but provides the basis for selecting remedial treatment. Accidental hydraulic fracturing caused by drilling or injection can be the reason for vertical leakage through confining beds, and acoustic televiewer logs can locate these fractures. The distribution and velocity of injected water and the location of chemical or thermal pollution may be determined by means of temperature logs. We have used temperature logs to map the horizontal and vertical distribution of injected fluids. Diurnal thermal changes in injected water provide the basis for measuring the velocity of flow and its change with time.

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RETENTION OF DISSOLVED CONSTITUENTS OF WASTE BY GEOLOGIC MEMBRANES

Clays and shales serve as semipermeable membranes, retarding by varying degrees the passage of the dissolved species with respect to water. The relative retardation by geologic membranes of cations and anions generally present in waste solutions was investigated using a high temperature filtration cell. The solutions were forced with varying hydraulic gradients through different clays and a disaggregated shale subjected to compaction pressures up to 10,000 psi and to temperatures from 20 to 90°C.

The efficiencies measured increased with increase of exchange capacity of the material used and with decrease in concentration of the input solution. The efficiency of a given membrane increased with increasing compaction pressure, but decreased at higher temperatures and higher hydraulic gradients for solutions of the same ionic concentration.

The results further show that geologic membranes are specific in that the degree of retardation is different in different dissolved species. The retardation sequences obtained varied depending on the material used and on experimental conditions. The retardation sequences for monovalent and divalent cations were generally as follows:

$$Li < Na < NH_3 < K < Rb < Cs$$
$$Mg < Ca < Sr < Ba.$$

The retardation sequences for anions at room temperature were variable, but at higher temperatures the sequence was:

$$HCO_3 < I < B < SO_4 < Cl < Br.$$

Monovalent cations generally were retarded with respect to divalent cations at the higher hydraulic gradients. This trend, however, was reversed at the lower hydraulic gradients. Extrapolation of the results to average hydraulic gradients encountered in subsurface formations indicates agreement with data obtained from field investigations which show that divalent cations generally are retarded with respect to monovalent cations.

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SALINE AQUIFERS—FUTURE STORAGE RESERVOIRS FOR FRESH WATER?

In the advanced industrial countries the most favorable, least expensive sites for surface reservoirs are already in use or the land already is preempted for other uses and is unavailable for the storage of water. In addition, there are many flat areas in coastal zones, also underlain by saline aquifers, that are unsuitable for water storage although a surplus of fresh water is available in such areas at certain times of year. The lack of a reliable, year-round supply of water has been a major factor in preventing commercial and residential development in these areas.

The storage of fresh water in slightly saline aquifers has been tried empirically several times with some success. To study the physical process in the laboratory we have constructed and operated several miniaquifers and, simultaneously, have devised some approximate mathematical models. The annual cycle of injection, storage, and withdrawal of the fresh water has been found to be feasible under the idealized assumptions normally found in groundwater hydrology—a horizontal, isotropic, homogeneous aquifer of uniform porosity, transmissivity, and storativity. Laboratory experiments on a single-well system built into a miniaquifer constructed of epoxy-consolidated, uniform blasting sand show that the efficiency of the process, per cycle, increases as the number of cycles increases. Our computational procedure verifies this and has enabled us to change inexpensively and quickly such parameters as density difference, dispersion coefficient, input rate and period, withdrawal rate, storage period, *etc.* The studies show that storage of fresh water in an aquifer that contains brine is feasible, if a sufficient number of cycles is considered. The cost, in terms of irretrievable fresh water, is calculable under these conditions.

Additional studies were and are being made on a 9-unit well field. Preliminary results show that although the recovery percentage at the end of the first cycle is smaller than that of a single well operating by itself, by the time the third cycle is reached a multiwell system is more efficient. A greater percentage of the water injected during the third cycle is recovered than is recovered by a single well under the same circumstances.

Most water-bearing formations dip and, in many, a measurable groundwater flow occurs under natural, undisturbed conditions. Each of these circumstances affects the position and configuration of the "bubble" of fresh water. For example, the injected fresh water is lighter than the saline water and should tend to move to the roof of the aquifer and thence updip. This should result in a lower recovery efficiency compared with that from a horizontal aquifer. However, the recovery efficiency depends greatly on the duration of the storage part of the cycle. Single-well experiments in a dipping aquifer verify and quantify this expectation. There are indications that it may be possible to overcome the effect of dip and to stabilize the position of the injected fresh water by constructing and operating a system of injection and withdrawal well updip and downdip from the injection well.

This paper is a progress report on work that is well underway but not yet complete. As to the effect of various combinations of dip, movement of native ground water, and density differences, on the recovery efficiency of a multiwell project, we have some qualitative ideas, but at present are trying to devise a quantitative basis for design that will handle all of the variables simultaneously.

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ASSE SALT MINE, FEDERAL REPUBLIC OF GERMANY—OPERATING FACILITY FOR UNDERGROUND DISPOSAL OF RADIOACTIVE WASTES

All investigations for the disposal of radioactive wastes originating from the different nuclear activities in Germany, mainly nuclear research and power production, were intended from the beginning to find a place where the wastes are excluded from the biocycle for the time necessary for their decay. Therefore, research and development work was concentrated on salt formations.

In 1965, Gesellschaft für Strahlen- und Umweltforschung bought, on behalf of the Federal Government of Germany, the Asse salt mine which had been shut down for economic reasons less than a year before. This salt mine had been in operation since 1908. Because the salt deposit is in the form of an anticline (more similar to a salt dome than to bedded salt deposits), a total of about 130 rooms was created on 13 different levels by a special type of room-and-pillar mining system.

Test disposal of low-level radioactive wastes was started in April 1967. Solid or solidified wastes, packed in 200-l drums, are stacked in the rooms. Those rooms filled with low-level wastes are sealed off. At present a total of about 22,000 drums has been disposed of.

In August 1972, disposal of intermediate-level radioactive wastes was started. Because of higher radioactivity and, therefore, higher dose rates, the 200-l drums with these wastes can be transported and handled only in shielded casks. With the present technology, about 80 drums have been disposed of.

Solidified high-level radioactive wastes will not be produced before 1975 in the Federal Republic. Therefore, no technical installations exist for their disposal in the Asse salt mine, but a broad research and development program has started. First test disposal is scheduled for 1976–1977.

The environment of the mine is thoroughly monitored. A hydrologic survey program is performed, as well as control of the radioactivity of water, air, and ground. Disposal of low- and intermediate-level radioactive wastes is free of charge. Total capital investments amount to about 18 million Deutsche Mark to date. Operating costs are about 2 million Deutsche Mark a year, including staff and scientific personnel.

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SUBSURFACE DISPOSAL OF WASTE IN KANSAS

The use of wells for the subsurface disposal of wastes has been practiced in Kansas since 1935. All the early waste-disposal wells were used to dispose of oil-field brine. Permits for the first industrial waste-disposal wells other than oil-field wells were issued in 1952.

Two state agencies have jurisdiction over the subsurface disposal of oil-field wastes in Kansas. Before using a well for the subsurface disposal of oil-field or gas-field brines, the operator must submit plans and specifications for each disposal well to the Kansas State Corporation Commission. These must be approved by both the State Corporation Commission and the Kansas State Department of Health. The Corporation Commission, through its Oil and Gas Conservation Division, determines that the use of the proposed well will not result in loss or waste of gas or petroleum resources. The Department of Health, through its Oil Field and Subsurface Disposal unit, Division of Environmental Health, determines that use of the proposed well will not result in pollution to the water resources of the state.

Before using a well for the subsurface disposal of industrial wastes other than oil-field or gas-field wastes, an application must be filed with, and a permit issued by, the Kansas State Department of Health. The maximum wellhead pressure that may be used to inject wastes into both classes of wells must be approved by the Department of Health. Periodic field checks of the amount of pressure used are made by field personnel of the Department of Health. The Oil Field and Subsurface Disposal unit is staffed by a supervisory geologist in Topeka and by 8 area geologists, each of whom is responsible for a specific section of the state.

At present, there are 3,200 approved oil-field and gas-field saltwater disposal wells in use receiving a total of about 4,000,000 bbl of salt water per day. Not included are 2,600 saltwater repressuring systems in the state, which are made up of from one to several hundred injection wells. The depths of the oil- and gas-field disposal wells range from less than 500 to about 6,000 ft. Thirty-eight zones ranging from Upper Permian to Precambrian are being used. About 60% of the wells inject wastes into limestones or dolomitic rocks, 25% into sandstone, 5% into sandy or gypsiferous shale, 5% into salt or anhydrite zones, and 5% into conglomerate or granite wash. Injection pressures being used range from gravity at the wellhead to 0.5 psi/ft of depth to the injection zone.

There are 31 industrial waste-disposal wells (other than oil- or gas-field wells) at 21 plants in the state including 10 LPG underground storage projects, 2 salt companies, 3 petroleum refineries, 4 natural gas compressor stations, 2 chemical manufacturing plants, and 2 fertilizer plants. Most industrial waste being disposed of in the subsurface consists of salt brine and is disposed of in Arbuckle rocks at depths ranging from about 3,000 to 6,000 ft. All wells are constructed to preclude any hazard to fresh water. The Department of Health's present policy concerning industrial wastes is that only those wastes that cannot be treated and disposed of by other practical methods will be considered for disposal in the subsurface. Use of the most permeable injection zone available at each site is required regardless of depth in order to eliminate the need for wellhead injection pressure.

Experience with both industrial and oil-field disposal wells shows that most operational problems are caused by (1) selecting an injection zone with inadequate permeability, (2) no preliminary waste treatment or inadequate waste treatment, or (3) failure to provide an effective maintenance program.

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CASE HISTORY OF SUBSURFACE WASTE INJECTION OF AN INDUSTRIAL ORGANIC WASTE

Since May 1968, an industrial organic waste has been injected at rates of 100–200 gal/minute into Upper Cretaceous sand and gravel aquifers near Wilmington, North Carolina. The industrial waste, an aqueous solution of acetic acid, formic acid, and various isomers of phthalic acids and their methyl esters, has been injected through 2 wells into 2 aquifers containing saline water, at depths of 850–1,000 ft (260–305 m) below land surface. The movement and transformations of the waste have been monitored in this study since February 1971, by a network of 14 observation wells which surround the injection wells at varied distances and depths.

Samples obtained from 4 observation wells which penetrate the disposal aquifers near the injection well indicate very little degradation of the waste near the point of injection. The composition of recently injected waste was essentially identical to the waste before in-