rials, toxic metals or substances, nuisance-stimulating nutrients, and waste heat. Treatment and control processes are now available for most industrial wastes. Some pollutants including complex chemicals, however, present difficult abatement problems.

The magnitude of the national industrial waste problem has remained relatively unknown. There has not been until the past few weeks a detailed inventory of industrial wastes. The Environmental Protection Agency within the past year embarked upon a three-pronged program to inventory, study, and regulate this vast waste complex.

Following a test mailing to refine the questionnaire and the instructions, a voluntary national industrial wastes inventory was begun in early August 1971. A comprehensive questionnaire has been mailed to 10,000 of the major water-using industries in the United States. The inventory questionnaire was designed to collect information on quantity and quality of wastewater constituents and discharge methods. Data from the inventory will be computerized to facilitate their use. These data will be extremely valuable in all governmental activities connected with the control of industrial wastes.

The Environmental Protection Agency is in partnership with the Corps of Engineers in the administration of the River and Harbor Act of 1899. Under the provision of this Act, each industrial waste discharge to the nation's waters will be regulated by a permit issued by the Corps of Engineers. The EPA will review, evaluate compliance with water quality standards, and recommend actions on the permit requests.

Comprehensive studies on 20 major industrial categories have recently been completed. These studies defined a feasible effluent level based upon production units for an industrial category. They present the best and most comprehensive compilation of data now available on wastewater management from these industrial categories.

MALINA, JOSEPH F., JR., Dept. of Civil Engineering, Univ. of Texas, Austin, Tex., and JOE C. MOSELEY II, Univ. of Texas, Executive Dept., Austin, Tex.

Disposal-Well Dimensions, Injection Rates, and Cost Responses

Deep-well injection as a means of liquid waste disposal is, at best, a costly and tricky operation. Nevertheless, despite the inevitable difficulties which occur, it has proven itself to be reliable, environmentally sound, and economically feasible for disposing of *certain* wastes in *certain* areas.

A mathematical simulation model has been developed for predicting the operational response of a disposal-well system. From the initial design parameters and the physical operating characteristics it is possible to estimate the cost of such an operation. Additionally, sensitivity analysis experiments can be performed to assess which design parameters, operational characteristics, or formation properties have the most significant impact on the overall system response.

Application of the model to date indicates that for favorable geologic conditions the cost of injection may range upward from \$0.25–\$0.40 per 1,000 gal; this figure includes O&M plus capital amortization, with the initial outlay ranging upward from about \$150,000. Even a ball-park cost estimate for a given injection system cannot be done until the key parameters (waste volume, well diameter, porosity, permeability, reservoir pressure, *etc.*) are known for that specific site.

Sufficient data are available from secondary sources to synthesize the basic characteristics of a "typical" injection well. (For this study, approximately 75 industrial disposal wells were considered.) Typical features include: (a) 90% of all wells in the U.S. are less than 6,000 ft deep with half between 2,600 and 4,200 ft, (b) only 10% operate with casinghead pressures greater than 1,050 psi, but 50% operate between 175 and 550 psi. These and other statistical characteristics were combined to create a set of fictitious—but representative—wells. It was upon this set of "standard" or "typical" wells that the following sensitivity experiments were performed. For our "typical well" designed to operate at 1,000 psi, an increase in wellhead pressure of 50% can be expected to raise the total unit cost from \$0.24 to \$0.32 per 1,000 gal. For a given flow rate, friction losses decrease rapidly as well diameter increases. For our well, an increase in diameter from 4 to 5 in., reduces the ratio of the pressure drop to driving pressure by 57%, thus substantially reducing energy requirements as a trade-off for a more expensive well. Responses to flow rate can be evaluated. For one of our "standard" wells, an increase in the flow rate from 400 to 600 gal/day increases the initial cost of \$224,000 by 53.5%, but lowered the unit cost by 21.2% from \$38.2 to \$30.1 per 1,000 gal. Formation impact can likewise be assessed. For our example, an unexpected drop in permeability from 60 to 40 md would increase the unit cost by 12.3%.

The above only begins to expose the type of information that simulation modeling can reveal. The modeling procedures and certain relations describing the basic processes are well understood. The weak link is data. The geologic—and other—uncertainties with which one must cope provide the real test. Only as more and better data become available will this approach reveal its true utility; hopefully it can be extended to include such things as probabilistic aspects of component failure, statistical reservoir analysis, *etc.*

McWILLIAMS, JACK, Amoco Production Co., Houston, Tex.

Large Saltwater Disposal Systems at East Texas and Hastings Oil Fields, Texas

The disposal of salt water produced with oil from the East Texas field has been successful in minimizing pollution of land areas and freshwater sources, and has been effective in maintaining bottomhole pressure. To date, 4.5 billion bbl of salt water have been returned to the producing reservoirs at a cost to the operators of approximately 2.5¢/bbl.

At Hastings field in Brazoria and Galveston Counties, Texas, Amoco is successfully disposing of 50,000–60,000 b/d of salt water by injection into salt-water-bearing formations below freshwater sandstones and above the oil-producing zones. The project is a "closed system," whereby the salt water produced is allowed no contact with air, thereby reducing corrosion attack on disposal facilities. To date, Amoco has injected approximately 500 million bbl of salt water.

OSTROOT, G. WARREN, and JOE RAMOS, Halliburton Services, Duncan, Okla.

Deep-Well Acid Disposal—Planning and Completion

Because of the magnitude of damage wrought to our natural resources, pollution control and environmental protection are a vital part of our everyday living. Pollution of air, land, and water has led to subsurface disposal (storage) of waste effluents. The Federal Government and the individual states are continually passing new laws governing deep-well disposal. Feasibility studies are mandatory, and must include an analysis of the disposal reservoirs, a detailed geologic study to include the presence of faults or abandoned wells that could be an avenue for contamination of potable waters.

Many of the cementing procedures used in the oil industry are also used in disposal wells; however, added precautions must be taken in the design of the casing and injection strings. These include the use of materials that are resistant to chemical attack, such as special alloys and fiberglass. Oil-well cements may be used in wells where the effluent is organic, weak organic acids, sewage waste, ferric chloride, and chemically treated effluents having a pH of 6 or above. A formulation of cement and liquid resin will resist attack from dilute acid solutions. The latest development in resin compositions is a blend of epoxy resin and an inert filler. This resin system has shown considerable promise for use in cementing disposal wells. It is resistant to concentrated acidic effluents and caustic, and provides excellent bonding properties to the tubular goods.

POLAND, J. F., U.S. Geol. Survey, Sacramento, Calif.

Subsidence and Its Control

Land subsidence due to fluid withdrawal has been reported from many parts of the world. It has developed most commonly in overdrawn groundwater basins, but subsidence of serious proportions also has been reported in several oil and gas fields.

Subsidence due to groundwater overdraft occurs in many places in Japan, where it has caused dangerous environmental conditions in several heavily populated areas. For example, in Tokyo, 2 million people in an area of 80 sq km now live below mean-high-tide level. Subsidence is only partly controlled; the difficulties of achieving full control are great.

The San Joaquin Valley in California is the area of the most intensive land subsidence in the United States. Subsidence affects 4,000 sq mi and was as much as 28 ft in 1969. The total volume of subsidence to 1970 is about 13 million acre-ft. Surface-water imports to subsiding areas are now decreasing subsidence rates, because groundwater extraction is reduced and artesian head is rising.

In the Santa Clara Valley at the south end of San Francisco Bay, overpumping of groundwater between 1917 and 1967 caused as much as 180 ft of artesian-head decline, and maximum land subsidence of 13 ft. A fourfold increase in surface water imports in 5 years has achieved a dramatic rise of artesian head—70 ft in 4 years. Subsidence rates have decreased from as much as 1 ft/year in 1961 to a few hundredths of a ft in 1970.

Wilmington oil field in the harbor area of Los Angeles and Long Beach, California, is not only the oil field of maximum subsidence in the United States—29 ft—but also the outstanding example of subsidence control by injection and repressuring. Large-scale repressuring began in 1958, using injection water obtained from shallow wells. Subsidence of some bench marks was stopped by 1960. By 1969, when 1.1 million b/d of water were being injected into the oil zones, the subsiding area had been reduced from 20 to 3 sq mi and parts of the area had rebounded by as much as 1 ft.

Methods employed to measure the change in thickness of sediments compacting or expanding in response to change in effective stress include: (1) depth-benchmark and counterweighted-cable or "free" pipe extensometers with amplifying and recording equipment, (2) casing-collar logs run periodically in a cased well, and (3) radioactive bullets emplaced in the formation behind the casings at known depths and later resurveyed by radioactive detector systems.

In evaluating potential land subsidence due to fluid withdrawal, an essential parameter is the compressibility of compactible beds. When effective (grain-to-grain) stress exceeds maximum prior (preconsolidation) stress, the compaction is primarily inelastic and nonrecoverable, and the compressibility may be 50–100 times as large as the elastic compressibility in the stress range less than preconsolidation stress.

If fluid pressures in a compacting confined system are increased sufficiently to eliminate excess pore pressures in the fine-grained sediments, the system will expand elastically and the land surface will rise.

POWERS, THOMAS J., Operation Service and Supply Corp., Cleveland, Ohio

Dilemma of Industrial Wastewater Treatment

Today industry is being forced to meet quality standards in all water effluents discharged or proposed to be discharged to public waters. This national policy demands the removal of substances from water or management of the processing so that restricted materials do not reach the water environment. Generally these restricted materials have no value in their present form or place and are, therefore, wastes.

Now the dilemma is this: having removed or isolated these materials at great cost, what do you do with them? Concentration of the materials may lessen cost of transportation and storage, but does not solve the ultimate disposal problem.

There are millions of tons of industrial residues being stored in open pits above ground. Carbonates, hydrates, silicates, sulfates, oils, tars, acids, and brines can be found stored in diked areas near industrial centers. Some of these stored materials contain small quantities of toxic substances. All of these materials are subject to leaching and reentering the environment. Maintenance of these open pits to avoid pollution is a never-ending concern.

The alternatives to pit storage have been ocean disposal, deep-well disposal, disposal by dilution during flood periods, and in the case of organic materials, incineration. One by one these alternatives are being legislated or regulated out of existence. The utopian philosophy of complete recycle is gaining popularity.

The atomic energy industry has for years isolated dangerous materials, immobilized them, and buried them on reservations far removed from processing sites. Treatment of the water may cost as much as $1.00/gal. Transportation and burial of residues are a large added cost.

Processing industries generate some very complicated wastewaters. The most difficult are those which contain both organic and inorganic substances in true solution.

The dilemma is cause for national concern, requiring study and resolution. The road to complete recycling, if there is such a thing, is long and costly. Politicians must be forced to look at both sides of the environmental protection coin.