to the oxygen balance, there are no significant differences between a percolative and a direct infiltration, probably because decisive oxygen gas quantities are no longer present after the first percolative seepage of a polluted raw water in an unsaturated zone above the water table. Absence of oxygen in a groundwater will involve the solution of iron and possibly also of manganese. Low oxygen concentrations also retard the elimination of bacteria and of tastes and odors. This elimination results preferably from aerobic biologic filtration. Furthermore, if the oxygen content does not exceed about 5 ppm no sufficient protective scales on the interior of the ferrous water supply pipes are formed. Therefore, poor oxygen balance systems must be improved by different processes of raw water pretreatment.

After the infiltration, the aerobic decomposition of organic matter and the elimination of bacteria mainly take place in short flow times. A case in point is a reduction of an average coliform content from 10^6 per 100 ml to 10 per 100 ml after about 1 day minimal and 7 days average retention time. Other empirical results confirm the excellent biologic filtration of the water during its lateral flow through the gravels. After the beginning of an artificial recharge and the following elevation of the water table, the biologic activity in the inundated natural filter rises only step by step in function of operating time. In the mentioned case, optimal coliform results were obtained at first after an operation time of about 70 days.

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Artificial Recharge in Coastal Plain Aquifer in Israel—Further Findings

Artificial groundwater recharge operations till the end of 1966 have been described in the *Bulletin* of the International Association of Scientific Hydrology, Annex No. 1, March 1967.

The present paper reviews artificial recharge practices followed in Israel since 1967.

The coastal plain aquifer is at present recharged through 99 wells and through 8 spreading grounds with a total area of 180 acres. The average yearly rate of recharge to this aquifer amounts to about 80 MCM/acre (64,000 acre-ft).

Recharge is practiced mostly during winter months, November through March, and sometimes also during April and October. The main source is mixed Lake Kinneret water, this supplying 68% of the recharged water; about 17% is storm runoff and 15% groundwater withdrawn from a limestone aquifer.

Recharge rates into wells range between 50 and 400 cu m/hour (220–880 gpm) and infiltration rates in the spreading grounds range between 0.2 and 3.0 m/day (0.7–10.5 ft/day), though initial infiltration rates in spreading grounds are usually lower for storm runoff water than for water from Lake Kinneret.

Recharge and infiltration rates decrease during recharge seasons; this decrease varies with the type of recharge installation and the type of water used.

The decrease in well recharge rates is observed mostly when single-purpose wells (unequipped wells drilled for recharge only) are recharged with Lake Kinneret water. Redevelopment of these wells over a short period does not suffice to restore the original recharge rates. The same Lake Kinneret water, when recharged into dual-purpose wells (wells that are normally pumped throughout the summer), causes only a small decrease in the recharge rate during the recharge period. Recharging the aquifer through both dual and single-purpose wells with groundwater from the limestone aquifer causes almost no decrease in recharge rates.

To assist in restoring infiltration recharge rates, the basins are dried out after each season, the upper layer of soil and silt removed, and the basin cultivated. This results generally in restoration of the infiltration rates to their original values.

In the dual-purpose wells, the first batch of water pumped after recharge had ceased for a short period was contaminated. This contamination (odor, turbidity, high counts of coliform bacteria) is due probably to the high content of organic matter in the recharged water. To overcome this pollution, short and intensive pumping for a few hours was carried out and the water discarded. Later, chlorination was applied for a few days.

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Underground Waste Disposal at New Johnsonville, Tennessee

Deep-well disposal of acidic wastes has been employed successfully at the E. I. du Pont Pigments Plant, New Johnsonville, Tennessee, since 1967. In 1965, as part of a program to reduce surface discharge of waste fluids, together with other methods for waste disposal, an investigation of the feasibility of subsurface waste disposal was conducted. Basic data were developed and from this a proposal was made to the state for drilling a deep disposal well. A public hearing, attended by local, state, and federal representatives, was held and all inquiries answered. Under state permit, a 6,700-ft geologic test well was drilled. Receptive zones were found in the middle and lower Knox-Copper Ridge Dolomites (Cambrian). Laboratory studies conducted with rock cores showed that the waste fluids are compatible with the formation rocks and their contained waters. Appropriate state agencies approved completion designs and the well was completed in 1966.

Acidic wastes were injected into the well at design rates and pressures from 1967 through 1971, at which time the well was retired from service. Two additional waste wells have been drilled and are operating successfully. A fourth well is scheduled to be drilled in the near future.

In addition to downhole monitoring systems on each well, the plant monitors many freshwater wells in the surrounding area, as well as 1 deep well on the plant property, for evidence of waste-fluid migration. To date, no vertical migration of waste has been observed.

A second deep monitor well is to be drilled in conjunction with the upcoming fourth waste well. At New Johnsonville it has been shown that a properly installed waste-disposal well system can successfully remove undesirable waste fluids from the biosphere.

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Laboratory Studies Related to Artificial Recharge

Artificial groundwater recharge, by any method, is subject to limitations caused by some mechanism degrading the hydraulic conductivity of the porous media through which the recharge water is being infiltered or injected. Reduction of hydraulic conductivity may be caused by suspended solids, bacterial growth, chemical reactions of dissolved solids with the porous media or existing native water, and air entrainment or dissolution of gases in interstices of the porous medium.

A comprehensive study of factors affecting artificial groundwater recharge should include laboratory determinations of the relation of the various causes of hydraulic-conductivity reduction. Problems pertaining to the effect of water quality in relation to the lithologic environment of a recharge system also should be studied in the laboratory.

A laboratory facility has been designed and equipped to provide means of testing flow through porous media columns. Any quality of recharge water from distilled water to activated sludge, can be constituted in quantities providing for indefinite term tests. Flow can be through repacked or field cores under constant flow or constant pressure.

A flow-test data acquisition and computation system provides punched tape data storage and real time computation and plotting of intrinsic permeability changes with column depth and time.

Water quality data are taken during the test, and characteristics of the porous media and suspended solids are determined. Accumulation of material in porous media interstices is visually observed with scanning electron microscopy.

The data are analyzed to relate the physical, biologic, and chemical effects in the porous media flow system with the objective of obtaining data that can be transferred to field situations and thus develop more economical artificial-recharge systems.

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HYDRAULIC FRACTURING AS TOOL FOR DISPOSAL OF WASTES IN SHALE

The growth of modern society and technology requires an increasing level of protection of the environment, and waste disposal is a growing problem, particularly for radioactive and toxic industrial wastes.

The injection of wastes mixed with cement grout into thick shale formations is a promising method for effectively immobilizing wastes in a nearly impermeable medium. Hydraulic fracturing serves as a tool to increase the permeability of shale during the grout injection. Ion exchange and adsorption agents can be added to the grout when it is mixed. After hardening of the grout, the injected wastes will become an integral part of the shale and remain there as long as the shale is not subject to erosion.

Problems concerning the safety of the method are phase separation and orientation of the hydraulically induced fractures. During hardening of the grout, phase separation may occur, that is, some liquid may separate. In such an instance, the mobility of wastes in the separated liquid may be greatly retarded by the very low permeability and high ion-exchange capacity of shale. If the separated liquid reached a groundwater reservoir, the concentration of contaminants would be greatly reduced further by dilution in the native groundwater.

In bedded shale there is a great difference in tensile strength between the direction normal to and parallel with bedding planes. This difference in tensile strength may favor the formation of fractures along low-angle bedding planes within a zone of limited vertical extent. However, not all shale formations produce bedding fractures, therefore before construction of a waste-disposal plant it is necessary to test the site by water or nontoxic grout injections tagged with radioactive isotopes to judge whether a "zone" of fractures can be induced parallel with the shale bedding planes. Injection pressure, movement of the ground surface, and gamma-ray logs made in observation wells are used to interpret the orientation of the hydraulically induced fractures during the site-selection tests. A case history of hydraulic fracturing at West Valley, New York, illustrates the method of selection of a site.

Waste disposal through an injection well is conducted in multiple-layered injection stages. The first injection starts from the deepest depth, then the injection zone is plugged by cement, and the second injection will be started about 10 ft above the first one. The repeated use of the injection well distributes the high cost of construction of injection and monitoring wells over many injections, thereby making hydraulic fracturing economically feasible as a tool for the disposal of certain types of wastes.

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LEGAL AND INSTITUTIONAL CONSIDERATIONS OF DEEP-WELL WASTE DISPOSAL

Deep-well injection of wastes is subject to two levels of legal and institutional constraints. The first consists of regulatory procedures established by state and federal legislation. Waste injection has traditionally been regulated by the states through use of a variety of statutory constructions and administrative organizations. Federal control over subsurface disposal has essentially been limited to radioactive wastes, but influence currently is being extended into the general area of underground waste management. The apparent intent of the Federal Water Pollution Control Act Amendments of 1972 is the subjugation of state regulatory procedures to federal standards, with actual administration of controls ultimately to remain with the states.

The second level of constraints consists of the property rights of adjacent landowners. These adjacent rights are important because injected wastes do not respect property boundaries and therefore may produce conflict with certain aspects of property ownership. The most obvious type of infringement involves injurious contamination of property interests by the injected waste. A more indirect case of contamination may involve the pressure-induced migration of naturally occurring pollutants such as mineralized water. Another potential type of pressure-related interference with property consists of structural damage from seismic activity initiated by injection. In some jurisdictions, even the unauthorized occupation of underlying space without measurable damage to the landowner may constitute a violation of property rights. The courts in most states have not been confronted with all these issues, but the party adversely affected by injection generally will be able to invoke a variety of legal actions, including nuisance, negligence, and trespass. In addition, some states accept the concept of strict liability regarding hazardous activities and the escape of deleterious substances, with the result that the injured party is relieved of the requirement of proving fault.

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INDUSTRIAL WASTEWATER-INJECTION WELLS IN UNITED STATES—STATUS OF USE AND REGULATION, 1973

Recent inventories of industrial wastewater-injection wells in the United States show that at least 250 wells have been completed to date (March 1973) in 24