change in reflection coefficient. This information then is related to the range of expected changes in reflection coefficient due to the injected waste materials, and subsequently to the feasibility of the seismic monitoring system.

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DEDUCTION OF FLOW PATTERNS IN VARIABLE-DENSITY AQUIFERS FROM PRESSURE AND WATER-LEVEL OBSERVATIONS

In previous potentiometric studies of variable-density aquifers, particularly studies related to oil exploration, certain gravitational effects apparently have been ignored. These include the effects of troughs formed by permeability barriers within the aquifers, and the effects of structural troughs, saddles, anticlines, and synclines. In intermontane regions these gravitational effects probably are negligible in comparison with observed head differences; in most other regions they can change appreciably the heads, or the potentials, that are available to cause flow.

A gradient in potential is not necessarily associated with flow, even though corrections are made for the average rate of change in density of water. Gravitational effects can cause the interface between water and an oil or gas deposit to be tilted, even if the water under the deposit is static. These effects can reduce the rate of flushing of brine by fresh water, or they can prevent flushing.

Previous potentiometric studies should be reevaluated to ensure that all gravitational effects have been taken into account.

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DESIGN AND OPERATION OF LAND-TREATMENT SYSTEMS FOR MINIMUM CONTAMINATION OF GROUNDWATER

The increasing interest in land-treatment systems for sewage effluent and other liquid wastes, as well as some solid wastes, poses a threat to the quality of the native groundwater even though the waste water itself undergoes a marked improvement in quality as it moves through the ground and becomes "renovated" water. To avoid large-scale spread of the renovated water into the groundwater basin, the renovated water should be collected again at some point by wells (deep aquifers) or drains (shallow aquifers) for reuse or release into the surface water. For the Salt River Valley, the effective transmissibility of the aquifer for recharge was evaluated from a pilot project and then used in the design of a full-scale system. This effective transmissibility was less than the aquifer transmissibility.

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UNDERGROUND STORAGE AND RETRIEVAL OF FRESH WATER FROM BRACKISH-WATER AQUIFER

In 1967, the U.S. Geological Survey, in cooperation with the City of Norfolk, Virginia, began a study concerning the injection of fresh water into a confined aquifer containing brackish water. The objectives of the study were (1) to determine whether the host formation would physically accept large volumes of fresh water, (2) to determine the degree of mixing of the injected fresh water with the saline water, and (3) to determine the percentage of recoverable potable water after long periods of storage.

During late 1971 and early 1972, three injection and withdrawal tests were carried out. In test 1, fresh water was injected at a rate of 400 gpm (gallons per minute). The specific capacity of the well decreased from an initial value of 15.4 to 9.3 gpm/ft of drawdown at the end of 260 minutes of injection. In test 2, the initial injection rate of 400 gpm decreased to 215 gpm after 7,900 minutes of injection. The specific capacity dropped from 14.2 to 3.7 gpm/ft during the same time interval. Test 3 began with the aquifer accepting water at a maximum rate of 290 gpm, and the injection rate fell to 100 gpm within 150 minutes and continued to decline to a low of 70 gpm after approximately 1,300 minutes. The specific capacity decreased from an initial value of 3.7 to 0.93 gpm/ft at the end of the test.

Specific capacities during the withdrawal phases dropped from 19.7 gpm/ft at the beginning of test 1 to 6.7 gpm/ft at the end of test 3. All attempts at redevelopment of the injection well failed to improve the specific capacity. Current-meter surveys conducted during injection and withdrawal pumping indicated that the reduction in flow rate and specific capacities was due to a uniform reduction in permeability of all contributing zones in the aquifer rather than to a complete shut-off of flow from selected parts of the aquifer.

All of the hydraulic data collected during the three tests indicated that a physical change of the formation materials had occurred. Specifically, it was felt that the uniform loss of specific capacity of the contributing zones was due to clay dispersion, a phenomenon well known to the petroleum industry. Chemical data collected during the three tests indicated that the sodium-rich clays also were involved in cation exchange. As fresh water was being injected, calcium and magnesium replaced sodium on the clays. During withdrawals, a reversible reaction occurred as the sodium concentration in the mixed fresh and formation water increased. The net effect of the replacement of sodium with calcium and magnesium was to decrease very slightly the tendency of the clays to disperse during the injection of fresh water. The cation exchange activity during both the injection and withdrawal phases had little to do with clay dispersion, which is more nearly a physical than chemical characteristic. However, the exchange activity noted during all three tests did indicate that the clays would readily respond to chemical treatment for the purposes of decreasing or eliminating clay dispersion.

Subsequently, a preflush of 3,000 gal of 0.2 *N* calcium chloride solution was injected in front of the fresh water in injection test 4. The initial specific capacity was 4.3 gpm/ft compared with the ending injection specific capacity of 0.93 gpm/ft in test 3. By redevelopment pumping during injection, the specific capacity was improved to a high of 5.3 gpm/ft. After 4 million gal of water had been injected, an additional 3,000 gal of 0.4 *N* calcium chloride solution was added to the formation. The injection specific capacity increased to a high of 7.12 gpm/ft.

The injection specific capacity fell off with time because only the area around the bore hole was treated to prevent clay dispersion. The data from test 4 indicated a maximum injection rate could be maintained by injecting for periods of 1,200 and 1,400 minutes, then withdrawing water for 30 minutes to remove from the aquifer any sand and clay particles that were clogging the injection zones.

A total of 20 million gal of fresh water was injected in test 4. The water was left in the aquifer for about 6 weeks before beginning the withdrawal phase. It had been determined from the first three injection tests that about 85% of the injection water could be recovered