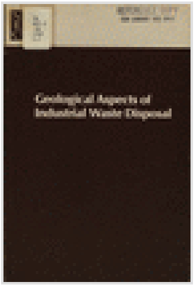

Geological Aspects of Industrial Waste Disposal (1982)

Pages
57

Size
5 x 9

ISBN
0309327512

Ad Hoc Committee on the Geological Aspects of Industrial Waste Disposal; National Research Council

Geological Aspects of Industrial Waste Disposal

Ad Hoc Committee on the Geological Aspects
of Industrial Waste Disposal
Geological Sciences Board
Assembly of Mathematical and Physical Sciences
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1982

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors, according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

Available from
Geological Sciences Board
Office of Earth Sciences
National Research Council
2101 Constitution Avenue
Washington, D.C. 20418

GEOLOGICAL SCIENCES BOARD

WILLIAM R. DICKINSON, University of Arizona, *Chairman*
SAMUEL S. ADAMS, Ertec Rocky Mountain Inc., Golden, Colorado
B. CLARK BURCHFIEL, Massachusetts Institute of Technology
LLOYD S. CLUFF, Woodward-Clyde Consultants, San Francisco
WALTER R. ECKELMANN, Exxon Corporation, New York City
WILLIAM W. HAY, Joint Oceanographic Institutions Inc., Washington, D.C.
CARROLL ANN HODGES, U.S. Geological Survey, Menlo Park
WILLIAM C. LUTH, Sandia National Laboratories
CHARLES J. MANKIN, Oklahoma Geological Survey, Norman
JACK E. OLIVER, Cornell University
RICHARD R. PARIZEK, Pennsylvania State University
DAVID M. RAUP, Field Museum of Natural History, Chicago
H. JESSE WALKER, Louisiana State University
E-AN ZEN, U.S. Geological Survey, Reston, Virginia
DONALD L. ZIEGLAR, Chevron U.S.A., Inc., Concord, California

LIAISON MEMBERS

LEON L. BERATAN, U.S. Nuclear Regulatory Commission
ROBIN BRETT, National Science Foundation
PHILIP COHEN, U.S. Geological Survey
PAUL R. FISHER, U.S. Army Corps of Engineers
JOHN G. HEACOCK, Office of Naval Research
LINN HOOVER, U.S. Geological Survey
GEORGE A. KOLSTAD, Department of Energy
JOHN F. LANCE, National Science Foundation
DALLAS L. PECK, U.S. Geological Survey
JAMES V. TARANIK, National Aeronautics and Space Administration

PARTICIPANTS

E. F. Osborn, *Chairman*
Distinguished Professor Emeritus
Carnegie Institution of Washington
Washington, D.C.

	Assigned Topics for Meeting on June 3, 1980
EILEEN CHASE Reference Aid Reference Department Kansas City Public Library Kansas City, KS	Suggested Research Topics on Soil-Leachate Interactions
JOHN C. FRYE Executive Secretary Geological Society of America Boulder, CO	Need for Geological Mapping to Locate Areas Suitable for Industrial Landfills
WILLIAM W. HAMBLETON Director and State Geologist Kansas Geological Survey Lawrence, KS	Geological Aspects of Aquifer Contamination
CHARLES J. MANKIN Director and State Geologist Oklahoma Geological Survey Norman, OK	Geological Considerations of Deep-Well Injection of Liquid Industrial Wastes
RICHARD R. PARIZEK Professor of Geology Department of Geosciences Pennsylvania State University University Park, PA	Field Demonstration Projects for Waste Disposal

	Assigned Topics for Meeting on June 3, 1980
CARL RAMPACEK Director Mineral Resources Institute University of Alabama Tuscaloosa, AL	Geological Aspects of Waste Disposal in the Mining Industry
ARTHUR A. SOCOLOW Director and State Geologist Bureau of Topographic and Geologic Survey Harrisburg, PA	Geological Considerations in Landfill Problems
ALBERT J. VON FRANK Environmental Director Allied Chemical (Retired) Apopka, FL	Industry's Need for Geological Data for Waste Control
M. GORDON WOLMAN Chairman Department of Geography and Environmental Engineering The Johns Hopkins University Baltimore, MD	Geologists and the Disposal of Industrial Waste

LIAISON MEMBERS

ROGER A. BLOOMFIELD
Manager, Solid Wastes Management
Division of Minerals Environmental Technology
U.S. Bureau of Mines
Washington, DC

ROBIN BRETT
Director, Division of Earth Sciences
National Science Foundation
Washington, DC

STEPHEN R. CORDLE
Environmental Engineer
Office of Environmental Processes and Effects Research
Environmental Protection Agency
Washington, DC

LEONARD F. KONIKOW
Research Hydrologist
Water Resources Division
U.S. Geological Survey
Reston, VA

*IAN D. MACGREGOR
Professor of Geology
Department of Geology
University of California
Davis, CA

MICHAEL H. ROULIER
Soil Scientist
Municipal Environmental
Research Laboratory
Environmental Protection
Agency
Cincinnati, OH

JEFFREY B. SMITH
Assistant Director
Unconventional Gas Recovery
Office of Gas
Department of Energy
Washington, DC

STAFF

JOSEPH W. BERG, JR.
Executive Secretary
Office of Earth Sciences
Assembly of Mathematical
and Physical Sciences
National Research Council
Washington, DC

GUEST

ROBERT G. TARDIFF
Executive Director
Board on Toxicology and
Environmental Health
Hazards
Assembly of Life Sciences
National Research Council
Washington, DC

*Formerly: Department of Energy.

PREFACE

The United States does not have a coordinated program for the disposal of industrial wastes, and the health and environmental problems associated with their disposal are becoming increasingly serious. In this report consideration is given to geological aspects, which play an important role in solutions to the problems and which are perhaps the least amenable to direct measurement of all the factors involved in the disposal of industrial wastes. The total significance of current and past practices is not known and is not addressed in this report. A much broader and comprehensive study is needed to make an assessment.

Industrial wastes are currently dumped on the surface or in shallow burial sites or pumped down wells under high pressure. Potential contamination of aquifers or surface-water supplies is the principal health concern in such disposal methods, and additionally some of the wastes can contaminate the soil or seep into basements of homes. Federal regulations such as those provided in the Resource Conservation and Recovery Act of 1976 and its amendments* have been put into effect to help safeguard the citizens from hazardous waste disposals. Yet, there is still need to develop systems for the safe disposal of the myriad of chemical waste products. As in the case

---

**U.S. Code Congressional and Administrative News*, Oct. 20 to Oct. 22, 1976, "Resources Conservation and Recovery Act," p. 2795.

The Solid Waste Disposal Act (Public Law 94-580) showing changes made by the 1978 and 1980 Amendments, 96 Cong., 2nd session, U.S. Govt. Printing Office, Washington, D.C., 1980.

of both radioactive wastes and urban refuse, so for industrial wastes, geological information is needed to find suitable solutions.

To identify the needed geological information, an *ad hoc* committee was convened for a one-day meeting on June 3, 1980, at the request of the Advisory Board to the Office of Earth Sciences of the National Research Council. The committee was supported by Program Initiation Funds of the National Academy of Sciences. Current activities in the field were reviewed with a view toward appraising the current status of research and identifying opportunities for the geological sciences to contribute to a better understanding of the materials and processes that are needed for the safe disposal of industrial wastes in the solid earth.

On behalf of the members of the *Ad Hoc* Committee on the Geological Aspects of Industrial Waste Disposal, I hope this report may be helpful in efforts to preserve the good health of our nation's citizens and to maintain an acceptable environment.

E. F. Osborn, *Chairman*
Ad Hoc Committee on the
Geological Aspects of
Industrial Waste Disposal

CONTENTS

1 SUMMARY

The safe disposal of industrial wastes is an increasingly serious national problem. When wastes are buried, it is possible to contain them or to provide attenuation of toxicity by the natural systems of the earth, provided that the chemical nature of the waste materials is known, information is available on reaction between these materials and the various rock types involved, and geological parameters of the site can be evaluated. The *ad hoc* committee concluded that needed geological studies for safe disposal, including waste-rock reactions, have usually not been made before wastes are dumped upon or pumped into the earth's crust. A coordinated program of basic research and demonstration projects should be developed, involving federal agencies, state geological surveys, universities, and industry. Geological mapping of the type that can be a guide to locating safe disposal sites is an acute need, as well as research on soil-leachate interactions and reactions between waste and various rock types, fluid flow and solute transport in rocks of low permeability, predictability of fracture patterns and parameters in rocks, and the hydrodynamics and geochemistry of deep basins. A much broader study is needed to assess the total significance to the nation of industrial waste disposal.

2 INTRODUCTION

Of the three interrelated facets of the ecosystem that receive all of society's wastes--air, water, and land--land disposal has been the least understood and least amenable to upgrading by the public-engendered environmental forces of recent decades. The disposal of waste at the earth's surface or in underground space is an industrial practice that has been used since manufacturing and other industrial activity began. Historically, these practices were not considered hazardous because (1) the volume of such activity was small, and (2) the environmental effects are slow to materialize. Thus, disposing of materials in a landfill or injecting liquids into subsurface rock strata was considered to be safe and effective. Beginning with the 1960's, industry, public policymakers, and the scientific community were made more aware of the public-health and environmental problems encountered with hazardous-waste treatment and disposal in the ground. Startling examples of the potential hazards of poorly managed waste disposal have been publicized, forcing attention and government action in this problem area. Such an example is that of the Love Canal area of New York, where families have been relocated and the population traumatized. At a minimum, this example illustrates a failure of policy in planning and management for the disposal of wastes and the subsequent use of the land. Other hazardous sites most assuredly do exist, although only a small number of health-related disasters have occurred. "The extent of the problem has yet to be measured adequately. A report to the U.S. Environmental Protection Agency in February 1979 estimated that there may be 32,000 to 50,000 disposal sites in the United States containing hazardous wastes, and of these, anywhere from 1,200 to 2,000 may pose significant risks to human health or the environment. Most of these dumps are still being used; perhaps 500 to 800 are abandoned."* Although the numbers given above have been questioned by members of the committee, all agree that a potentially serious problem does exist.†

The essential requirement for the long-term security of underground disposal of industrial wastes is the ability to predict accurately the behavior of the geological medium into which the waste has been emplaced. Furthermore, it is sometimes necessary to predict such consequences accurately over lengthy periods of time (centuries or even millennia). For land burial of solid waste, or for well injection of liquid wastes, the types and characteristics of the rocks interfacing with the waste materials are essential factors in waste isolation or in rendering the waste harmless to health. The geologist, therefore, must play an important role in providing the knowledge and information required to determine that the selection of disposal sites are consonant with protection of public health and the environment over the long term.

Despite what would appear to be a very small-scale effort on the part of geologists, in relation to the scale of the waste problem, significant work has been accomplished--enough to indicate the opportunities and needs. Geological maps, readily understandable to non-scientists, have been prepared for some areas, for example, the Chicago region of northern Illinois and the Texas gulf coastal area. These maps have been serving as helpful guides in selecting suitable landfill waste-disposal sites and in avoiding sites that would result in serious future contamination of water supply or other

---

**Environmental Quality, 1979*. The tenth annual report of the Council on Environmental Quality, December 1979, U.S. Government Printing Office, Washington, D.C., p. 174.

†A press release entitled, *Environmental News*, issued by the Environmental Protection Agency, dated 3 October 1981, describes the 114 disposal sites in the United States considered by that agency to be the most hazardous from the standpoints of public health and threat to the environment.

health or ecological problems. State geological surveys have taken the lead in this field. Numerous geological studies of problems connected with deep-well injection have been made, with summaries appearing in monographs of the American Association of Petroleum Geologists.

In consideration of the current national attention directed at land disposal of wastes and at the urging of scientists familiar with the field problems involved, a one-day conference was held to consider geological aspects of the topic. The participants met on June 3, 1980, for the purpose of considering the role that geologists can play in seeking to establish a more effective and safer means of disposing of industrial wastes and of formulating a judgment as to the advisability of activating a broader study of this topic in the near future. Participants were from universities, industries, governmental agencies (federal and state), and professional societies. Nine brief papers on pertinent topics (Appendixes A-I) were written by the participants and distributed before the meeting. These papers concern the role of geologists in the disposal of wastes, the great value (and scarcity) of appropriate types of geological maps for location of sites for disposal of municipal solid wastes, the problem of the contamination of aquifers, geological considerations in deep-well injection of liquid wastes, problems of disposal of wastes from the mining industry, and, in general, the great need for information on those properties of rocks that play such an important role in the underground containment of waste. The authors emphasize that the information available to determine the capability of geological environments to accept such industrial wastes safely and effectively is for the most part fragmentary and inadequate. The information must be acquired not only to meet demands for immediate decisions to dispose of wastes at specific sites, but also the cumulative knowledge of the behavior of waste-land/water systems must be acquired over the longer term. The papers and the discussion at the meeting on June 3, 1980, are the bases of this report. The report does not cover all aspects of industrial waste disposal, but the expertise of the participants was judged to be sufficient to highlight major geological problems, ongoing services and research, and needed actions.

3 INDUSTRIAL WASTE DISPOSAL

By-products of industrial processes (wastes) should be disposed of either through total containment for a specified length of time and/or attenuation of the toxicity of the wastes in natural systems of the earth. In order to do this effectively, the amount and composition of the wastes and of the products of decomposition after burial must be known, and appropriate information about the confining earth materials and fluid flow in surface and subsurface geological systems must be available and must be used. Serious aquifer contamination is possible and may be under way at present in the United States but can be minimized through actions based on studies of the physical and chemical characteristics of each particular aquifer. In some cases, for example, an aquifer may be rehabilitated through flushing, but more definitive studies are needed in this field (see Appendix F).

It is critically necessary to identify materials in the earth and to characterize their capacity to absorb, retain, or transmit wastes of known physical and chemical properties and to predict the intensity, timing, and transformation of wastes as they are confined or dispersed to the surrounding environment. In addition, there is urgent need for more information on potential disposal areas to help ensure that the disposal of wastes does not compromise potential future resource development. This is a massive job and requires achieving new levels of scientific and technical understanding and the implementation of better waste-disposal guidelines and practices. In this manner, the general public will receive improved protection through a planning process that includes known options.

The two common earth-disposal methods for wastes are by (1) landfill burial and (2) deep-well injection. Each practice is discussed below and a concluding statement made regarding the need for geological information.

LANDFILL WASTE DISPOSAL

Wastes are put into subsoil or rock and covered. Geological considerations are affected by the intended process of each landfill--whether it be to dilute and disperse or to concentrate and contain. For safe disposal, the processes must be understood and spelled out in precise, quantitative, scientific terms. It is essential to define clearly the nature of the materials to be disposed of, e.g., organic versus inorganic, physical format and volumes, chemical composition and chemical reactivity. These data must be developed accurately and completely and in a timely and thoroughly scientific manner, conditions rarely met at present.

The geological parameters of a disposal site that need to be understood are the stratigraphy, mineralogy, geochemistry, structure, groundwater flow, and topographic characteristics. This geological information must be related to the properties of the wastes and to the dynamics of the flow systems within the earth. Mineral resources and resources potential are also matters to be weighed when selecting a disposal site. In recognition of the potential impact of landfill wastes on the groundwater regimen, it is essential to define additional, relevant parameters for each prospective site, including precipitation, runoff, evapotranspiration, primary recharge areas, depth and fluctuation of the water table, porosity-permeability characteristics above and below the water table, perched water tables of the area, and subsurface flow rates and directions. The lead time for investigations to ensure safe disposal is years, and much of the needed research is not being done at present (see Appendixes B, C, H, and I for specific examples).

DEEP-WELL WASTE DISPOSAL

The most notable deep-well waste-disposal activity is the disposal of oil-field brines. This is a widespread activity in the petroleum-producing regions and involves tens of millions of barrels of fluid daily (see Appendix D). This disposal practice is regulated by state agencies in a generally consistent manner, although the specific requirements do vary from state to state. At present, federal regulations governing oil-field brine disposal are being promulgated by the Environmental Protection Agency (EPA) under amendments to clean-water legislation.

Disposal of other industrial liquids is small in volume by comparison with the disposal of oil-field brines. Nevertheless, the practice of deep-well disposal of industrial liquid wastes is growing rapidly, without a needed geological information base.* In Pennsylvania, for example, despite the fact that about one-half million oil and gas wells have been drilled, little information useful for waste disposal is available. Where information was obtained that could be useful now, it may not have been tabulated and made available because there was no perceived need. The hydrodynamics of Pennsylvania basins remains essentially unknown.

Most sedimentary basins in the United States have been described in a general way. Information pertaining to the size, shape, general geological setting, and tectonic history of most of the basins is publicly available. However, important details are either commonly not known or not available in the public domain. For instance, the general lithology, spatial distribution, and structural configuration of a formation potentially capable of accepting industrial liquid wastes may be known, but little or no information may be available on the petrophysics of that formation nor on the composition of its contained fluid. Petrophysical parameters, such as mineral composition, porosity, permeability, and density, are in many instances critical to the effective injection of fluids and to their safe containment and/or the attenuation of their toxic materials. The physical and chemical properties of the rock-formation fluids play an equally important role. Reactions between these fluids and those being introduced into the formation may result in precipitation of solids near the well bore and the effective sealing of the formation to further liquid-waste injection. Conversely, such reactions may be beneficial in increasing permeability and thereby enhancing the formation for liquid-waste disposal. If appropriate information is available, characteristics of the reactions between the waste and groundwater systems

---

*A. M. Piper, *Disposal of Liquid Wastes by Injection Underground*, U.S. Geological Survey Circular 631, 1969.

can be determined in advance and the end effects probably predicted.

Although much has been learned from the several decades of experience garnered from oil-field brine disposal, the injections of other industrial wastes present possibly serious contamination problems. To date, the analysis and resolution of these problems seem to have been on an *ad hoc* basis. Thus, injection of liquids in a particular instance may be judged to be safe, following a thorough study, but little may be accomplished in developing an adequate information base and methodologies pertaining to general solutions with broad application. A careful analysis of this rapidly growing industrial activity is clearly in order. The goal should be an acceptable environment, including clean groundwater, and waste disposal at an acceptable cost.

CONCLUSION

The scope and potential ramifications of the land-disposal problem are enormous, particularly in the long view. The problem is one that demands the best of local, regional, and national planning and management. Furthermore, it is evident that the improvement of disposal practices must be supported by a sound and conclusive science, which, in turn, must be persuasive to nonscientific policymakers and the general public.

Programs should be implemented or expanded by the federal and state governments and private industry to provide especially for the following: (1) the making of appropriate geological maps, (2) the determination of the petrophysical and petrochemical properties and the general character of host rocks and their interactions with the waste materials, (3) the analysis of groundwater-flow systems, (4) geological studies of deep basins, and (5) research on the characterization and rehabilitation of aquifers. Information from these recommended programs should be formulated so that it can be used in the decisions that are being and will be made in the disposal of industrial wastes to help ensure safe disposal practices.*

---

*Examples are:

P. M. Brown and M. S. Reid, *Geologic Evaluation of Waste-Storage Potential in Selected Segments of the Mesozoic Aquifer System Below the Zone of Fresh Water, Atlantic Coastal Plain, North Carolina Through New Jersey*, Geological Survey Professional Paper 881, U.S. Government Printing Office, Washington, D.C. 1976.

P. M. Brown, D. L. Brown, M. S. Reid, and O. B. Lloyd, Jr., *Evaluation of the Geologic and Hydrologic Factors Related to the Waste-Storage Potential of Mesozoic Aquifers in the Southern Part of the Atlantic Coastal Plain, South Carolina and Georgia*, Geological Survey Professional Paper 1088, U.S. Government Printing Office, Washington, D.C., 1979.

4 SERVICES AND RESEARCH

Federal agencies, particularly the EPA, the U.S. Geological Survey (USGS), the Bureau of Mines (BuM), and the Department of Energy (DoE) have important responsibilities relating to the disposal of nonnuclear industrial wastes. They conduct in-house research, as well as funding contract research programs that relate to the geological aspects of waste disposal. It is estimated that at least $30 million is being spent annually by the federal government for research on nonnuclear wastes. The EPA is engaged in research on chemical treatment of wastes and on the siting of waste areas and clean-up problems and also supports research at universities on a modest scale; the USGS has a program aimed at understanding the applied and theoretical aspects of groundwater systems; the BuM is involved with problems relating to the mining industry (leaching and acid-mine drainage, for example); the DoE (Office of Health and Environmental Research, Office of Energy Research) supports basic research in nonnuclear solid wastes, and research on coal-conversion and coal-combustion wastes reflects a substantial research commitment to "industrial solid wastes"; the National Science Foundation (NSF) supports a broad range of basic research, and some is related to waste-disposal problems. It would appear that coordination among the various agencies should be encouraged for more beneficial results.

State geological surveys are involved with waste-disposal problems in several ways, for example, in the making of maps of surface and near-surface rock types and in the study of water supply, potential landfill areas, and old mine collapse areas (see Appendixes C and E). Pennsylvania requires geologists to be involved in the regulatory processes of land disposal of wastes, and the geological surveys of Oklahoma and Kansas have been involved in developing regulations to control the disposal of brines associated with petroleum production. Important technical information has been gained on the general subject of subsurface liquid disposal of hazardous nontoxic waste. In some cases, federal regulations override the state's authority, such as in the case of the EPA's pending legislation on underground injection of oil-field brines.

Industry's primary need is to define and locate sites where industrial wastes of specified character can be put down (see Appendix G). Geological information is usually supplied to industry by consultants, although a few companies have staff geologists. In general, the problems of today had their genesis several decades ago, and, in some cases, the data are lacking about earlier disposal products and processes. The options for disposal are declining for many reasons (permits and restrictions on interstate movement, for example), whereas the quantities of wastes are increasing. This trend can be reversed to provide for more options if an adequate information base is established.

Universities have only a small research effort directly applicable to this problem. The size of the research effort results partly from the small scale of program support for such research, partly because emphasis has never been directed toward this type of problem and partly because disposal of wastes has been looked upon as a task lacking in scientific problems. The basic science needed for the safer disposal of industrial wastes, however, presents many problems that are suitable and timely subjects for university research. The components of the systems in the earth (mineralogy, porosity, directional permeability, surface chemistry and physics, chemical reactions, for example) need to be understood. In most cases, the dynamics related to disposal are poorly known. The reservoir systems in the earth are in need of greater study. They are complex and time variant, and, when impurities are added, the systems become more complex.

5 ACTIONS NEEDED

The following list summarizes major actions identified by this study that would aid in the safer disposal of industrial wastes.

1. There is an immediate need for an interdisciplinary study to define better the specific problems that are crucial to establishing acceptable waste-disposal practices. Policy and management should be included in the study as well as scientific and technical considerations of the waste-land/water systems.

2. The overall federal program on industrial waste disposal should provide for adequate fundamental research by both university and government scientists and engineers. As a facet of this effort, the crustal studies program now getting under way, under the aegis of the Continental Scientific Drilling Committee (National Research Council), is especially relevant as an opportunity for germane research.

3. The dynamics of the interactions of waste and earth materials should be studied as a system. The problem of matching the geological parameters of formations (porosity, permeability, and sorption capacity, for example) with chemical and physical components of wastes to obtain the desired attenuation of the components is extremely important.

4. State geological surveys should work more effectively with industries to help solve problems of waste disposal, particularly in the development of criteria for site selection. Geological mapping should be done with the view of aiding in the selection of candidate sites, and more detailed topical maps should be made by state agencies for these sites. Site-specific investigations

should be conducted in increasing detail until the most acceptable site is identified. At that time, in-depth studies of the waste-earth system should be made with an aim toward acceptable alterations of the groundwater and the environment.

5. Better utilization should be made of data collected from holes drilled for other specific purposes such as exploration or foundations (see Appendix I); incentives should be given to collect and release the kinds of hydraulic and geochemical data that could be used to help determine the response of fluid flow and solute transport to injections of industrial wastes in deep wells.

6. Specific problem areas suggested for priority action are the following:

(a) The nature of soil-leachate interactions, such as the effects of naturally occurring salts in fine-grained soils, the effects of chemicals such as sodium carbonate on the permeability of soils, and the effect of directional permeability (horizontal versus vertical).

(b) Evaluation of phenomena associated with fractured rocks, including the geological origin and nature of fractures, predictability and detectability of fracture patterns and parameters, hydraulic properties, and solute transport in fractured rocks.

(c) Behavior of rocks of low permeability, including their role as confining layers or barriers to fluid flow and solute transport, their hydraulic properties on a regional scale, their chemical reactivity with wastes or leachates, and their suitability as waste repositories.

(d) The possibility and cost of the rehabilitation of aquifers.

APPENDIX A: Geologists and the Disposal of Industrial Waste

M. Gordon Wolman

To the extent that industrial wastes will be disposed of in any natural media--land, water, or air--earth scientists must have a significant role to play in formulating policy and in decisions about land disposal at specific locations. The role of the geologist becomes increasingly important as more and more wastes are to be disposed of in the ground and hence in association with the water, soils, and organic constituents within the earth. It is the geologist who should have the knowledge and information required to assure that the design, operation, and maintenance of disposal facilities are consonant with protection of the environment over the long term.

As in all matters of politics and policy, the rediscovery of the profligate behavior of human beings and the disposal of wastes places the apparent additive burden of immediate solutions to waste-disposal problems on top of the reality of the necessity for unending solutions to waste disposal within the earth for all future time as it has been for all past time of man. The tasks are not new. The stratigraphy of solid waste is the classic stratigraphic section of archaeologists and geologists. It is the multiplicity of new materials unique to man and absent in nature, the density of social structures, and new knowledge of the mobility of substances within the earth that lend urgency to the concern for the safe disposal of industrial wastes.

It should be a task of geologists to identify materials in the earth and their capacity to absorb, retain, or transmit wastes with diverse properties and to predict the intensity, timing, and transformations of wastes as they are confined or dispersed to the surrounding environment.

The combined study of the flow of fluids in permeable media, the chemistry of transformations, and the structure and stratigraphy of earth materials has not been common among large numbers of geologists. Indeed, without figures to support the assertion, it appears that relatively few individuals and institutions have specialized in such studies. Further, agronomists and soil physicists have often been primarily concerned with the upper strata of the soil, while geologists have generally concerned themselves with larger systems dominantly at greater depths. Fewer individuals have sought to link soil moisture and groundwater behavior specifically to the special problems involved in the disposal of industrial wastes.

It would probably be a mistake to assume that what are now conceived to be thoughtless techniques of waste disposal were conscious efforts to avoid laws or social precepts of former eras. Not only was waste disposal conceived along the lines of out of sight, out of mind, many of those responsible for waste disposal were unaware of potential hazards. The continuing task confronting society is large, complex in concept, and equally complex in execution. The combination of general principles of geophysical behavior joined to unique conditions at waste-disposal sites will demand of geologists not only broad training in geophysics but training in fundamental and classical geological principles as well. As in so many facets of environmental management, geologists will be called on to deal with engineers, biologists, public officials, and citizens as the siting of waste-disposal facilities moves to the point where it counts, that is, where disposal sites must be in someone's backyard. The task is immense, the job is clearly for the geologist.

SELECTED REFERENCES

Committee on Geological Sciences (1972). *The Earth and Human Affairs*. Wastes and Pollution, pp. 82-97. Division of Earth Sciences, National Research Council-National Academy of Sciences. Canfield Press, San Francisco, California.

Impact of the Geosciences on Critical Energy Resources (1978). Selected Symposium 21, American Association for the Advancement of Science. Westview, Boulder, Colorado.

APPENDIX B: Field Demonstration Projects for Waste Disposal

Richard R. Parizek

Industrial wastes can vary widely in their chemical character and be in gaseous, liquid, or solid form. Some can be treated by land application systems when geochemical, biochemical, and physical processes operate to filter and renovate pollutants derived from these wastes. Industrial liquids and sludges have been applied to the land with varying success by surface flooding and irrigation, stockpiling and spreading of sludges, storage in lined and unlined basins and lagoons, and land burial operations. Land-application systems involving relatively simple wastes such as municipal waste waters and sludges applied to the land under controlled conditions and the disposal of municipal solid wastes using the "sanitary landfill method" have been the subject of several studies, including the two noted below.[1,2]

It should be clear that even these relatively simple wastes can and have posed pollution threats within and adjacent to the disposal sites for various reasons outlined in the reports even when disposed of under controlled conditions. Some more toxic substances should produce leachates of poorer quality that are more stable, nonbiodegradable or only slowly biodegradable, and not readily attenuated as they migrate through soil-rock-hydrologic systems. Wastes of these types pose particular pollution threats that may be long term in nature. A concept of "land storage" rather than "land disposal" should be adapted when dealing with these wastes. Soils, rock, and hydrologic systems must be selected that will ensure containment, long-term storage, and slow release of pollutants and contaminants under controlled and acceptable conditions. Natural, geological, hydrologic, and engineering barriers will be needed to contain these wastes and their by-products of weathering. Soil-rock-water systems should not be called on to provide renovation and treatment to these wastes, rather to provide containment for engineered facilities, a stable foundation, and an opportunity to control the slow release of these contaminants within known sectors of soil-water and groundwater flow systems. These same soil and rock deposits also can be exploited to allow for a future opportunity to collect and treat these leachates in the event they are not contained or attenuated within soil-water and groundwater flow systems as anticipated.

The long-term stability of some toxic chemicals and possible mechanisms for their later release in our environment demand that we must understand their full chemical character and geochemical behavior when released into the biosphere through incineration, land treatment, and disposal or discharge to aqueous systems. Toxic metals, for example, may be retained on soil particles at spray irrigation sites for years until they may be released in soluble form when soil pH decreases in response to change in environmental conditions, i.e., "acid rain" or changes in land use. Also in time, soil particles can be eroded from uplands and transported into streams and lakes where entrained, and previously stable pollutants are recycled into new environments that may cause these pollutants to become "available" in more toxic form. The methalation of lead to produce a toxic form of lead within aqueous environments may be a case in point.

I see limits to the ability of natural systems to treat and contain pollutants adequately, hence I strongly endorse the need for a more adequate understanding of this entire industrial-waste problem.

SELECTED REFERENCES

1. R. R. Parizek, "The Sanitary Landfill Method of Solid Waste Disposal," presented at the Conference on Solid Waste Management Alternatives for Crawford County, Pennsylvania, held at Allegheny College Campus Center, June 7, 1978.
2. *Land Application of Waste, Water, and Sludge (LAWWS)*, Reference Manual, A Continuing Education and Cooperative Extension Service Program, The Institute for Research on Land and Water Resources, The Pennsylvania State University, October 1978.

APPENDIX C: Geological Considerations in Landfill Problems

Arthur A. Socolow

PROBLEM AND PREMISE

In an era when scientific and public attention has been focused primarily on the problems and fears related to nuclear wastes, the disposition of industrial wastes has no equal in terms of hazard, daily volumetric yield, and extent of geographical occurrence. It is the very magnitude of volume and geography that creates the interface of industrial waste with geology, while it is the hazardous and toxic nature of so much of the wastes that now forces us to address scientific skills to that interface.

Old-fashioned dump sites utilize the concept of solving the problem by spatial separation, while ignoring the issues of contamination and aesthetics. The so-called sanitary landfill attempts to resolve the aesthetics issue yet inadequately deals with contamination; too much "out of sight, out of mind" syndrome is attached to this method. Science, in its most systematic, creative, and applicable procedures, must come forward to aid in this universal problem.

DATA NEEDS--THE GEOLOGY

Once it is recognized that there is a clear-cut, ongoing interface between industrial wastes and geology, it is essential to identify thoroughly the geological parameters, including the lithology, structure, groundwater, and topographic characteristics. The geology of each proposed disposal site, and its surrounding area, must be inventoried in detail, analyzed, and understood. The stratigraphy and structure must be delineated, as well as the petrography, mineralogy, and texture. Mineral resources and resources potential must be evaluated, as well as the topography, with concern for slope stability and runoff conditions.

In recognition of the potential impact of landfill wastes on the groundwater regimen, it is essential to define all the relevant parameters for each prospective site, including precipitation, runoff, evapotranspiration, primary recharge areas, depth and fluctuation of the water table, porosity-permeability characteristics above and below the water table, perched water tables of the area, and subsurface flow rates and directions.

DATA NEEDS--THE WASTE

In recognition that a landfill is an interface between geology and the wastes, it is equally essential to define clearly the nature of the materials to be disposed of, e.g., organic versus inorganic, physical format and volumes, chemical composition and chemical reactivity. These data must be developed accurately and completely and in a timely and thoroughly scientific manner; it is the last that is invariably lacking.

THE GOAL AND THE PROCESS

Impacting directly on the geological considerations is the intended process of each landfill--whether it be to dilute and disperse or concentrate and contain. Each requires its own set of favorable conditions, and each process involves different chemical-physical processes, which themselves must be carefully defined in advance. The processes must be understood and spelled out in precise, quantitative, scientific terms.

THE TIMING, LANGUAGE, AND CHALLENGE

The geological consideration and data needs outlined above require comprehensive, time-consuming research and investigations; they cannot be accomplished on demand in short order. There must be ongoing programs of topical research and areawide investigations in order to provide the site-specific data as needed. The lead time for proper investigations measures in terms of years. The results of all investigations must be made available promptly to all interested parties in a format that is intelligible. In the final analysis, there must be an acceptable language of communication with the decision maker, who is likely not to be a scientist.

Industrial waste disposal is beginning to receive the attention it deserves--at least in the public sector. It has taken a number of disastrous occurrences to bring this about. It is now time for the scientific community also to give the subject proper attention. This is, of course, in part a matter of financial and manpower support. But there is also an attitudinal question of acceptability in the scientific community; this mundane subject of waste disposal is not to be looked down on by scientific investigators. There is need and opportunity for sophisticated research in those mountains of waste and vast areas of waiting land. The scientific community has a responsibility to respond to the challenge at the interface.

SELECTED REFERENCES

Atkin, G., Jr. (1973). *Solid Waste Management 1965-1973: A Story of CHAOS*. Northwest Engineering, Inc., Tidioute, Pa. 16351, 27 pp.

Bergstrom, R. E. (1968). *Disposal of Wastes: Scientific and Administrative Considerations*. Illinois State Geological Survey, Environmental Geology Notes, No. 20.

Brown, L. F., Jr., W. L. Fisher, and J. F. Malina, Jr. (1972). *Evaluation of Sanitary Landfill Sites, Texas Coastal Zone--Geologic and Engineering Criteria*. Bureau of Economic Geology, University of Texas at Austin, Geological Circular 72-3, 18 pp.

Cartwright, K., and F. R. Sherman, Jr. (1972). *Electrical Earth Resistivity Surveying in Landfill Investigations*. Proceedings of the 10th Annual Engineering and Soils Engineering Symposium, Moscow, Idaho, pp. 77-92.

Clyde E. Williams & Associates, Inc. (1972). *The Use of Sand and Gravel Pits for Sanitary Landfills*. National Sand and Gravel Association, Project No. 6, 139 pp.

Dunne, N. G. (1977). *Successful Sanitary Landfill Siting: County of San Bernardino, California*. U.S. Environmental Protection Agency, Publication SW-617, 31 pp.

Emrich, G. H. (1970). *Discussion of the Proposed Guidelines for Sanitary Landfills--Groundwater and Percolation*. Environmental Foundation Conference on the Application of Environmental Research and Development on Landfill Disposal of Solid Wastes, Deerfield, Mass., Aug. 24-28.

Emrich, G. H., and R. A. Landon (1971). *Investigation of the Effects of Sanitary Landfills in Coal Strip Mines on Ground Water Quality*. Pennsylvania Department of Environmental Resources, Bureau of Water Quality Management, Publication No. 30, 58 pp.

Emrich, G. H., G. L. Merritt, and R. D. Rhindress (1969). *Geocriteria for Solid Waste Disposal*. Northeast Section, GSA, Pittsburgh, Pa., Feb.

Environmental Management Council (1975). *An Environmental Approach to Selecting Potential Sanitary Landfill Sites in Monroe County*. Monroe County Legislature, Rochester, N.Y., 27 pp.

Foose, R. M., and P. W. Hess (1976). *Scientific and Engineering Parameters in Planning and Development of a Landfill Site in Pennsylvania*. Geomorphology and Engineering, Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pa., pp. 289-312.

Fungaroli, A. A., and G. H. Emrich (1970). *Pollution of Subsurface Water by Sanitary Landfills*. U.S. Department of Health, Education, and Welfare, U.S. Public Health Service, 132 pp.

Giddings, M. T. (1977). "The Lycoming County, Pennsylvania Sanitary Landfill: State-of-the-Art in Ground-Water Protection," Ground Water, Vol. 15, No. 1, pp. 5-13.

Haug, L. A., and R. J. Black (1972). *Sanitary Landfill: One Part Earth to Four Parts Refuse*. U.S. Environmental Protection Agency, Solid Waste Management Series (SW-6), 10 pp.

Hughes, G. M. (1972). *Hydrologic Considerations in the Siting and Design of Landfills*. Illinois State Geological Survey, Environmental Geology Notes, No. 51, 22 pp.

Hughes, G. M., and K. Cartwright (1972). "Scientific and Administrative Criteria for Shallow Waste Disposal," Civil Engineering--ASCE, Vol. 42, No. 3, pp. 70-73.

Hughes, G. M., R. A. Landon, and R. N. Faruolden (1971). *Hydrogeology of Solid Waste Disposal Sites in Northeastern Illinois*. U.S. Environmental Protection Agency, Rept. SW-12d, 154 pp.

Landon, R. A. (1969). "Application of Hydrogeology to the Selection of Refuse Disposal Sites," Ground Water, Vol. 7, No. 6.

Le Grand, H. E. (1964). "System for Evaluation of Contamination Potential of Some Waste Disposal Sites," J. Amer. Water Works Assoc., Vol. 56, No. 8, 11 pp.

Lessing, P., and R. S. Reppert (1971). *Sanitary Landfill Sites in Southeastern West Virginia*. West Virginia Geological and Economic Survey, Environmental Geology Bull. No. 3, 16 pp.

Lessing, P., and R. S. Reppert (1972). *Sanitary Landfill Sites in Central West Virginia*. West Virginia Geological and Economic Survey, Environmental Geology Bull. No. 5, 19 pp.

Lessing, P., and R. S. Reppert (1972). *Sanitary Landfill Sites in Northern West Virginia*. West Virginia Geological and Economic Survey, Environmental Geology Bull. No. 7, 15 pp.

Merritt, G. L., and W. C. Bucciarelli (1970). *The Geologic Aspects in the Planning and Implementation of the Pennsylvania Solid Waste Management Act*. Pa. Department of Environmental Resources, Bureau of Solid Waste, 42 pp.

Miller, D. W., ed. (1980). *Waste Disposal Effects on Ground Water*. Premier Press, Berkeley, Calif., 512 pp.

Parizek, R. R., and G. H. Emrich (1967). *Renovation of Pollutants from the Sanitary Landfill in Carbonate Rock Terrain*. Cooperative Study between Dept. of Geology, Pennsylvania State University and the Pennsylvania Department of Health.

Pennsylvania Department of Health (1970). *A Plan for Solid Waste Management in Pennsylvania*. Solid Waste Section, Solid Waste Publication 3, 162 pp.

Reppert, R. S., and P. Lessing (1971). *Sanitary Landfill Sites in Southwestern West Virginia*. West Virginia Geological and Economic Survey, Environmental Geology Bull. No. 4, 16 pp.

Reppert, R. S., and P. Lessing (1972). *Sanitary Landfill Sites in Northwestern West Virginia*. West Virginia Geological and Economic Survey, Environmental Geology Bull. No. 6, 18 pp.

Schneider, W. J. (1970). *Hydrologic Implications of Solid Waste Disposal*. U.S. Geological Survey, Circular 601-F, 10 pp.

Turk, L. J. (1970). *Disposal of Solid Wastes--Acceptable Practice or Geological Nightmare*. Environmental Geology, pp. 1-42, Washington, D.C.: American Geological Institute Short Course, AGI.

U.S. Environmental Protection Agency (1971). *Recommended Standards for Sanitary Landfill Design, Construction, and Evaluation and Model Sanitary Landfill Operation Agreement*; Publication SW-86+s, 23 pp.

Waldrip, D. B., and R. V. Ruhe (1974). *Solid Waste Disposal by Land Burial in Southern Indiana*. Water Resources Research Center, Indiana Univ., Bloomington, 110 pp.

Walker, W. H. (1974). "Monitoring Toxic Chemical Pollution from Land Disposal Sites in Humid Regions," Ground Water, Vol. 12, pp. 213-218.

Zanoni, A. E. (1972). "Ground-Water Pollution and Sanitary Landfills--A Critical Review," Ground Water, Vol. 10, No. 1, pp. 3-13.

APPENDIX D: Geological Considerations of Deep-Well Injection of Liquid Industrial Wastes

Charles J. Mankin

There is a small but growing body of literature on the subject of geological considerations of deep-well disposal of hazardous and toxic wastes. Significant among the papers on the subject are two American Association of Petroleum Geologists' publications; Memoir 10, *Subsurface Disposal in Geologic Basins--A Study of Reservoir Strata* and Memoir 18, *Underground Waste Management and Environmental Implications*. These publications present a good overview of the subject and describe issues that deserve more investigation.

The deep-well disposal of industrial wastes is a long-standing practice for selected areas of industrial activity. The most notable of these activities is the disposal of oil-field brines. This is a widespread activity in the petroleum-producing regions and involves tens of millions of barrels of fluid daily. The practice is regulated by state agencies in a generally consistent manner, although the specific requirements do vary from state to state. At present, federal regulations governing oil-field brine disposal are being promulgated by the Environmental Protection Agency under the amendments to the clean-water legislation.

Disposal of other industrial liquids is small in volume by comparison with the disposal of oil-field brines. Nevertheless, the practice is widespread and involves a broad range of liquids, including a large number of hazardous and toxic substances. Moreover, the practice of deep-well disposal of industrial liquid wastes is growing rapidly.

The safe disposal of industrial liquid wastes by deep-well injection requires a thorough knowledge of a range of geological parameters. However, the information available to assess the potential of geological environments that will safely and effectively accept such industrial liquid wastes is for the most part fragmentary and inadequate. Most sedimentary basins in the United States have been described in a general way. Information pertaining to the size, shape, general geological setting, and tectonic history of most sedimentary basins in the United States is publicly available. However, many important details are commonly either not known or not available in the public domain. For instance, the general lithology, distribution, and structural configuration of a formation potentially capable of accepting industrial liquid wastes may be known, but little or no information may be available on the petrophysics of that formation nor on the composition of its contained fluid. Petrophysical parameters, such as mineral composition, porosity, permeability, and density, are in many instances critical to the effective injection of fluids and to their safe containment.

The physical and chemical properties of formation fluids are important also in effective fluid injection. Reactions between the formation fluids and those being introduced into the formation may result in precipitation of solids near the well bore and effectively seal the formation to further liquid-waste injection. Conversely, such reactions may be beneficial in increasing permeability and thereby enhancing the formation for liquid-waste disposal.

Although much can be learned from the several decades of experience garnered from oil-field brine disposal, the injection of other industrial wastes presents some unique problems. To date, the analysis and resolution of these problems seem to have been on an *ad hoc* basis. Thus, individual problems are solved or at least accommodated, but little is accomplished in developing general solutions with broad application.

It would be presumptuous to attempt to identify the myriad of questions that arise in the examination of deep-well disposal of liquid industrial wastes. Nevertheless, listing a few general categories of such questions is instructive in developing a better understanding of the problems.

- Interactions of the injection fluid, the receptor formation, and the contained formation fluid.
- Effect of injection pressure on the mechanical integrity of the receptor formation and the associated confining strata.

- Tectonic stability and long-range integrity of the receptor formation and the associated confining strata.
- Long-range changes in the physical state of the receptor formation and its contained fluids through chemical interactions (e.g., evolution of gas phases).

The consequences of deep-well injection of liquid industrial wastes are incompletely understood. Information collected to date suggests a number of problems or at least potential problems that warrant examination. A careful analysis of this rapidly growing industrial activity is clearly in order.

SELECTED REFERENCES

Braunstein, J., ed. (1973). *Underground Waste Management and Artificial Recharge*, American Association of Petroleum Geologists, special publication, 2 volumes, 931 pp.

Cook, T. D., ed. (1972). *Underground Waste Management and Environmental Implications*, American Association of Petroleum Geologists, Memoir 18, 412 pp.

Galley, J. E., ed. (1968). *Subsurface Disposal in Geologic Basins--A Study of Reservoir Strata*, American Association of Petroleum Geologists, Memoir 10, 253 pp.

APPENDIX E: Need for Geological Mapping to Locate Areas Suitable for Industrial Landfills

John C. Frye

The successful and safe operation of an industrial landfill is dependent on many factors, including topography, drainage, climate, and regional groundwater regime. However, in every case the character and composition of the rock materials in the first 50 to 100 feet below the surface of the unexcavated site are vitally significant to its proper operation. These characteristics must be determined in detail before the operation of a landfill is undertaken.

Geological mapping is of several types and may be based on differing philosophical approaches. There are those maps that graphically depict the distribution of indurated rock units even though they may be overlain by a 100 feet or more of so-called unconsolidated deposits; there are maps that depict only the unconsolidated surficial deposits while ignoring their thickness and underlying rocks; there are maps designed to show the distribution of ages of rocks or deposits graphically; there are maps that show classification of surface solum; maps depicting structure; and so on.

In planning geological mapping as an aid to location and subsequent development of a landfill, it is the distribution of lithologic characters and mineralogic compositions that are of first importance. The surficial unconsolidated deposits (if present) should be shown as well as the indurated rocks, at whatever depth, below the unconsolidated deposits.

During the past decade, special mapping techniques have been designed to meet the needs of this rather specialized use. Geological mapping is essential to the location and development of a proper landfill, but the geological map must be designed and executed with the end use of the map in mind.

APPENDIX F: Geological Aspects Of Aquifer Contamination

William W. Hambleton

Rock-leachate interactions, disposal in deep well, and landfill problems are subsets of geological aspects of aquifer contamination. More broadly, we are concerned with mobilization, transport, and fixation of chemical constituents in natural systems. For purposes of discussing problems that require the increased attention of geological scientists, mobilization, transport, and fixation of chemical constituents in natural systems might be characterized further as follows:

BETTER DEFINITION OF THE CHEMISTRY OF WASTE SYSTEMS

Angino, in an attempt to develop a finite-difference approximation of a two-dimensional diffusion model for groundwater movement, reported that any model now developed is likely to be of little use owing to the large variance of chemical data on waste. The necessary chemical data on the specific chemistry of waste solutions simply are not available.

BETTER CHARACTERIZATION OF AQUIFERS

In addition to the usual hydrologic properties, confined and unconfined aquifers should be better characterized in terms of fracture permeability, flow path length and direction, and sorption characteristics. Aquifer contamination implies change in the natural equilibrium state of fluid in a porous medium. Characterization of that natural equilibrium state is essential to understand the change induced by contamination.

GEOCHEMICAL COMPATIBILITY OF WASTES AND AQUIFERS

Geochemical compatibility includes both the effects of the aquifer and its fluids on the waste and the effects of the waste on the aquifer. The waste may be changed through chemical reactions, precipitation, sorption, and the like as a function of fluid content, aquifer rock characteristics, and clay mineralogy and content. Likewise, the aquifer itself may be changed profoundly by the waste in terms of pore space constriction through precipitation, swelling of clays, dispersion of nonswelling particles, and dissolution of carbonates, sulfates, and halides.

DEEP-BASIN ANALYSIS

There is need for analysis of deep basins in terms of their possible dynamic stability (hydrologic). Included are capabilities to model mass transport and osmotic diffusion across aquitards.

REHABILITATION OF AQUIFERS

The literature contains many references to the slow flushing of aquifers but few data. The possible rehabilitation of aquifers through flushing needs much more definitive study.

Investigations, such as those mentioned above, should be directed toward capability for predictive modeling and the development of sensitivity analysis.

SELECTED REFERENCE

Flores, R. L., and E. C. Angino (1978). "Predicting the pollution potential of leachates from hazardous waste sites in groundwater quality effects associated with residual waste planning," *Kansas Water Quality Management*, Chap. 5, p. 111.

APPENDIX G: Industry's Need for Geological Data for Waste Control

A. J. von Frank

INTRODUCTION

The objective of this Committee is to consider the special role that geologists can play in seeking to establish a more effective and safer means for disposing of industrial wastes and to develop judgments, directions, and goals should such a role be decided on.

I believe forward-looking industry would welcome an *aggressive entry by the geological sciences* into the field of surface and subsurface waste disposal.

Of the three interrelated facets of the ecosystem that receive all of society's wastes--air, water, and land--land disposal has been the least understood and least amenable to the upgrading environmental forces of recent decades. Until the beginning of this decade, industry, public policy, and the scientific community failed to recognize hazardous waste treatment and disposal as a major public-health and environmental problem.

Probably the most significant deficiency has been the inability to guarantee the integrity of permanent storage in the soil. It would seem that the geological sciences represent the body of knowledge best structured to address this problem.

INCREASING CRITICALITY OF THE PROBLEM

Planning management for air- and water-pollution control, theoretically at least, can foresee discharges in equilibrium with a livable environment. Not so for the land. The land becomes the permanently accumulating repository of all wastes that cannot be physically or economically destroyed, including those formerly polluting the air and water.

The production of these nondestructible wastes, and therefore stresses on the land environment, increases at some exponential rate related not only to the production of goods but also to the constraints put on the disposal of wastes to the air and the water. It increases further as our energy problems move us to greater reliance on coal and nuclear-power generation. Yet with these long-term ominous prospects, outlet options have steadily decreased over the past decade through cancellation of dump permits, difficulties in getting new sites, closure of toxic material incinerators, prohibitions on ocean disposal, policy or statutory constraints on interstate movement of wastes for land disposal, zoning restrictions, and other public pressures. Yet, no significant outlet options have appeared in this period.

INDUSTRY'S NEEDS

Turning to the question of industry's need for geological data for waste disposal: up to a point, industry's needs are identical with the government's, both regional and nationwide. The government's need statutorily flows from its permit approval processes and its powers of prohibition as well as its obligations in comprehensive planning. An increasingly critical need is the definition and locations where categorized industrial wastes can be put down--geological mapping and the attendant judgments plus the political preparation necessary for effective implementation. Beyond that point, industry's obligations should deal primarily with specifics on a case-by-case basis. No two industrial wastes are alike--even generically similar wastes (such as coal ash) can and do differ in their environmentally significant contaminants, in leachate characteristics, *and* in their capacities for migration in given soils.

Another dimension of the industrial problem deals with prior disposals. The U.S. Environmental Protection Agency has estimated there may be 30,000 to 50,000 sites nationwide where toxic or hazardous wastes were improperly disposed of in past years, and as many as 1200-2000 of them may present "imminent" threats to human health. Most of these dumps are still being used; perhaps 500-800 are abandoned. The principal danger from most of these sites is the pollution of groundwater, the source of about half the drinking-water supplies in the nation. Resolution of the problems associated with these earlier dumps has proven to be inordinately difficult; aside from the legal and economic aspects (which may be overriding in many cases), sound techniques for *in situ* encapsulation, redirecting percolation, and judgments on long-term migration into usable aquifers seem to be in a primitive stage.

CONCLUSION

In conclusion, the scope and ramifications of the land-disposal problem are enormous, particularly in the long view. The problem is one that demands the best of regional and national planning, but it is evident that such planning will get nowhere unless it is supported by a sound and conclusive science, which in turn must be persuasive to nonscientific policy makers and an understandably suspicious public. The potential contributions of the geological sciences in these directions cannot be underestimated.

The role of the geological sciences in land disposal should be akin to the forceful and creative role played by the biological sciences in water-pollution control and by the chemical, physical, and medical sciences in air-pollution control. This should not be a passive role devoted to the development of arcane data; rather, if it is to be effective, it should be directly supportive of the regulatory agencies in bringing the force of its judgments credibly into the public-hearing process and ensuing decisions.

I might add that, if the geological sciences truly accept the challenges that face them, they will never be the same.

NOTES

1. Chemical Manufacturers Association - Environmental Management Committee has recently set up a task force to consider groundwater management. (Research requirements not yet established.)
2. Report of the Hazardous Waste Advisory Commission, January 1980, State of New Jersey (references and recommendations).

3. A survey by the Chemical Manufacturers Association reports only 1 of 475 industry surface impoundments containing hazardous wastes would meet new disposal criteria. Preliminary estimates by the Association indicate an expenditure of nearly $900 million would be required for the chemical manufacturing industry.
4. No public agency has enough money to clean up all the inactive dumps, costs that have been estimated at $28 billion to as much as $55 billion. (10th Annual Report Council on Environmental Quality, Chapter 3.)

APPENDIX H: Geological Aspects of Waste Disposal in the Mining Industry

Carl Rampacek

Wastes generated by the mining, mineral processing, and metallurgical industries now total about 2.3 billion tons annually. As shown in Figure 1 and Table 1, these wastes include a variety of materials and substances all of which must be disposed of economically and with a minimum of environmental degradation. Generally, these wastes are produced in the supply channels close to the mineral resource. Thus, literally mountains of solid-waste residue from such activities as mining, dredging, quarrying, and beneficiation are piled, for example, near copper, iron, phosphate, bauxite, lead-zinc, and coal mining and processing operations. Nonmetallic mineral mining and processing generate additional solid wastes, which contribute to the volume of materials discarded. Leaching and smelting and refining also yield solutions, gases, slags, and drosses that add to the burden. How effectively disposal of these substances is accomplished in the future will depend, in part, on the availability of a thorough knowledge and understanding of the unique role of basic geology, geological structures, engineering geology, and hydrogeology as they relate to specific sites and to regional areas that serve as the mineral-waste repositories.

Some mining industry wastes pose more serious problems than others. For example, coal mining and processing wastes may be a source of acidic ferric sulfate and other pollutants such as trace elements, which may contaminate surface and/or underground waters. Effective containment of the wastes to prevent or minimize the adverse environmental impact of the effluents may well depend on a thorough understanding of the surface and subsurface geology. In contrast, problems associated with the disposal of the

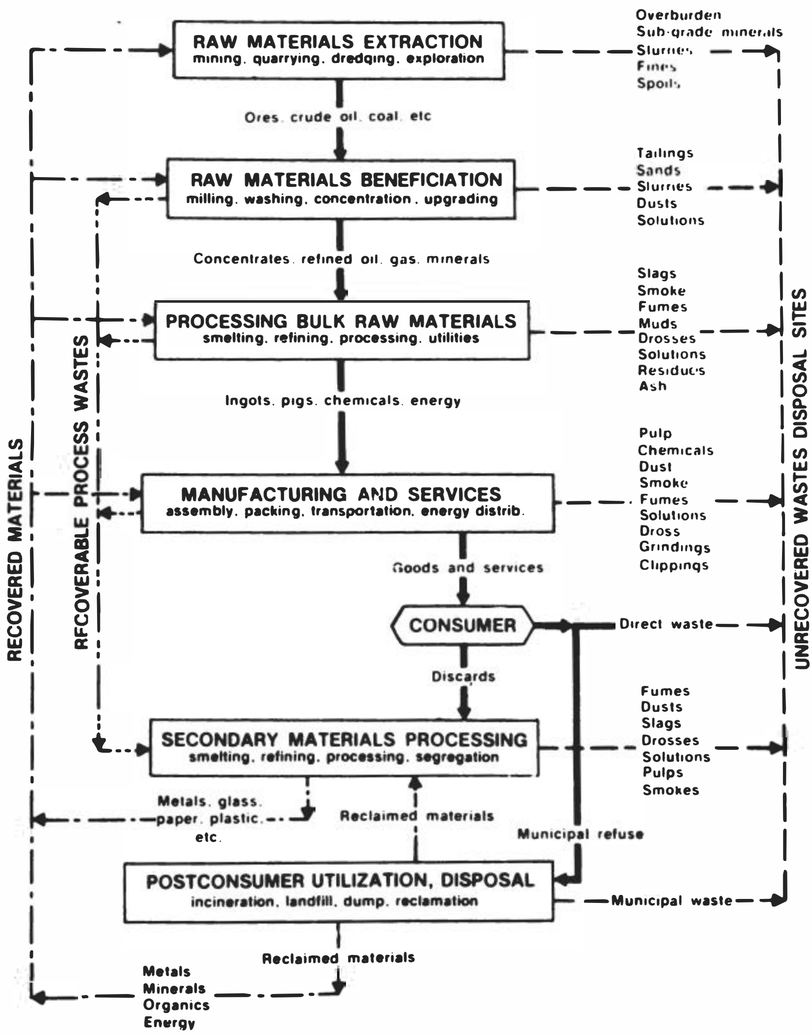

FIGURE 1 Materials supply, utilization, and disposal sections.

TABLE 1 Wastes Generated by the Mineral and Fossil Fuel Industries (1975)

Industry	Mine Waste	Mill Tailings	Washing Plant Rejects	Slag	Processing Plant Wastes	Total (Thousands of Tons)
Copper	680,400	266,800		5,200		952,400
Iron and steel	257,900	154,600		26,000	2,200	440,700
Bituminous coal	12,800		107,100			119,900
Phosphate rock	216,000		137,300	4,000	50,000	407,300
Lead-zinc	5,200	17,400	1,000			23,600
Aluminum					14,700	14,700
Anthracite coal			2,000			2,000
Coal ash					67,800	67,800
Other[a]					285,900	285,900
TOTALS	1,172,300	438,800	247,400	35,200	420,600	2,314,300

[a]Estimated waste generated by remaining mineral mining and processing industries.

relatively barren, siliceous rock overburden and matrix from spodumene ore mining may be minimal.

From an engineering standpoint, basic geological data are essential for eliminating potentially hazardous conditions resulting from improper design, placement, and construction of impoundment dams and mineral processing ponds, or of mine rock waste piles. The hazardous conditions that may result are dam or waste pile failure due to structural instability, inability to retain area rain runoff water adequately, and excessive siltation.

Instances of waste-disposal problems and tragedies possibly attributable to lack of adequate geological information are cited in the literature. Several specific examples are as follows:

- In the lead-zinc mining district of northwestern Illinois careful attention to geological details may have avoided a critical water problem. Extensive underground mining required the installation of dewatering facilities. This lowered the local water table to such an extent that domestic wells in the area had to be deepened in order to intercept the drawn-down water horizon. Also, tailing pond discharge water was allowed to flow into old underground mine workings, resulting in local groundwater quality deterioration. Geohydrological investigations might have predicted this condition in advance and thus avoided or lessened the severity of the problem.
- Copper-mining operations in the southwestern United States are encountering problems with possible underground water contamination resulting from copper-ore processing. Domestic water users in the vicinity of stored flotation plant tailings and leach-plant residues claim that the quality of water from their wells is deteriorating because of seepage of the process water into the aquifer. The extent of contamination, if any, and predictions of water-quality deterioration over the long term are difficult to assess owing to a lack of basic geological/hydrological data for the areas before the ponds were constructed.
- The recovery of alumina from bauxite by the Bayer process generates a semifluid, caustic "red mud," which must be impounded behind huge dams. As yet, seepage of the caustic effluent into the subsurface formations, or occasional escape of the solutions from the impoundments during heavy rains, has not been a cause of major concern. But the question arises as to how much capacity the earth and the hydrological systems in the vicinity of the ponds have to continue to assimilate the waste solutions. This

is one instance in which the geologist working with the engineer and other earth scientists might contribute to a better understanding of what may be expected.

- In 1966, in Aberfam, South Wales, an estimated 140,000 cubic yards of coal mining and processing wastes plummeted down the side of Merthyr Mountain, destroying a school and 18 houses with a loss of at least 144 lives. Investigation of the disaster established that the stability of the waste materials had been impaired by a spring, which lubricated the lower portion of the pile and the underlying soil to the extent that it flowed en masse down the slope. Obviously, a better understanding of the geology of the area, of the groundwater behavior, and of the soil properties might have averted this tragedy. Also, in 1972 a coal refuse disposal facility located near Buffalo Creek, West Virginia, failed after several days of rainfall, sending a rush of mud and water through a narrow valley downstream from the dam. A number of coal-mining towns were wiped out, with a loss of about 100 lives. Investigation of the Buffalo Creek failure revealed that this and other disposal facilities were generally constructed with little technical thought given to planning and design. Geotechnical and hydraulic aspects of refuse materials and disposal were seldom considered. These factors now are being considered in constructing refuse disposal facilities, but much more needs to be done.

As a better understanding is gained of the physical geology and topography, subsurface structure and the hydrological characteristics of the areas adjacent to or underlying disposal sites, environmental degradation and contamination of the land surface, groundwater, and surface water by the leachates and sediment from mine wastes can be minimized. Thus, geological data can play a vital role in assuring proper mineral waste disposal in the following ways:

- As an aid to site selection and design of tailing ponds and other surface facilities;
- In predicting groundwater pollution potential based on local and regional lithological, hydrological, and structural factors, which can influence containment;
- In delineating potentially deleterious conditions such as zones of high pyrite content; and
- In mapping and characterizing natural materials used in construction of containment and/or retention structures.

For some areas and disposal sites there are adequate geological data available on which to base realistic decisions regarding waste pile and dam construction and the containment of potentially harmful contaminants that occur in the wastes. Unfortunately, the detailed geological data needed to assure proper waste disposal are not available for the variety of waste materials being generated and the many disposal sites that must be considered. This suggests that a survey of the availability of adequate geological data to meet these needs is warranted.

SELECTED REFERENCES

Groundwater Study South of Tucson is Inconclusive (1979). Arizona Edition of *Pay Dirt*, December, p. 31. P.O. Drawer 48, Bisbee, Ariz.

Miller, D. W., ed. (1977). *Waste Disposal Effects on Ground Water*. Geraghty and Miller, Inc., Syosset, New York; Premier Press, Berkeley, California. A photographic reproduction of *The Report to Congress, Waste Disposal Practices and Their Effects on Ground Water*. January. Office of Water Supply and the Office of Solid Waste Management Programs, U.S. Environmental Protection Agency.

Rampacek, C. (1980). "Progress in mining and mineral waste utilization," in *Proceedings of the Seventh Mineral Waste Utilization Symposium* jointly sponsored by the U.S. Bureau of Mines and IIT Research Institute, Chicago, Illinois, October 20-21.

Spendlove, J. J. (1976). *Recycling Trends in the United States: A Review*. U.S. Bureau of Mines Information Circular 8711.

Underground Disposal of Coal Mine Wastes (1975). A report to the National Science Foundation by the Study Committee to Assess Feasibility of Returning Underground Coal Mine Wastes to the Mined Out Areas. Environmental Studies Board/Board on Energy Studies. National Academy of Sciences, Washington, D.C.

APPENDIX I: Suggested Research Topics on Soil-Leachate Interactions

Eileen Chase

There are some surprisingly basic and important matters pertaining to industrial-waste disposal that I believe need to be researched. Mostly they have to do with the movement of leachate through clayey soils. I realize that the Environmental Protection Agency has been sponsoring some research on this issue, but there are still plenty of good questions left to ask, and plenty of people needing answers. And the answers must be in language that can be understood by people as diverse as geologists, civil engineers, chemists, lawyers, officials, and plant operators.

By way of background I wish to observe that subsoil, though apparently old familiar stuff, is uncharted territory scientifically speaking. The agronomist is interested in the top 5 feet of soil at most. The geologist concentrates on the rock below, and the engineer only wants to know how reliable the subsoil is for foundation purposes. When people became aware of the need for responsible waste disposal, the bulk of the design work was assigned to sanitary and civil engineers, who borrowed techniques and terminology from geology, hydrogeology, and soils mechanics. Now the time has come (and gone) to codify the techniques of safe disposal into scientifically sound and workable state regulations. However, there still are no good answers to the "surprisingly basic" questions I mentioned before, and instead of good regulations we have a climate of "trial and error," "state of the art," "best guess," or overdesigning as ways of getting things done.

The first basic concept requiring research is "permeability." From my vantage point in an engineering firm it seems that permeability has become a magic number. The concept was borrowed from hydrogeology and is often interpreted as velocity. After all, it is measured in centimeters per second, isn't it? Somehow people from site operators to PhD's have not apprehended that permeability is a function of (among other things) drawdown and head.

Drawdown, which implies the free flow of water in the soil, is supposed to occur in virtually clay-free materials. People in the water-well business will assert that a small amount of clay in granular material will prevent the flow of water, and it is not uncommon in drilling to come across subsoil of shale, which is bone dry though it has had thousands of years in which to become saturated. These two observations are evidence that the concepts and formulas of hydrogeology may not apply to soils that are fine grained. In some cases, the soil is too impervious for head (saturated thickness) to build up, too chemically reactive for water to flow. In short, such soils simply do not have permeability. They are soils that hold water on or near the surface until the sun reappears and evapotranspiration is re-established. These soils account for perched water tables and willow trees in wheat fields. In Kansas City we even have a proverb for them: "Too wet to plow in the morning, too dry to plow in the afternoon."

Meanwhile, back at the office (government, engineering, or newspaper, whichever you wish), it is not uncommon to hear that leachate from a disposal site will eventually penetrate any thickness of any soil, no matter how impermeable, no matter how fat. I think that this view is wrong and that it is essential to resolve this issue--to find out if there are soils that have no permeability, to determine how extensive they are, and to describe them in language that people in many disciplines can understand.

Meanwhile, back at the laboratory, technicians are running falling-head permeability tests on fine-grained soils and getting answers like 10^{-8} cm/sec or what have you. Someone might argue that this demonstrates that these soils are permeable, but I am not alone in thinking this procedure a dubious one. At present, there is no standard procedure for the falling-head permeability test. How can we be certain that a sample fills its cylinder without gaps along the sides? Furthermore, laboratories are taking liberties such as forcing water through the samples under pressure (amount unspecified) to saturate them or pulling a vacuum (amount again unspecified) on the bottom to speed up the test. It is possible that these methods are merely forcing water down the sides of the cylinder or jiggling horizontal passageways open. In one recent investigation for a landfill, this test yielded results of 10^{-6} and 10^{-10} cm/sec on virtually identical samples from the same depth. (A different method, deriving a permeability value from a consolidated test, gave consistent results of around 10^{-9} cm/sec.) I do not think anyone is willing to live with a test that gives answers that vary 10,000-fold, and so I propose that the validity of the falling-head test and methods of improving it be objects of study.

Another aspect that needs study is the effects of desiccation on clayey soils. I was discussing the question of permeability with J. Hadley Williams of the Missouri Geological Survey, and he told me of an instance in which a glacial clay from northern Missouri showed a falling-head permeability of 10^{-5} cm/sec after a prolonged drought. Normally such a soil would show a permeability of around 10^{-9} cm/sec, but this soil showed no real decrease in permeability after a week in the permeameter. If desiccation increases permeability to this extent, it should be quantified and taken into consideration in landfill design.

Another surprisingly basic question that no one seems to be thinking about is the matter of horizontal versus vertical flow in fine-grained soils. Some engineering texts discuss such variations in coarser soils but are silent on this topic when it comes to fine ones. Indeed, there has not been a need to think about the matter until recently. I think that part of the reason this matter has been ignored is that much of our industry, shallow groundwater, and environmental awareness occur in the northeast, an area where unstratified glacial till predominates. I also suspect that erroneously equating permeability with velocity of flow directed downward has contributed to gap. Some models presented diagrammatically assume that almost no horizontal flow occurs.

Now, unless the disposal pit is located in something like a sand dune, chances are good that flow of leachate will have both horizontal and vertical components. The exception might be a thick glacial till, as noted above. In the West and South, people have to turn to fine-grained deposits that are marine, alluvial, aeolian, lacustrine, or proglacial in origin. They all involve some stratification, but there are no tests of horizontal permeability being performed and no predictions of leachate movement being made on the basis of horizontal permeability. The falling-head permeability test measures vertical permeability of a sample taken from a Shelby tube, and the consolidation test has as one of its assumptions that flow in the sample takes place only along vertical lines.

Horizontal movement of water is probably not an insoluble problem. It could be that disturbing and remolding soil just beyond the limits of the disposal site is all that is required. It could also be that the swelling of active clay minerals eliminates or decreases horizontal flow so that there is no problem. In any case, the occurrence and degree of horizontal permeability in fine-grained soils deserve attention and research.

(Recently I saw a report on a promising landfill site in which the possibility of horizontal flow of groundwater was expressly denied, with no references offered as authority. No explanation was offered for the fact that boreholes that were dry when drilled were full of water the next day.)

Another topic on which more information is required is the role of naturally occurring soluble salts in fine-grained soils. This is particularly critical in arid regions. How is permeability affected by long-term dissolution or alteration of these salts? It is known that plain water may cause piping or embankment failure in salty soils. What effects do chemical wastes have, and what are some practical tests that would indicate possible problems?

Yet another matter that needs research is, "What are the effects of chemical wastes on soil fabric and chemistry?" We need to quantify the effects of acids and bases, probably with an eye to insisting that they be neutralized. There are also techniques for decreasing permeability, such as treatment with sodium carbonate, which seem to be old hat to some people but which are not well known to the disposal industry. If such methods are really helpful, they should be documented and allowed for in regulations. Finally, the effects of organic chemicals on soil fabric and mineralogy is an untouched field. Like most geologists, I do not know much about organic chemicals, so I think we should get together with the organic chemists and discuss this problem.

Having criticized most of the methods people are now using to choose sites and predict leachate movement, I would like to make some positive suggestions for ways of improving the present discouraging situation. Although there are some wastes that have been disposed of on land that should not have been, there are others for which land disposal is the best method at present. I believe that if we make a toxic compound, we can unmake it somehow. But a cadmium atom will always be a cadmium atom, and the best place for it is a nice, thick bed of fat clay.

What are needed are maps showing thickness, "permeability" (both horizontal and vertical), and depositional environment of clayey subsoils across the nation. A good source for much of these is the detailed logs of test holes for big electric power lines. There are thousands of towers across the nation, and each tower calls for a 30- to 50-foot test hole and perhaps some laboratory tests. I see no reason why the electric utilities, particularly those in the Rural Electrification Administration, would not allow these data to be correlated.

One thing that would make all soil-test work more useful would be a thorough and cogent study of the relationship between the Atterburg limits and clay mineralogy, attenuation capability, and/or permeability. The Atterburg limits are the most common test run on fine-grained soils, and being able to correlate them with other properties on the basis of authoritative research would mean a great savings in time and effort.