trenton and Black River names, which are widely used.

The sequence is composed mainly of limestone and dolomite in this well and in the adjacent Ohio Valley area. A considerable amount of sandstone may be present in the Theresa Formation. The Potsdam Formation, which is equivalent to the Mt. Simon Formation, is primarily sandstone.

Available data indicate some possibility of disposal into each of the horizons, but good permeability and porosity are not consistently present in any part of the sequence. The Theresa Formation appears to be the most generally promising interval, but locally other units or none at all may be suitable. Overlying Ordovician shales provide good vertical confinement provided unplugged oil or gas wells do not penetrate the shales.

The top of the Trenton lies about 4,800 ft. beneath the ground surface in this well and is deeper than this toward the southwest into the Appalachian basin portion of the Ohio Valley. The cross section in Fig. 10 correlates these rocks from within the northern part of the Appalachian basin into the northern part of the Illinois basin. The combined Trenton and Black River Groups remain nearly constant in thickness from east to west but other rock units thicken considerably, particularly the sandstones at the base. The thickness of sediments covering these rocks also varies as the cross section proceeds from the Appalachian basin onto the Cincinnati arch and then into the Illinois basin.

NOMENCLATURE USED BY McGUIRE & HOWELL IN KENTUCKY				GENERAL ROCK TYPES AND THICKNESS IN KENTUCKY		CORRLELATIONS: N.E. TENNESSEE S.W. VIRGINIA			CORRLELATIONS: OHIO & U. MISS. VALLEY
M. ORDOVICIAN	BLACK RIVER	TYRONE OREGON CAMP NELSON		400-1000'	LIMESTONE	CHICKAMAUGA	EGGLESTON HARDY CREEK BEN HUR WOOLWAY HURRICANE BRIDGE MARTIN CREEK		PLATTEVILLE
M. ORDOVICIAN	CHAZY	JOACHIM DUTCHTOWN ST. PETER EVERTON	WELLS CREEK-ST. PETER	0-800	DOLOMITE, SHALE, AND SANDSTONE	CHICKAMAUGA	ROB CAMP POTEET DOT		GLENWOOD ST. PETER
L. ORDOVICIAN	KNOX GROUP	BEEKMANTOWN	NEWALA	0-1000+	DOLOMITE	BEEKMANTOWN	MASCOT KINGSPORT	PRARIE DU CHIEN	SHAKOPEE
L. ORDOVICIAN	KNOX GROUP	BEEKMANTOWN	LONGVIEW	0-1000+	DOLOMITE	BEEKMANTOWN	LONGVIEW	PRARIE DU CHIEN	NEW RICHMOND
L. ORDOVICIAN	KNOX GROUP	BEEKMANTOWN	CHEPULTEPEC ROSE RUN SS	350-750	DOLOMITE WITH SANDSTONE AT BASE	BEEKMANTOWN	CHEPULTEPEC SANDSTONE BEDS	PRARIE DU CHIEN	ONEOTA MADISON SS JORDAN SS TREMPLEALEAU
CAMBRIAN	COPPER RIDGE			700-1500	DOLOMITE	COPPER RIDGE			TREMPLEALEAU
CAMBRIAN									FRANCONIA
CAMBRIAN	CONASAUGA			50-320	LIMESTONE	MAYNARDVILLE NOLICHUCKY MARYVILLE ROGERSVILLE RUTLEDGE PUMPKIN VALLY			DRESBACH
CAMBRIAN	ROME			250-4560+	SANDSTONE, SILTSTONE, SHALE, LIMESTONE AND DOLOMITE	ROME			EAU CLAIRE
CAMBRIAN	SHADY			0-160	DOLOMITE	SHADY-TOMSTOWN			EAU CLAIRE
CAMBRIAN	BASAL SAND			80-300	SANDSTONE	ERWIN			MT. SIMON
Pe									

CORRELATIONS OF CAMBRIAN, LOWER ORDOVICIAN, AND EARLY MIDDLE ORDOVICIAN FORMATIONS MODIFIED FROM McGUIRE AND HOWELL, 1963)

As in New York, all of the rocks in the stratigraphic interval are potential disposal zones throughout the extent of the cross section. The relative adequacy of each zone varies with geographic location. The suitability of the Mt. Simon Formation increases greatly from east to west as its thickness increases. The Eau Claire contains much more sandstone in some areas than in others and has generally better potential in areas where it is thickest. Zones of porosity and permeability occur at or near the top of the Trenton and in the Cambrian limestones and dolomites below the Trenton-Black River Groups, but such zones are not consistently present.

The nomenclature shown on the west (left-hand) side of Fig. 10 has been widely used throughout northern Ohio, Indiana and Illinois for these rocks, but a variety of other names are used in Kentucky and Tennessee as shown in the table on the following page. The Trenton Limestone and equivalents, which lie immediately over the Black River, are not shown in the tabulation. In Kentucky, the Trenton consists of the Lexington Limestone, which lies on the Tyrone, and the Cynthiana Limestone.

As of 1963, only 50 oil and gas test wells had been drilled as deep as the top of the Copper Ridge and only 9 to Precambrian basement in Kentucky, so the amount of information concerning the deep formations is very limited. Available data indicate that intervals through the entire Cambrian-Ordovician sequence have potential for underground disposal. However, the necessary combination of thickness, porosity and permeability is not consistently present in any one of the units.

Ordovician Shale Sequence

Throughout most of the Ohio Valley, the limestone and dolomites of the Trenton and Black River Groups are overlain by a shale or shale-limestone sequence of Ordovician age. This unit is over 2,000 ft. thick in the northern Appalachian basin but thins to about 200 ft. in thickness in the northern Illinois basin (Fig. 10). It is not present in parts of central Tennessee.

Rocks of this sequence are divided into the Utica, Lorraine, and Queenston Formations in western New York; and the Eden, Maysville and Richmond in Ohio, Kentucky, and central Tennessee. The name Maquoqueta Shale is applied in the Illinois basin and vicinity, and the Martinsburg Shale is applied in the Illinois basin and vicinity, and the Martinsburg Shale and Sequatchie Formation occupy this interval in West Virginia.

The shale or interbedded shale-limestone lithology of the sequence provides vertical confinement for the underlying rocks in much of the Ohio Valley and in particular across the Cincinnati, Waverly and Kankakee arches where these beds frequently separate fresh and saline water-bearing rocks. The Ordovician shale sequence is not generally a promising disposal horizon, but in the northern Appalachian basin, where it is over 2,000 ft. thick, sandstones such as the Oswego, which occurs at the base of the Queenston Shale, offer some potential.

Silurian-Devonian Sequence

A heterogeneous sequence of Silurian and Devonia rocks overlies Ordovician strata throughout the basin areas of the Ohio Valley. The Silurian-Devonian sequence is not present across the Cincinnati arch and the Nashville dome because it was either not deposited in this area or because it has been removed by erosion (Fig. 6). The principal sedimentary rock types within the Silurian-Devonian sequence include limestone, dolomite, shale, sandstone, salt, anhydrite and gypsum.

The sequence has a thickness of over 4,000 ft. in the north-central portion of the Appalachian basin, but thins toward the margins of the basin, particularly northwest toward the Cincinnati arch. Westward from the Cincinnati arch, the thickness increases to about 1,500 ft. in the central Illinois basin. Northward, the thickness increases to over 7,000 ft. in the central Michigan basin. The top of the Silurian-Devonian sequence lies at depths of greater than 7,000 ft. in the central Appalachian basin and greater than 5,000 ft. in the central Illinois basin.

In the Appalachian basin of New York, the Silurian-Devonian sequence consists of the sandstones and shales of the Medina and Clinton at the base, the remainder of the sequence being primarily limestone, dolomite and evaporite beds with lesser amounts of shale and sandstone. Subdivisions used in western New York are shown below. The character and thickness of this sequence and some of the names applied to it change rapidly when traced laterally.

Generalized Silurian-Devonian
Sequence in Western New York

Rock Unit Age	Rock Unit Name	
Devonian	Onondaga Limestone	
	Oriskany Sandstone	
Silurian	Salina Group	
	Lockport Group	
	Clinton	Rochester Shale
		Irondequoit Limestone
		Reynales Limestone
		Neahga Shale
	Medina	Thorold Sandstone
		Grimsby Sandstone
		Cabot Head Shale
		Whirlpool Sandstone

The sandstones of the Clinton and Medina are replaced by inter-bedded sandstones and shales in western New York, western Pennsylvania and eastern Ohio and by limestones west of central Ohio, as shown in Fig. 10. The names change with the lithology and the Clinton and Medina of New York are the Brassfield and "Niagran" limestones and dolomites in western Ohio.

In that area of the northeast Ohio Valley where disposal into Devonian and Silurian rocks is indicated as most likely to be feasible (Fig. 9), the Clinton-Medina interval is from 200 ft. thick in the west to 1,200 ft. thick in the east. The sandstone content ranges from nearly 100 percent in the east to very little in the west.

The 3,000 ft. of carbonates, evaporites and shales that comprise the Silurian-Devonian sequence above the Clinton in south-central New York thins to about 1,200 ft. at the eastern end of the cross section of Fig. 10 and continue to thin toward the west. This is almost entirely because of variation in the thickness of the Salina Group. The total Lockport to Onondaga unit thins toward the southwest also and is not present in southeastern Kentucky and most of Tennessee.

One significant sandstone unit, the Oriskany sandstone, occurs in this interval just below the Onondaga Limestone. The Oriskany is not present everywhere, and when present it is often impermeable. It does, however, have potential as a disposal interval in areas of the northern Appalachian basin, and was the original disposal interval in the Jones and Laughlin well at Aliquippa, Pennsylvania.

The Silurian-Devonian sequence is composed of about 500 to 1,000 ft. of dolomite and limestone in the Illinois basin. One set of rock unit names that is applied to this sequence in the northern Illinois basin is shown below. Other names are also used.

Subdivisions of the Silurian-Devonian Carbonate Sequence
in the Northern Illinois Basin

Rock Unit Age		Rock Unit Name
Devonian		Grand Tower Dolomite
		Cedar Valley Limestone
Silurian	Niagran	Racine Limestone
		Joliet Limestone
	Alexandran	Alexandran Series Limestones

Silurian and Devonian age limestones and dolomites do not generally have ..fficient porosity and permeability for disposal purposes in the Illinois basin, ..: locally there are zones in this sequence that would be satisfactory.

..vonian Shale Sequence

Throughout the Zone I and Zone II portions of the Illinois and Appalachian ..sins shown in Fig. 9, Devonian Shales overlie the Silurian and Devonian strata ..eviously discussed.

Within Zones I and II in the Ohio Valley portion of the Appalachian basin, ..e Devonian shale sequence is a wedge-shaped mass that ranges from a minimum of ..out 400 ft. thick in the west to over 7,500 ft. thick in the east. In the west, ..e sequence is almost entirely shale but numerous sandstones appear toward the ..st as shown in Fig. 10.

In Figure 10, the basal 100 feet or so of the shale sequence is termed the ..amilton Shale and the remainder the Ohio Shale. These beds are largely grey to ..lack shale. As the sequence thickens toward the east the percentage of black shale decreases and sandstones, siltstones, and red-colored sediments become abundant and the nomenclature becomes complex. As many as thirty sandstone units have been named in the Devonian oil fields of Pennsylvania and perhaps equally as many in West Virginia. These sandstone beds are generally lenticular and individual ones cannot be traced far.

In the western part of Zone II within the Appalachian basin the Devonian shale sequence is a series of shales that provide confinement for underlying potential disposal zones. In the eastern part of Zone II and in Zone I, the sequence provides confinement and has many sandstones that are potential disposal zones. However, the large number of oil and gas wells drilled into these sandstones in Pennsylvania and West Virginia limits their potential considerably.

The New Ablany Shale of the Illinois basin is a black shale with some lenses of limestone in the lower part. It ranges in thickness from 50 ft. in the north to over 400 ft. in the south, but it is generally 100 ft. thick or less. The New Albany Shale provides a convenient marker bed to separate Devonian and Mississippian strata (the uppermost part of the New Albany may be Mississippian in age), and also acts as a somewhat limited hydrologic barrier between them.

Mississippian-Pennsylvanian Sequence

Mississippian and Pennsylvanian age rocks are present at the surface throughout most of the major synclinal basin areas of the Ohio Valley, but have been removed by erosion from parts of the Cincinnati arch and its continuations (Fig. 2). Up to about 1,000 ft. of Permian age rocks overlie Pennsylvania age strata in the central part of the northern Appalachian basin, but are not present elsewhere and are grouped with Pennsylvanian age rocks.

The sequence is composed primarily of shale, sandstone, and conglomerate lesser amounts of limestone and coal. The combined vertical thickness of Mississippian and Pennsylvanian strata reaches about 3,000 ft. in the north central Appalachian basin and 5,000 ft. in the central Illinois basin. This thickness of rocks immediately limits the possibilities of underground disposal in those areas to Mississippian and lower Pennsylvanian strata and to areas where the sequence reaches half its maximum thickness or more.

A generalized geological column of the Mississippian-Pennsylvanian sequence in Roane County, West Virginia, is shown in the table on the following page. The groups shown are ones recognized throughout the portions of southwestern Pennsylvania, western West Virginia and southeastern Ohio where disposal into Mississippian and lower Pennsylvanian strata is most likely to be feasible. Many of the Mississippian and lower Pennsylvanian sandstone units have physical characteristics satisfactory for waste disposal, but the large number of abandoned and active oil and gas wells that penetrate these rocks greatly restricts their potential as disposal units.

The thickness of Mississippian and Pennsylvanian rocks increases toward the southeast in the Appalachian basin and the total thickness of Mississippian rocks alone aggregates as much as 4,500 ft. in Greenbriar County, W. Va. In southern West Virginia, eastern Kentucky and southwestern Virginia, Mississippian strata alone range in total thickness from 1,000 to 6,000 ft. One set of rock unit names that has been used in that area is shown below. Each rock unit appears to have some potential for underground disposal, since they have each produced gas in this area.

Generalized Geological Section of Mississippian Rocks in

Southern West Virginia, Southwestern Virginia, and Eastern Kentucky

(Constructed from data by Wilpolt and Marden 1959)

Rock Unit Age		Rock Unit Name	Thickness	Principal Rock Type
MISSISSIPPIAN	PENNINGTON GROUP	Bluestone Formation	300-1,000	Shale, sandstone, limestone, and twin coal beds
		Princeton Formation	0-250	sandstone
		Hinton Formation	300-1,700	red shale and siltstone
	Bluefield Formation		200-1,950	calcareous shale, some limestone and sandstone
	Greenbriar Limestone		250-850	limestone and dolomite

Groundwater -- A primary consideration in the appraisal of an injection proposal is the protection of potable groundwater. In this regard the question arises: which groundwaters are potable and to be protected and which are of low enough quality (high salinity) to be used for disposal purposes?

Groundwaters oontaining less than 1,000 mg/l of dissolved solids will be protected except under unusual circumstances. Water containing less than 500 mg/l is presently considered to be acceptable for potable water to be used by interstate carriers (U. S. Public Health Service, 1962), and formerly (U. S. Public Health Service, 1946) if such water was not available, water containing 1,000 ppm of dissolved solids was considered acceptable. The minimum salinity may be set at a level higher than 1,000 mg/l of dissolved solids to provide a margin of safety. Water with several times this dissolved solids content is now used in some geographic areas and may be more widely used in the future.

Illinois agencies have defined fresh water as that containing less than 5,000 mg/l and consideration is now being given to revising this figure to 10,000 mg/l (Bergstrom, 1968, p.2). As previously mentioned in the discussion of the New York regulations, groundwaters in that state have been classified, based on quality. According to the New York classification, water having a total dissolved solids content of 1,000 mg/l or less is considered to be fresh. Waste injection is prohibited in aquifers containing water with a dissolved solids content of 2,000 mg/l or less.

In Fig. 7 is shown the approximate depth to aquifers containing greater than 1,000 mg/l of dissolved solids in the Ohio Valley and adjacent areas. This map gives a very broad indication of the depth range to which surface casing must extend in order to close off aquifers containing potable water. It also shows that there are no saline water-bearing aquifers to be used for disposal in portions of the eastern Ohio Valley. If waters containing more than 1,000 mg/l of dissolved solids are considered fresh, then larger areas of the Ohio Valley would be unsuited for underground disposal, and the depth to the fresh water-saline water interface would be extended. A more detailed map of the fresh water-saline water interface in Kentucky has been prepared by Hopkins (1967).

The details of groundwater occurrence that should be examined in considering underground disposal at a specific location can be obtained from various published reports and from state and federal agencies. Deutch and others (1965) and Wyrick (1968) describe groundwater resources of the Ohio Valley and Appalachia respectively, and reference the available published reports on groundwater occurrence in these areas.

Mineral Resources -- The occurrence of oil, gas, coal, mineralized brines, and occasionally other less abundant minerals require consideration in preparing and evaluating injection proposals. Oil, gas and coal are widely distributed and important resources in the Ohio Valley and mineralized brines are also of economic importance to a number of industries.

Of the mineral resources, oil and gas most frequently require consideration because of their abundance and because rock units that contain them are often physically well suited for waste injection. In Fig. 8 the relative intensity of oil and gas field development in the Ohio Valley area is shown. Intense development of oil and gas resources does not necessarily preclude injection disposal. However, the potential for such disposal will within certain areas, be greatly limited because of oil and gas development. For example, in the Lima-Indiana oil field area shown in Fig. 8, nearly 75,000 wells were drilled during the late 1800's and early 1900's. These oil wells are now abandoned and many of their locations are unknown.

Because of the inadequate plugging practices used at the time when the Lima-Indiana field was abandoned, it is now not possible to contemplate injection into the Trenton Limestone or any of the horizons above the Trenton in that area. Injection into the deeper Mt. Simon Formation, which lies well below the Trenton, is still possible as is illustrated by the Sohio Petroleum Company injection well at Lima, Ohio.

It is not practical to list all of the situations similar to this that exist in the Ohio Valley. However, matters such as this must be considered individually at the time when underground disposal is actually contemplated at a specific location.

Coal is also a very abundant resource in the Ohio Valley, as illustrated by the fact that about 77 percent of the bituminous coal produced in the United States in 1964 was mined in the area. Coal resources are in the Pennsylvanian age rocks of the Appalachian and Illinois basins.

It is necessary to insure adequate casing and cementing of wells in areas where coal is now being mined to prevent possible contamination just as in the case of groundwater. This is recognized in coal-producing states, where special well construction regulations apply to oil and gas wells when they are drilled in coal-producing areas. Such regulations would also be expected to be applied to disposal wells, perhaps even in a more stringent form.

Underground bituminous coal mines that have been developed to date have been primarily above stream drainage level in the Appalachian basin because of the increased cost of extracting coal as the mines become deeper. However, as the shallower coal resources are exhausted, the mines are becoming deeper and will eventually reach depths where injection disposal may be possible. Some mines are already approaching such depths, for example, the Island Creek Coal Company-Republic Steel Corporation mine in Buckhannon County, Virginia, the deepest coal mine in North America, is 1,350 ft. deep. With this possibility in mind, it will be necessary to consider the presence of deep coal reserves, as well as oil and gas, in evaluating injection proposals.

Some natural subsurface brines and salt formations also require protection. Natural brines and brines obtained by dissolving solid salt with water circulated from the surface are used as sources of salt and chemicals by industries in the Ohio Valley. The Silurian age Salina Formation (Fig. 10) contains natural, In the Illinois basin, Mississippian strata reach a maximum total thickness about 3,500 feet in the southeast and thin toward the northwest. The lower portion of the Mississippian System, which reaches a maximum thickness of 2,000 ft. includes strata of the Kinderhook and Osage-Meramec (Valmeyeran) Series.. Kinderhook and Osage rocks are principally shale and calcareous siltstone with some beds of fine sandstone and siliceous limestone. The Meramec Seriés.includes, in ascending order, the Salem Limestone, the St. Louis Limestone, and the Ste. Genevieve Limestone.

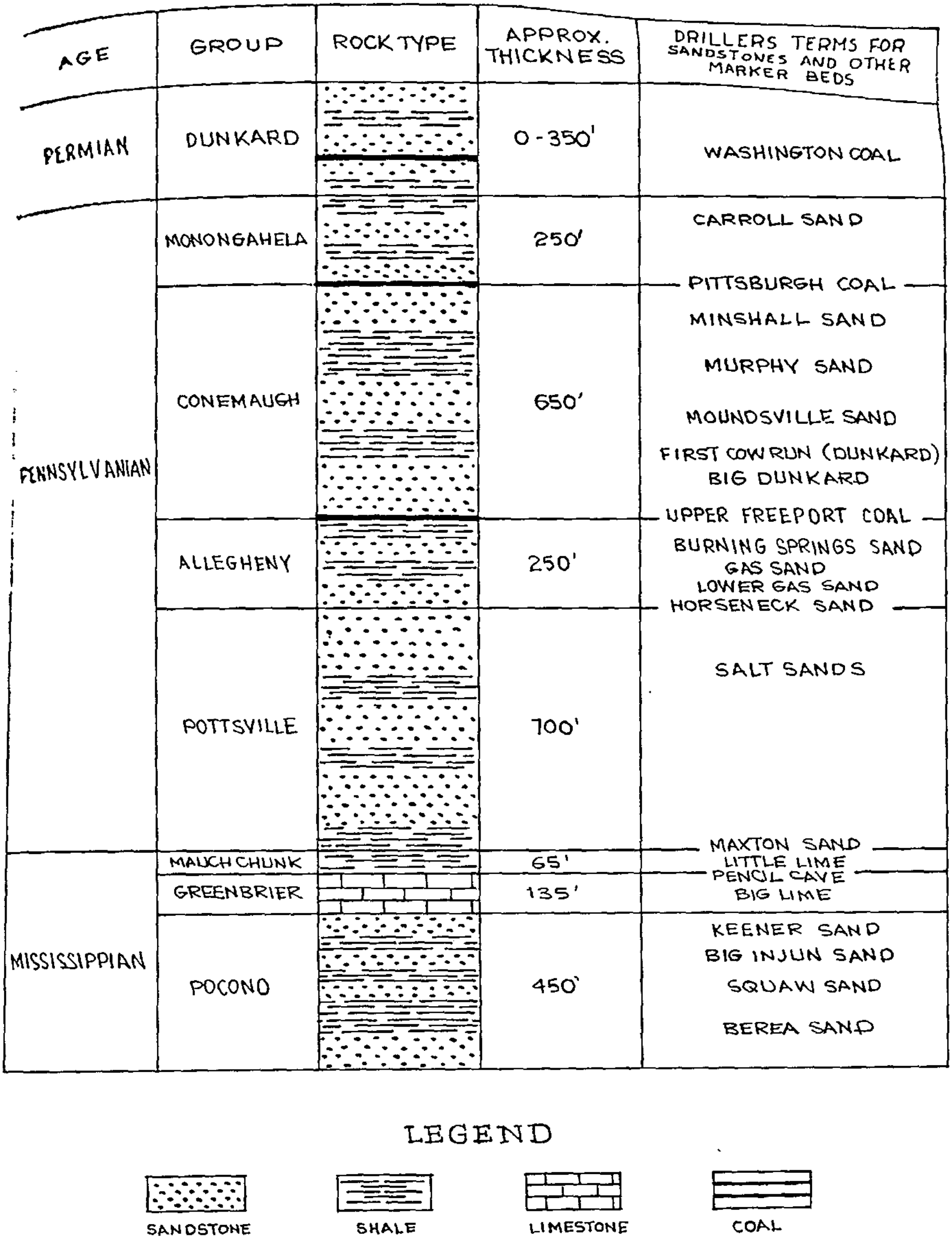
There are occasional sandstone beds in the Osage Series which have potential as disposal intervals, but the principal units of interest are the limestones of the Meramec Series. These limestones may have fracture or solution porosity and permeability or may have porous and permeable oölitic or sandy intervals. The Ste. Genevieve Formation is a particularly prolific oil producing unit in the Illinois basin and contains potable water in a narrow band along the Ohio and Mississippi rivers.

The Chester Series includes the Mississippian rocks above the Ste. Genevieve Formation. This interval reaches a maximum thickness of 1,400 feet in the southeastern Illinois basin and consists of alternating limestone-shale and sandstone-shale intervals, many of which are oil producing. Some of the individual sandstones of the Chesterian Series are the Palestine, Waltersburg, Tar Springs, Cypress, and Bethel sandstones. The Tar Springs and Cypress sandstones are principal aquifers used as sources of brine in the secondary recovery of oil.

Pennsylvanian age rocks of the Illinois basin attain a maximum thickness of about 2,500 feet in Edwards County, Illinois, and consist principally of shale, sandstone and siltstone, with lesser amounts of limestone and coal.

Pennsylvanian age rocks occur at the surface and contain potable water to depths as great as 900 feet. Below the potable water, Pennsylvanian age sandstones contain saline water and some oil accumulations. These sandstones are potential disposal horizons, but are of generally low permeability and may be of limited areal extent.

In Fig. 9 is shown the area within the Illinois basin where Pennsylvanian, Mississippian, or older strata may be suitable for disposal purposes. Two disposal wells in extreme southwestern Indiana are used for injecting wastes into sandstones of Mississippian age.



Generalized geological columnar section of Mississippian, Pennsylvanian and Permian rocks, Roane County, W. Va.

solid-salt beds; these are mined by conventional underground mining methods and also by circulation of water from the surface which dissolves the salt and is returned to the surface for use. The extent of salt beds in the Salina Formation is shown in Fig. 6. Other formations used as sources of brine in the Ohio Valley are the Silurian age Clinton, which is used in eastern Ohio, and the Pennsylvanian age Salt Sands, which have been used in the Charleston, W. Va. area.

Seismisity -- The past history of earthquake activity in an area must be considered because an earthquake might potentially damage injection well facilities or alter geohydrologic conditions. In addition, because of the possibility that injection into the Denver Rocky Mountain Arsenal well may have induced earth tremors (Healy and others, 1968), the susceptibility of an area to such induced seismic activity should be examined.

Within and near the Ohio Valley Region, two localities stand out as having been affected by significant earthquakes during recorded time.

Three of the most intense earthquakes that have been recorded in this country were centered near New Madrid, Missouri, and occurred in December 1811 and January and February 1812. All three of these earthquakes were of greater intensity than any that have occurred in California, including the 1906 San Francisco earthquake. A total area of at least 2,000,000 square miles was shaken and significant topographic changes occurred, including the formation of Reelfoot Lake, Tennessee. Because the epicenter area was largely a wilderness, few lives were lost.

The area of southeast Missouri and areas of adjoining states is still an active one and more than one hundred earthquakes have been reported there since 1812.

An earthquake occurred November 9, 1968, near Broughton, Hamilton County, Illinois, about 100 miles northeast of the epicenter of the New Madrid earthquakes. The intensity was about 7 as compared to an estimated intensity of 12 for the New Madrid earthquakes. Preliminary reports from the oil and gas industry (Heigold, 1968) reveal that subsurface hydrologic changes and minor damage to well facilities occurred.

A second area in the Ohio Valley where relatively intense earthquakes have been recorded is in western New York. Here earthquakes with intensities of 8 were recorded in 1929 and 1944. These two earthquakes were centered near Attica and Massena, New York, respectively. Changes in groundwater conditions reportedly occurred in 1929. A less intense 1966 earthquake was also centered near Attica, New York.

Data from a recently published map depicting the degree of seismic risk is reproduced in Figure 14. These data agree with the above discussion and indicate that there is a possibility of major earthquake damage in the extreme southeast and northeast portions of the Ohio Valley and of moderate to minor damage elsewhere in the area.

There is no known precedent for regulatory policy and requirements that will take seismic risk into account. Tentative suggestions are:

(1) Special attention should be given to standby facilities in areas where major or moderate earthquake damage is considered possible; and

(2) Injection wells should not be constructed at sites where major earthquake damage is considered possible and where subsurface faults occur that could shift and cause damage to well casing.

<u>Hydrodynamics</u> -- The usual discussion of subsurface disposal conveys the impression to the reader that the naturally occurring fluids in deep aquifers are in a static state. For many purposes this can be assumed to be the case in the Ohio Valley area. However, deep subsurface fluids are naturally in motion, although slowly, and the fact that they are moving should be considered in managing subsurface disposal.

At present, there is not enough information to allow examination of hydrodynamic factors, particularly in the case of the deep Cambrian-age strata that account for most of the injection wells that have been constructed to date. If accurate initial fluid pressure data are obtained from wells that are drilled in the future eventual determination of the regional patterns of fluid movement in the deep subsurface of the Ohio Valley may be possible.

It will also be necessary to obtain accurate data on injection rate and pressure during the operation of injection systems to determine the local and regional effect of these systems on the injection horizons.

Summary of Geologic and Hydrologic Factors

The geology and groundwater hydrology of the Ohio Valley have been broadly considered in view of the potential for subsurface waste injection in the area. Implications of the previous discussion are partly summarized in Fig. 9. Here is indicated the relative feasibility of deep-well disposal as constrained by the thickness of sedimentary rocks, geologic structure, and the presence of saline water-bearing aquifers.

Areas underlain by metamorphic and igneous crystalline rocks provide virtually no potential for subsurface disposal of liquid waste. Areas where subsurface waste injection is indicated as being of limited feasibility are those where:

No aquifers containing more than 1,000 mg/l of dissolved solids are available, as indicated in Fig. 7;

The sedimentary sequence is less than 1,500 ft. thicker than the minimum depth to saline water;

Structural geologic conditions are considered sufficiently complex to cause unusually great uncertainty about subsurface hydrology.

Within the areas where the above limitations do not apply, waste injection is shown as being most likely to be feasible in one or more of the stratigraphic sequences indicated in Fig. 9. In Zone I, disposal is shown as being most likely to be feasible in Pennsylvanian, Mississippian, or older rocks. There is at least 1,500 to 2,000 ft. of Mississippian-Pennsylvanian sedimentary rock present containing water with 1,000 mg/l or more of dissolved solids in Zone I. In Zone II, there is at least 1,500 to 2,000 ft. of Silurian-Devonian rock present containing saline water and in Zone III there is at least 1,500 to 2,000 ft. of Ordovician and Cambrian sedimentary rock present containing saline water.

It must be recognized that while Fig. 9 offers some broad geographic guidelines, it cannot be literally used to specify where subsurface injection may or may not be permitted. For example, in constructing the map, aquifers with water containing more than 1,000 mg/l were considered as having waste disposal potential, whereas, at least in Illinois and New York, the dissolved solids content would have to be greater (10,000 mg/l and 2,000 mg/l, respectively) before an aquifer could be considered for waste injection.

Some other limitations of the map are:

It does not consider the presence of unplugged abandoned wells or mineral resources, such as oil, gas, coal, or usable brine.

The fact that 1,500 ft. or more of saline water-bearing sedimentary rock is present does not assure that a suitable porous and permeable injection horizon or a suitable confining interval will be present.

Careful examination may show that geologic structural conditions will permit disposal within portions of the areas shown to have generally complex geologic structure and, on the other hand, there are locations in the remainder of the basin where geologic structure may locally preclude subsurface disposal.

The above points are emphasized to dispel any illusion that this report, and Fig. 9 in particular, can be used to make specific decisions on the geologic and hydrologic aspects of individual proposals for subsurface waste injection. The information will be found useful in establishing the framework for reaching such decisions.

SYSTEM INSTALLATION AND OPERATION

This section of the report deals briefly with requirements relating to well construction, surface equipment, operating conditions and procedures for abandonment.

Well Construction

The variability of geologic situations and the characteristics of wastes precludes establishment of rigid specifications for injection-well construction. Each injection system requires individual consideration with respect to waste volume and type, and the geologic and hydrologic conditions that exist. Certain general requirements, however, can be outlined.

Construction of well facilities for an injection system includes drilling, logging and testing, and completion activities. A hole must first be drilled, logged, and tested before it can be ascertained that it should be completed as an injection well. The completion phase includes: Installation and cementing of the casing; installation of injection tubing; and other related procedures such as perforating or slotting the casing and stimulating the injection horizon. Generally, it is necessary to install and cement at least some of the casing during drilling.

Drilling programs should be designed to permit installation of the necessary casing strings with sufficient space around the casing for an adequate amount of cement. Samples of the rock formations penetrated should be obtained during drilling, and it may be necessary to have formation cores or water samples at horizons of particular importance to provide necessary geologic and hydrologic data. Complete logging and testing of wells intended for injections should be required. Such data should be filed with the appropriate state agency or agencies.

In Table 6 is summarized the information desired in subsurface evaluation of the disposal horizon and the methods for obtaining this information.

TABLE 6 -- Summary of Information Desired in Subsurface Evaluation of Disposal Horizon, and Methods Available for Evaluation

Information desired	Methods available for evaluation
Porosity	Cores, electric logs, radioactive logs, sonic logs
Permeability	Cores, pumping or injection tests, electric logs
Fluid pressure in formations	Drill stem tests
Water samples	Cores, drill stem tests
Geologic formations intersected by hole	Drill time logs, drilling samples, cores, electric logs, radioactive logs, caliper logs
Thickness and character of disposal horizon	Same as above
Mineral content of formation	Drilling samples, cores
Temperature of formation	Temperature log
Amount of flow into various horizons	Injectivity profile

Design of a casing program depends primarily on well depth, character of the rock sequence, fluid pressures, type of well completion, and the corrosiveness of the fluids that will contact the casing. Where fresh groundwater supplies are present, a casing string (surface casing) is usually installed to below the depth of the deepest groundwater aquifer immediately after drilling through the aquifer (Fig. 13). One or more smaller diameter casing strings are then set, with the bottom of the last string just above or through the injection horizon, the latter determination depending on whether the hole is to be completed as an open hole or gravel-packed or is to be cased and perforated.

The annulus between the rock strata and the casing is filled with a cement ...ut. This is done to protect the casing from external corrosion, to increase ...ing strength, to prevent mixing of the waters contained in the aquifers behind casing, and to forestall travel of the injected waste into aquifers other than disposal horizon.

Cement should be placed behind the complete length of the surface casing and ...ind the entire length of the smaller diameter casing strings also, or at least a sufficient length to provide the desired protection. It is suggested that least one inch of annular space be allowed for proper cementing. Casing cen-...alizers, other equipment, and techniques such as stage cementing can give added ...urance of a good seal between the strata and the casing and should be encouraged where applicable.

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

Neat portland cement (no sand or gravel) is the basic material for cementing. ...ny additives have been developed to impart some particular quality to the cement. ...ditives can, for example, be selected to give increased resistance to acid, sul-...ates, pressure, temperature, and so forth.

It is recommended that waste be injected through separate interior tubing rather than the well casing itself. This is particularly important when corrosive wastes are being injected. A packer can be set near the bottom of the tubing to prevent corrosive wastes from contacting the casing. Additional corrosion pro-tection can be provided by filling the annular space between the casing and the tubing with oil or water containing an added corrosion inhibitor.

It is frequently desired to increase the acceptance rate of injection wells by chemical or mechanical treatment of the injection zone. Careful attention should be given to stimulation techniques such as hydraulic fracturing, perforat-ing and acidizing to insure that only the desired intervals are treated and that no damage to the casing or cement occurs.

The type of well-head equipment can be a consideration in cases where the build-up of high back-pressure is a possibility. In such cases, the well head should be designed to "bleed-off" back flows into holding tanks or pits before pressures reach a hazardous level. High back-pressures can be developed by chemical reactions in the formation. This possibility was recognized in designing the E. I. duPont de Nemours well at New Johnsonville, Tenn. In this case, a ferric-chloride solution is being injected into dolomite and limestone which could cause an excessive build-up of carbon dioxide gas pressure.

Surface Equipment

Surface equipment includes holding tanks and flow lines, filters, other treat-ment equipment, pumps, monitoring devices, standby facilities.

Surface equipment associated with an injection well should be compatible with the waste volume and physical and chemical properties of the waste to insure that the system will operate as efficiently and continuously as possible. Experience with injection systems has revealed the difficulties that may be encountered due to improperly selected filtration equipment and corrosion of injection pumps.

Surface equipment should include well-head pressure and volume monitoring equipment, preferably of the continuous recording type. Where injection tubing is used, it is advantageous to monitor the pressure of both the fluid in the tubing and in the annulus between the tubing and the casing. Pressure monitoring of the annulus is a means of detecting tubing or packer leaks. An automatic alarm system should signal the failure of any important component of the injection system. Filters should be equipped to indicate immediately the production of an effluent with too great an amount of suspended solids.

Standby facilities are essential in order to cope with any malfunction of a well that might occur. Such facilities could be in the form of a standby well, a waste treatment plant, or holding tanks or ponds.

Operating Program

The operating program for an injection system should conform with the geological and engineering properties of the injection horizon and the volume and chemistry of the waste fluids.

Injection rates and pressures must be considered jointly, since the pressure will usually depend on the volume being injected. Pressures are limited to those values that will prevent damage to well facilities or to the confining formations. The maximum bottom-hole injection pressure is commonly specified on the basis of well depth. It may range from about 0.5 to 1.0 psi per foot of well depth depending on geologic conditions, but seldom is allowed to exceed about 0.8 psi per foot of depth.

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

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

Observation wells can be constructed to monitor the pressure or water quality changes that occur in the injection horizon or in the overlying groundwater aquifers. Such wells have not been widely required but are an additional precaution that can be provided.

Abandonment of Wells

Each state in the ORSANCO district has an agency charged with supervising the abandonment of oil and gas wells and these agencies have developed regulations for well plugging and abandonment.

Such regulations often provide for the segregation of water-bearing intervals with cement and the plugging of other intervals with "mud or other equally non-porous materials." It is recommended that waste injection wells be plugged from bottom to the surface with cement to provide all possible segregation of aquifers.

The pulling of casing, which is sometimes allowed during the abandonment of oil and gas wells, should be entirely forbidden in the case of waste-injection wells. In addition, oil and gas well abandonment regulations sometimes provide for the cutting off of the surface casing below the ground, the intent being to prevent interference with farming or other uses. In contrast to this practice, it is suggested that a permanent surface monument be established at the location of waste-injection wells at the time they are abandoned, so that there will be no future doubt concerning the well location.

APPENDIX A

A-1 Application for a permit to drill, deepen, or convert and test a well for industrial waste injection

A-2 Waste injection well drilling and testing report

A-3 Application for a permit to use a well for industrial waste injection

A-4 Industrial waste injection well operational report

A-5 Application for permit to plug and abandon a waste injection well

A-6 Waste injection well plugging and abandonment report

APPENDIX A-1

APPLICATION FOR A PERMIT TO DRILL, DEEPEN, OR CONVERT AND TEST A WELL FOR INDUSTRIAL WASTE INJECTION

I. APPLICANT (must be legally responsible party)

1. Company name ____________________
2. Authorized representative ____________________ Title ____________
3. Address ____________________
4. City ____________________
5. Phone number ____________________

II. APPLICATION IS TO DRILL ☐ DEEPEN ☐ OR CONVERT ☐ AND TEST A WELL FOR WASTE INJECTION

III. LOCATION OF PROPOSED INJECTION WELL

1. County ____________________
2. Township ____________________ Range ____________
3. Section ____________________
4. Footage and direction from nearest section lines or other legal boundaries ____________________
5. Ground elevation ____________ ft.

IV. SUMMARY OF PROPOSED PROGRAM

1. Anticipated total well depth ____________ ft.
2. Proposed injection interval(s) in order of probable priority

Formation Name(s)	Anticipated Formation Depth (top)
____________________	____________
____________________	____________
____________________	____________

3. General waste character_ ______________________

4. Proposed injection rate (gpm)______________________

5. Anticipated injection pressure Average__________(psi)

Maximum __________(psi)

V. SUBMIT WITH APPLICATION

1. $__________ Fee

2. Feasibility report (see attached outline)

Report prepared by:

____

(Registered Professional Engineer

Certified Professional Geologist)

Permit Number: ______________________

Approval Date______________________

OUTLINE OF FEASIBILITY REPORT TO ACCOMPANY APPLICATION TO DRILL, DEEPEN OR CONVERT AND TEST A WELL FOR INDUSTRIAL WASTE INJECTION

WELL LOCATION

A. General map and description of well location showing cultural and geographic features and boundaries of property owned or leased by the applicant.

B. Detailed plat showing proposed injection wellsite and locations of all types of existing wells within two miles of injection well site.

C. Well records of wells shown in B., including ownership, available subsurface information, and well plugging records.

GEOLOGY AND GEOHYDROLOGY

A. Structural geologic features in the immediate well location and general vicinity. Provide a surface geologic map.

B. Geologic and Engineering Description of subsurface rock units.

1. General types and characteristics including a geologic column.
2. *Potential injection horizons and confining beds
   - a. Lithology
   - b. Thickness
   - c. Areal Distribution
   - d. Porosity
   - e. Permeability
   - f. Reservoir pressure and temperature
   - g. Chemical characteristics of reservoir fluids
   - h. Formation breakdown or fracture pressure
   - i. Hydrodynamics

C. Geohydrology of fresh-water aquifers at the site and in the vicinity

1. Depth
2. Thickness
3. General character
4. Usage

* In the case of new wells reservoir properties are estimates, in the case of existing wells they should be measured values, if available.

D. Mineral resources and their occurrence at the well site and in the immediate area.

1. Oil and gas

2. Coal

3. Brines

4. Others of significance

III. PROPOSED (OR EXISTING) WELL DESIGN AND CONSTRUCTION AND TESTING PROCEDURES

A. Drilling, coring, and testing program

B. Casing and tubing -- size, grade, type, weight, setting depth

C. Cement -- type including additives and amount

D. Other subsurface equipment

E. Well-head equipment

IV. PROPOSED (OR EXISTING) SURFACE EQUIPMENT INCLUDING LOCATION AND MATERIALS OF CONSTRUCTION

A. Holding tanks and flow lines

B. Filters

C. Pumps

D. Flow and pressure monitoring devices

E. Other

V. RAW WASTE CHARACTERISTICS

A. Industrial process from which waste is derived

B. Physical and chemical description of waste -- including variations

C. Volume -- including variability in rate of production

D. Compatibility with subsurface fluids

E. Alternative means of treatment or disposal including cost comparisons.

VI. PROPOSED PREINJECTION WASTE TREATMENT PROGRAM

A. Settling

B. Filtration

C. Chemical Treatment

D. Concentratin or Dilution

E. Other

VI. PROPOSED OPERATING PROGRAM

A. Injection program including average and maximum rates, and estimated yearly total for each year through projected well life.

B. Injection pressures including average and maximum

C. Monitoring techniques

VII. PROPOSED CONTINGENCY PLAN IN EVENT OF UNANTICAPATED WELL FAILURE DURING OPERATION — continues

APPENDIX A-2

WASTE INJECTION WELL DRILLING AND COMPLETION REPORT

I. Well owner

1. Name____
2. Address____
3. City____

II. Well Drilling or Well Conversion Permit Number____________________

III. Location Description (if different than in original application)

____

____

IV. Drilling and Coring Record

1. Date drilling commenced ________________________________
   (month) (day) (year)
2. Date drilling completed________________________________
   (month) (day) (year)
3. Chronological drilling record (submit on separate sheet)
4. Well* Cored From__________ft. to__________ ft.Recovery__________ft.
   From__________ft. to__________ ft.Recovery __________ft.

   Cores were: ☐ Lab analyzed ☐ Described
5. Drilled total depth__________ft.
6. Plugged-back total depth_________ft.

V. Casing and Cement

	Hole Size	Casing Size, Weight and Grade	Depth Set	Amount of Cement	Top of Cement
Surface					
Intermediate					
Injection					
Liner					

* List cores and samples submitted to State on a separate sheet

II. Logs

Check drilling logs compiled:

[ ] Driller's log [ ] Sample log [ ] Drilling time [ ] Others: ____________

Check other logs run:

[ ] Gamma ray-neutron [ ] Temperature [ ] Caliper [ ] Cement bond

[ ] Resistivity [ ] S.P. [ ] Others: ____________

II. Tests:

Type test	Duration of test	Zones tested From To	Amounts and kinds of fluids produced or injected during test
	hrs.	ft.- ft.	
	hrs.	ft.- ft.	
	hrs.	ft.- ft.	

III. Stimulation

Zones treated	Treatment: Perforated, acid treated, etc.	Details of treatment: Kinds and amounts of materials, rates, pressures, dates, etc.

The information given is a correct record of the well and all work done.

______________________ ______________________ ______

(Signature) Representing (company) Date

To be submitted within 30 days after completion of construction and testing, along with copies of all logs, field and laboratory test data, drilling and core samples, and formation fluid samples.

APPENDIX A-3

APPLICATION FOR A PERMIT TO USE A WELL FOR WASTE INJECTION

I. APPLICANT (Must be a legally responsible party)

1. Company name____________________
2. Authorized representative____________ Title________
3. Address____________________
4. City____________________
5. Phone Number____________________

II. WELL DRILLING OR WELL CONVERSION PERMIT NUMBER____________

III. SUMMARY OF PROPOSED PROGRAM

1. Total well depth____________________
2. Proposed injection intervals:

Formation name(s)	Depth of Injection interval(s) Top	Bottom

3. Proposed injection rate:

Average____________gpd Maximum____________gpd

Average____________gpm Maximum____________gpm

4. Proposed well-head and bottom hole injection pressure

Average well-head pressure________psi: Maximum________psi

Average bottom-hole pressure________psi: Maximum________psi

IV. REPORT ON WELL CONSTRUCTION AND TESTING (SEE REPORT OUTLINE ON ATTACHED PAGES)

Report prepared by:

____

(Registered professional engineer or Certified Professional Geologist)

Permit number____________

Approval date____________

Restrictions not specified above____________

OUTLINE OF SUMMARY REPORT TO ACCOMPANY

APPLICATION TO USE A WELL FOR WASTE INJECTION

I. GEOLOGIC DESCRIPTION OF SUBSURFACE ROCK UNITS

A. Geologic column of rock units penetrated

B. Observed characteristics of injection horizons and confining beds

1. Lithology
2. Thickness
3. Porosity
4. Permeability and/or formation acceptance rate during testing
5. Reservoir temperature and pressure
6. Chemical characteristics of reservoir fluids
7. Formation breakdown or fracture pressure. Include well logs, core analyses, injectivity test data, water analyses, etc. used in determining 1 through 7, or refer to previously submitted logs and data.

C. Observed characteristics of fresh water aquifers

1. Depth to fresh water
2. Thickness and character of fresh water bearing strata
3. Fresh water quality including analyses

D. Description of any mineral resources encountered during drilling

II. DRILLING AND CONSTRUCTION OF WELL

A. Drilling, construction and testing history

B. Materials of construction (if different than originally proposed)

III. SURFACE EQUIPMENT (if different than originally proposed)

IV. PREINJECTION WASTE TREATMENT PROGRAM (if different than originally proposed)

V. OPERATING PROGRAM (if different than originally proposed)

VI. CONTINGENCY PLAN (if different than originally proposed)

APPENDIX A-4

INDUSTRIAL WASTE INJECTION WELL OPERATIONAL REPORT

I. WELL OPERATOR

1. Name ______________________________

2. Address ______________________________

3. City ______________

4. Phone number ____________ ______

5. Permit number ______________________________

II. SUMMARY OF OPERATIONAL DATA

A. Injected Volumes

1. Maximum daily volume specified in permit ________ gal/day

2. Present average daily volume ____________ gal/day

3. Total volume injected to date ____________ gal.

B. Injection Rate

1. Maximum injection rate specified in permit ______ gpm

2. Maximum injection rate during month __________ gpm

3. Average injection rate during month __________ gpm

C. Injection Pressure

1. Maximum well-head injection pressure specified in permit

__________ psi

2. Maximum well-head injection pressure during month

__________ psi

3. Estimated average well-head injection pressure during month

__________ psi

DETAILED OPERATIONAL DATA (supply detailed well operating record to accompany this report).

IV. INSTRUCTIONS

A. Each operator of an injection project shall furnish information on this form not later than the 10th day of the month following the month reported.

B. If several wells are utilized, report each one separately.

C. Fill in reverse side of form relative to daily injection practices.

D. Continuous recording charts will be made available upon request.

E. All operational problems, changes in injection system or wastes are to be reported when they occur.

INJECTION WELL OPERATING RECORD

1. CONTINUOUS OPERATING PERIOD					2. INJECTION RATE (GPM)		3. PRESSURE (PSI)				4. FLUID INJECTED (GAL.)	
Start		End		Length of Period (days & hrs.)			Well-Head Injection			Casing Tubing Annulus	Operating Period	Total Cumulative
Date	Time	Date	Time		Aver.	Max.	Max.	Min.	Estimated Average			

APPENDIX A-5

APPLICATION FOR PERMIT TO PLUG AND ABANDON A WASTE INJECTION WELL

I. Well operator:

1. Name________________________________

2. Address________________________________

3. City________________________________

4. Waste injection well permit number________________

II. Description of proposed plugging procedure:________________

____

III. Planned date and time of plugging:________________

IV. Present well status:

1. Total volume of waste injected________________

2. Present injection rate________________

3. Present injection pressure (well-head)________________

4. Present well shut-in pressure________________

V. Plugging operations will be conducted by:

1. Name of Company________________________________

2. Address________________________________

3. City________________ State________________

____ ____________

Signature of Authorized Representative of Operator Date

____ ____________

1. Application for a permit to plug and abandon shall be filed at least 30 days in advance of planned date of operation.
2. The planned date and time of plugging should be specific and the operation must be witnessed by a representative of the________________
(regulatory agency)

APPENDIX A-6

WASTE INJECTION WELL PLUGGING AND ABANDONMENT REPORT

I. Well operator:

1. Name ______________________________
2. Address ______________________________
3. City ______________

II. Description of plugging:

Plug materials	Depth From - To (feet)

III. Final well status

1. Total volume of waste injected ____________ as of ____________ (date)
2. Final well shut-in pressure ______________________

IV. Associated work:

Pits and excavations filled ( ) yes

Equipment and debris removed ( ) yes

Permanent monument emplaced ( ) yes

Executed this __________ day of ____________, 19____,

State of ____________________________ County of ______________________________

____

(Signature of affiant)

____

(Typewritten name and title)

On this ___________ day of ___________, 19_____, before me appeared

____________________________________, known to me to be the person whose name is subscribed to the above instrument, who being by me duly sworn on oath, states that he is authorized to make the above report and that he has knowledge of the facts stated therein, and that said report is true and correct.

SEAL

My commission expires __________________

____

(Notary Public)

Plugging witnessed by ____

Authorized state representative