jection except for increased concentrations of silica, aluminum, and certain trace elements indicating slow dissolution of alumino-silicate minerals by the organic acids in the waste. Native aquifer water was mostly displaced by the injected waste, and carbonate minerals within the Upper Cretaceous sands and gravels were dissolved and decomposed by the organic acid waste constituents.

Since June 1972, trace quantities of waste were detected in an observation well 1,500 ft (457 m) north of the original injection wells, and a weekly sampling program was instituted to monitor the geochemical transformations during passage of the waste front. After the appearance of methane gas, the dissolved organic carbon concentration of the waste varied inversely with methane gas evolution, indicating reductive conversion of the waste to methane. Increased concentrations of ferrous iron, hydrogen sulfide gas, and sulfide precipitates were additional indicators of geochemical and microbiologic reductive processes.

The waste front was found to be broad and diffuse to the extent that the waste would disappear during certain periods of sampling. Measurements made up to February 1973 indicated that the waste concentration was not sufficiently high to affect pH, alkalinity, specific conductance, and most of the standard inorganic water-quality parameters.

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HAZARDS OF WASTE DISPOSAL IN GROUNDWATER BASINS

As problems of waste disposal become more critical, and environmental constraints more demanding, serious consideration is being given to isolated zones in groundwater basins as burial grounds for hazardous wastes. Proponents have suggested various geologic environments—thick impermeable clay or shale layers, heavily pumped subsidence basins, deep saline water bodies, *etc.*—as being safe disposal sites. However, several hydrogeologic constraints must be understood fully before a prospective site can be considered "isolated."

Unconsolidated deposits, even at great depth, are highly sensitive to changes in applied stress. Interstitial fluids may be squeezed from even relatively impermeable beds by modest stress changes. Compaction of the deposits below 2,500 ft has been induced in the San Joaquin Valley by groundwater pumping. As much as 30 ft of vertical shortening in 3,000 ft of water-bearing deposits has been measured. At Alpaugh, more than 4 ft of surface subsidence, principally due to the compaction of fine-grained beds at depth, has resulted from 250 ft of artesian head decline. Interstitial arsenic, presumably "locked" in clay interbeds for thousands of years of interaquifer circulation, now is being squeezed into the aquifers.

Hydraulic stresses in a developing groundwater basin may affect beds considerably below the deepest pumping wells. Theoretically, seepage stresses, and thereby groundwater movement, ultimately would affect all beds down to basement or some underlying truly impermeable layer. Slow drainage continues from each interbed as long as excess pore pressures exist in that interbed. Injection of wastes into clay or shale interbeds would cause a sharp increase in pore pressures in these interbeds.

Subsidence areas are usually poor candidates for waste-disposal sites. Generally, they have demonstrated their close communication with the groundwater system, their direct response to pressure changes, and their high compressibility. Heavily depleted artesian aquifers are not empty reservoirs ready for refilling. Rather, the groundwater systems are "full" and adjusting to the various stresses imposed on the basin. Compaction recorders show that pore pressures throughout the vertical section respond rapidly to pumping stresses.

Horizontal and vertical ground movement, caused by horizontal and vertical groundwater flow, can be a serious threat to surface or buried structures. Subsidence affects probably 7,000 sq mi in California alone in amounts to 28 ft in a few places, and has caused the failure of thousands of deep and shallow water and oil wells. Horizontal shear stresses and surface tension cracks are a continued threat in a developing groundwater basin.

Saline-water bodies in a basin are not necessarily permanently out of touch with the circulation system of the basin. Hydrologic stresses may force some of this saline water into the circulating groundwater system. Evidence suggests that upward seepage stresses may extend below the freshwater-saline water interface; also, in some areas, saline water may be moving upward into the freshwater zones.

Few regions of a groundwater basin are isolated from the circulating flow system. Although injecting liquid wastes deep underground is sometimes expedient, the effects are complex and never ending. Long-lived radioactive wastes require isolation from the hydrosphere for periods of time ranging from 1,000 to several hundreds of thousands of years, but much waste material, to be "safe," must be contained *forever*. And who can anticipate future natural and man-made stresses on the system?

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SITE INVESTIGATIONS FOR BEDDED-SALT PILOT PLANT IN PERMIAN BASIN

High-level radioactive waste contains long-lived nuclides that require complete confinement for long periods of geologic time. Rock salt long has been acclaimed as the preferred geologic medium for the ultimate disposal of these wastes, inasmuch as its unique self-healing properties make it impervious to the intraformational circulation of groundwaters. Data have been compiled on the nature and extent of all major salt deposits in the conterminous United States; however, specific site studies have been confined to the Permian basin, to central Kansas, and to a large tract of federally owned land in southeastern New Mexico. A series of coreholes has been drilled to provide the critical data for selecting appropriate disposal levels and assessing the hydraulic characteristics of the overlying and underlying formations. Selective parts of the cores have been analyzed to determine the quantities and characteristics of various minerals in the evaporite section and, in particular, of any hydrated minerals and rocks that could dehydrate upon heating because of radioactive decay of the wastes. Measurements of the physical properties of these rocks also have been made to calculate their deformational behavior.

Because of the need for long-term waste confinement, several unique studies have been initiated. The long geologic history of relative quiescence, coupled with data on historic earthquakes, strongly suggests that the Permian basin will continue to be tectonically stable for the next few hundreds of thousands of years, or for the effective lifetime of the wastes. In addition, studies of subsurface salt dissolution show that the rate of basinward migration of the relatively shallow edges