turbid water should not be limited by the movement and accumulation of suspended sediment in the basin material.

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U.S. ENVIRONMENTAL PROTECTION AGENCY POLICY ON SUBSURFACE EMPLACEMENT OF FLUIDS BY WELL INJECTION

The Federal Water Pollution Control Act Amendments of 1972 (public law 92–500) provide for comprehensive controls on surface water, but do not provide for specific regulatory control over subsurface water at the federal level. The only applicable regulatory provision of the act is for a federally approved state permit program which, among other things, requires a qualifying state authority to issue permits to control the disposal of pollutants into wells. Because of provisions in the new legislation requiring upgrading of the quality of discharges to both air and surface water, an increased assault on the quality of the nation's groundwater resources is anticipated. The EPA policy statement does not purport to have legal sanction, but rather puts the Agency on record as being opposed to the emplacement of materials by subsurface injection without strict controls and a clear demonstration that such emplacement will not interfere with present or potential use of the subsurface environment, contaminate groundwater resources, or otherwise damage the environment. The EPA policy does have some clout, however, in that it is designed to discourage the diversion of wastes treatable on the surface to the subsurface for the purpose of avoiding discharge permits or other provisions of P.L. 92–500, and most certainly will be used by the states in designing permit programs that will meet federal approval for the disposal of pollutants in wells.

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SUBSURFACE DISPOSAL OF LIQUID INDUSTRIAL WASTES IN ALABAMA

Five subsurface disposal wells have been drilled and completed in Alabama. These are: Stauffer Chemical Co., Mobile County; Ciba-Geigy, Inc. (2), Washington County; U.S. Steel Corp., Jefferson County; and Reichhold Chevmicals, Inc., Tuscaloosa County. The Geological Survey of Alabama has been involved directly in all 4 projects. The Survey served as a consultant to the Alabama Water Improvement Commission (the state agency responsible for protection of surface and groundwater in Alabama) on the Stauffer and Ciba-Geigy projects, and as consultant and supervisor on the U.S. Steel Corp. and Reichhold Chemicals, Inc., projects. The Environmental Protection Agency provided some funding on the research aspects of the Reichhold Chemicals, Inc., disposal well. These projects were undertaken as a research effort to insure that the responsible state agencies are fully cognizant of all aspects of this method of waste disposal.

At present, in Alabama, subsurface disposal is permissible for some types of wastes, if the well is properly designed and completed in an appropriate geologic environment, if conventional methods of waste treatment have been evaluated and proved to be inadequate, and provided an adequate monitoring system has been installed.

The Stauffer and Ciba-Geigy wells are in the Coastal Plain geologic province and the U.S. Steel and Reichhold Chemicals, Inc., wells are in Paleozoic sediments of the Warrior basin, The geology, drilling, completion, and testing techniques are presented as a basis for decision making for approval or rejection of the proposed deep-well disposal projects by a regulatory agency.

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ELECTRONIC DATA PROCESSING FOR DECISION MAKING IN SUBSURFACE INJECTION OF LIQUID WASTES

The West Virginia Geological Survey began a pilot study on subsurface industrial waste disposal in 1972 under a research grant from the U.S. Bureau of Mines. Electronic data processing (EDP) was chosen as the means of information assimilation and output. Data output includes maps showing freshwater and saltwater levels, oil and gas well locations, structure contours, isopachs, fracture pressure gradients, formation pressures, *etc.* A cost and effort determination has been made for each type of output, and leads to an overall evaluation of EDP for decision making in subsurface waste injection.

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EFFECTS OF WASTE PERCOLATION OF GROUNDWATER IN ALLUVIUM NEAR BARSTOW, CALIFORNIA

Barstow is 96 mi northeast of Los Angeles in the Mojave Desert region of southern California, adjacent to the normally dry Mojave River. Groundwater in alluvial fill is the only reliable source of water for the main water purveyors (the city of Barstow and the U.S. Marine Corps Supply Center). The alluvial aquifer near Barstow has been subjected to contamination from percolation of industrial and municipal sewage for nearly 60 years. The contamination has forced the abandonment of several domestic wells because of taste, odor, and foaming, and it threatens the well field serving the U.S. Marine Corps Supply Center. An intensive investigation was made to determine (1) the nature of groundwater degradation; (2) the areal and vertical extent of the degradation; (3) the rate and direction of movement of the degraded water; and (4) the effects of several proposed management practices designed to alleviate the problem.

A series of 53 observation wells was installed within the 10-sq-mi study area to supplement data from existing domestic and irrigation wells. Groundwater samples were analyzed for the usual chemical constituents plus arsenic, hexavalent and total chromium, dissolved organic carbon, detergents, ammonia, phosphates, and oil and grease. Concentration gradient for dissolved solids and several individual constituents were defined in 3 dimensions. The dispersive characteristics were investigated by use of a 2-well tracer-dilution test.

The chemical stratification found within the aquifer indicates that an old plume of degraded water (produced by percolation from sewage facilities near Barstow) occupies the lower part of the alluvial aquifer. Since 1910 this plume has moved down gradient about 4 mi. A more recent overlying plume of degraded water occurs near the downstream edge of the deeper plume. This recent plume is produced by effluent from sewage-treatment facilities installed in 1968. Detergent concentrations beneath this site reflect the current use of LAS-type detergents in contrast to the ABS types that are found in the deeper zones of degradation.

Distribution of nitrogen and chloride has indicated that the gradual increase in dissolved-solids concentrations in the Marine Corps wells is caused by the use of treated sewage effluent on a local golf course. Areal and vertical mapping of the degraded water indicates that the water supply at the Marine base will be affected if no measures are taken to avoid contamination.

A digital water-quality model of the aquifer was built to aid in evaluating the effects of several alternative ground-water management practices. The model first was verified by comparison with existing hydrologic data and then used to calculate the water-level and water-quality conditions that might occur in the aquifer within the next 20 years. Model results indicated that by 1991 present sewage-percolation practices would result in dissolved-solids concentrations exceeding 900 mg/l in the Marine Corps well field.

Two of the alternative water-quality management practices that were evaluated with the model are:

(1) The oxidation ponds could be lined to prevent further percolation, and the effluent piped out of the study area. The model indicated that this would cause water-level declines in excess of 70% of the saturated thickness of the aquifer in the vicinity of the Marine Corps well field. This is probably unacceptable.

(2) The percolation of treated sewage effluent could be allowed to continue, and a line of barrier wells could be drilled between the sewage-treatment facility and the Marine Corps well field. The barrier wells would be pumped at a lesser rate than the rate of recharge from the oxidation ponds, to lessen the undesirable effects. The model indicated that by 1987 a constant rate of pumping from the barrier wells would effectively limit the movement of the degraded plume toward the well field. However, by 1991 the increasing quantities of percolation from the oxidation ponds would greatly exceed the barrier pumping rate and the highly concentrated parts of the degraded plume would approach the edge of the Marine Corps well field. Judicious choice of barrier pumping rates would probably extend the effectiveness of the barrier beyond 1987.

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Injection of Acidic Industrial Waste into Saline Carbonate Aquifer—Geochemical Aspects

A section of carbonate rocks that includes several highly permeable cavernous zones filled with saline water underlies the south part of peninsular Florida at depths from 1,500 to 4,500 ft. Because these cavernous zones are capable of yielding or accepting large quantities of fluids, they are used for storage of industrial and municipal liquid waste at several places. One such place is at the south end of Lake Okeechobee near Belle Glade, Florida, where the effluent from a sugar mill and liquid waste from the production of furfural processed from sugar cane bagasse have been injected at depths between 1,500 and 2,200 ft. The waste ranges in temperature from 71 to 103° C, in pH from 2.6 to 4.5, and is highly organic (COD 6,000–26,000 mg/l). Since 1966 more than 800 million gal of this waste have been injected. Injection rates range from 400 to 800 gal/minute at pressures of 30–60 psi at the wellhead. The waste is partly neutralized almost immediately to a pH of 5.5 by dissolution of limestone. Caliper logs show localized patterns of dissolution of the carbonate aquifer. Anaerobic degradation of the organic waste begins near the injection well, as indicated by the presence of hydrogen sulfide, methane, carbon dioxide, and nitrogen.

The waste has moved both upward and laterally in the aquifer system, as detected by water quality changes in monitor wells. Upward movement of altered waste into an overlying brackish-water zone was detected by a 1,400-ft monitor well 75 ft away from the injection well. Lateral movement was detected by a monitor well in the injection zone 1,000 ft away. When upward movement of waste was detected, injection was discontinued and the well was drilled and cased several hundred feet deeper. Data collected since the well was deepened are inconclusive regarding the effectiveness of the increased well depth in restricting the waste to the injection zone. Investigations to date at Belle Glade clearly point up the value of a sound monitoring program.

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Role of Borehole Geophysics in Underground Waste Storage and Artificial Recharge

The optimum utilization of underground space for the emplacement and storage of waste and surface water can be achieved through an understanding of the geohydrologic environment. The emplacement of liquid waste and the artificial recharge of aquifers generally requires the drilling of exploration, injection, and monitoring wells. Some geophysical logs are run on almost all wells drilled for deep disposal. Even more information could be obtained, however, by utilization of all available logging techniques. To date, geophysical well logging has not been applied widely to artificial recharge projects; however, borehole geophysics is being used by the U.S. Geological Survey to study geohydrologic parameters related to recharging the Ogallala Formation on the High Plains of Texas.

Geophysical well logs provide preinjection data necessary for the selection of environments for liquid waste or water storage. Logs provide data on the location, thickness, and lateral continuity of storage zones and confining beds, percent and distribution of total or effective porosity, and the relative magnitude of permeability. Intergranular and fracture porosity can be discriminated by crossplotting acoustic velocity and neutron or gamma-gamma logs. The distribution and orientation of preinjection fractures can be determined by acoustic televiewer logs. Logs provide data on the chemical quality of the native fluids and the mineralogy of the aquifer, which are necessary to predict chemical reactions with injected fluids. The temperature and conductivity of the interstitial fluids may be measured directly and their specific gravity and viscosity may be calculated from log data.

Because aquifers overlying injection zones can be polluted by improper well construction or well failure, geophysical well logs should be used to guide the design, construction, and maintenance of injection and monitoring wells. It is important to answer questions such as: are the casing strings and screens properly installed; are they plugged or corroded; does the grout fill the annular space and is it properly bonded to the casing; and, are there leaks through the casing, between pipe strings, or through the annulus?

After waste injection or artificial recharge has started, logs provide *in-situ* measurements of changes in the system. We have found that an increase or decrease in porosity caused by solution or precipitation in pore spaces or cavities may be detected. This type of information not only explains changes in well efficiency