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