Annotated Bibliography on Artificial Recharge of Ground Water, 1955-67

By D. C. SIGNOR, D. J. GROWITZ, *and* WILLIAM KAM

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ANNOTATED BIBLIOGRAPHY ON ARTIFICIAL RECHARGE OF GROUND WATER, 1955–67

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INTRODUCTION

Artificial ground-water recharge has become more important as water use by agriculture, industry, and municipalities increases. Water management agencies are increasingly interested in potential use of recharge for pollution abatement, waste-water disposal, and re-use and reclamation of locally available supplies. Research projects and theoretical analyses of operational recharge systems show increased scientific emphasis on the practice. Overall ground-water basin management systems generally now contain considerations of artificial recharge, whether by direct or indirect methods.

Artificial ground-water recharge is a means of conserving surface runoff for future use in places where it would otherwise be lost, of protecting ground-water basins from salt-water encroachment along coastal areas, and of storing and distributing imported water.

The bibliography emphasizes technology; however, annotations of articles on waste-water reclamation, ground-water management and ground-water basin management are included. Subjects closely related to artificial recharge, including colloidal flow through porous media, field or laboratory instrumentation, and waste disposal by deep well injection are included where they specifically relate to potential recharge problems.

Where almost the same material has been published in several journals, all references are included on the assumption that some publications may be more readily available to interested persons than others.

Other publications, especially those of foreign literature, provided abstracts that were used freely as time limitations precluded obtaining and annotating all materials. Abstracts taken from published sources are noted. These are: "Abstracts of North American Geology," U.S. Department of the Interior, Geological Survey; "Abstracts of Recent Published Material on Soil and Water Conservation," ARS–41 series, Agricultural Research Service, U.S. Department of Agriculture; "Water and Water

Engineering," published by Fuel and Metallurgical Journals, Ltd., London, England; "Journal of Geophysical Research," American Geophysical Union, Washington, D.C.; "American Society of Civil Engineers Transactions," New York; "Selected Bibliography of Hydrology, United Kingdom, for the Years 1955–59," International Association of Scientific Hydrology; "Water Wells, an Annotated Bibliography," California University Water Resources Center Archives Report 13; "Re-use of Effluent in the Future With an Annotated Bibliography," by G. A. Whetstone, Texas Water Development Board Report 8, Austin, Tex.; "Journal of Water Pollution Control Federation," Washington, D.C.; and "A List of Selected Technical References on Artificial Recharge of Ground-Water Reservoirs," compiled by Roy W. Graves, Tulsa University, Information Services Department, Tulsa, Okla. Other notations are self-explanatory, and initials are those of the authors (DCS, DJG, WK). An unpublished compilation of recharge references by Arnon Arad sponsored by the United Nations Educational, Scientific, and Cultural Organization during a training period with the U.S. Geological Survey was also used.

The bibliography is arranged alphabetically by author. Where an author has more than one publication, the arrangement is chronological; where an author has more than one publication in a given year, a, b, c, . . . are added. The indexing is by subject and geographic location. Each article was assigned the key words or phrases to best characterize its contents. Units of measure are as they were in the original article; abbreviations retained are generally those in common use such as mg/l (milligrams per liter), ppm (parts per million), gpm (gallons per minute), km (kilometers), m (meters), cu m per hr (cubic meters per hour), cfs (cubic feet per second), me/l (milliequivalents per liter), psi (pounds per square inch), BOD (biochemical oxygen demand), sq m (square meters), gpd (gallons per day), and mgd (million gallons per day).

The bibliography was prepared because of the worldwide interest in the field of artificial recharge and the need for a single source of references to the literature published since 1954. The work is a sequel to the "Annotated Bibliography on Artificial Recharge of Ground Water Through 1954," by D. K. Todd, U.S. Geological Survey Water-Supply Paper 1477, published in 1959.

BIBLIOGRAPHY

Aberbach, S. H.

1967. (and Sellinger, A.). Review of artificial ground-water recharge in the Coastal Plain of Israel [with French abs.]: Internat. Assoc. Sci. Hydrology Bull., v. 12, no. 1, p. 65–77.

The Coastal Plain aquifer of Israel, of Pliocene-Pleistocene age, stretches from Binyamina in the north to the Gaza Strip in the south—a distance of about 112 km—and has an average width of about 15 km. The allowed withdrawal is estimated at about 200 MCM/year [million cu m per year].

As a result of an average yearly withdrawal of 426 MCM/year during the last 10 years, the water levels dropped to a dangerously low position below sea level at distances of 3–5 km from the coast, causing sea water intrusion which, in Tel Aviv and Emek Hefer, endangered water-supply wells.

As a countermeasure, artificial ground-water recharge through wells was practiced in Emek Hefer since 1959. Recharge was practiced in 7 wells at a rate of 6 MCM/year, the water coming from adjacent Cretaceous limestone aquifers.

In Tel Aviv a fresh-water barrier was established in 1964 by injecting Lake Kinereth water into 17 wells during winter at a rate of 6 MCM/winter. In the rest of the Coastal Plain, water was injected to the aquifer through about 40–45 wells at a total yearly rate of about 10–12 MCM.

Recharge by spreading is practiced in Yavneh at a rate of about 10–13 MCM/winter; also recharge by spreading is practiced with floodwater of Nahal Shikma at a rate of up to 8 MCM/winter. (Authors' abs.)

Alexander, W. A.

1959. Ground-water recharge in lower Tule River Irrigation District, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 82–84.

Cyclic storage in the lower Tule River Irrigation District is encouraged. Artificial recharge from sinking basins, earth canals, overirrigation and percolation from the Tule River and its natural distributaries is reviewed. (DJG)

Amramy, Aaron

1965. Waste treatment for ground-water recharge: Internat. Jour. Air and Water Pollution, v. 9, n. 10, p. 605–619, table.

Plans for waste-water reclamation from the metropolitan area of Tel Aviv, Israel, by ground-water recharge are discussed. Infiltration studies in spreading basins are described. The author concludes that, for the Tel Aviv conditions, it is not necessary to subject waste water to conventional methods of biological treatment in order to produce an effluent suitable for recharge; instead the relatively cheaper method of sewage treatment by lagoons, at much heavier loadings than currently used as design criteria in the United States, is sufficient for the purpose. An effluent from sewage stabilization

lagoons, containing suspended organic matter largely in the form of live algae, can be applied to dune sand overlying suitable subsoil layers without the danger of clogging and without marked diminution of the infiltration rate. The recharged water, subsequently recovered from properly spaced wells, can attain potable quality providing the spreading basins are operated intermittently. (From author's conclusions.)

Archambault, J.

1967. (and Margat, J.). L'alimentation artificielle des nappes en France [Artificial recharge of aquifers in France] [in French with English abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 213–217.

The paper summarizes the study of artificial recharge and underground storage in France. It presents the objectives of the study together with the main achievements in these fields. (From authors' abs.)

Arya, S. P. S.

1966. (and Chandra, Satish). Design principles of artificial recharge projects: Irrigation and Power [India], v. 23, no. 2, p. 257–276.

The aim of the authors in presenting this paper is to formulate some principles and a procedure for the design of artificial recharge projects based on the available theoretical and experimental work on the subject. The fields in which further research is needed are also pointed out. (From abs. in Water and Water Eng.)

Baars, J. K.

1957. Artificial ground-water production by biofiltration in fine sandy soils: Jour. Sci. Food and Agriculture, v. 8, p. 610–616, tables.

In connection with the artificial production of ground waters, a distinction must be made between those systems which are continuously in operation and those which are only run during autumn, winter, and early spring. The difference between the two systems is of fundamental importance with regard to the oxygen supply needed for mineralization.

Given the right conditions, the purifying effect of the soil may be considerable. These conditions include the availability of oxidizing agents and whether free oxygen or nitrate oxygen is present in sufficient quantity to oxidize the organic matter in the water. If this condition is fulfilled, fine sandy soil may be considered an ideal medium for this oxidation process. Coarser material, having a smaller ratio of surface area to volume, is less suitable, because the water passes through more quickly. In fissured rocks, considerable velocities may be attained and purification will be very doubtful. In such situations, layers of sand should be employed on these rocks, which may thus form a medium where oxidation can take place. (From author's conclusion.)

1958. (and Boorsma, H. J.). Pollution of ground water: Internat. Assoc. Sci. Hydrology Pub. 44, v. 2, p. 279–289, tables.

A general consideration is given on the theoretical possibilities of oxidizing polluting substances present in surface waters by bacterial action when this water penetrates into the soil toward the ground water.

The paramount importance of the presence of oxygen, free or in the nitrate form, is pointed out. This is confirmed by results of an investigation made of the artificial ground-water scheme, now in operation, in the dunes of the coastal region in the Netherlands. (From authors' abs.)

Baffa, J. J.

1967. (and Bartilucci, N. J.). Wastewater reclamation by ground-water recharge on Long Island: Water Pollution Control Federation Jour., v. 39, no. 3, pt. 1, p. 431–445.

All the communities in Nassau and Suffolk Counties draw their water from the Cretaceous-Quarternary beds with a sustained water table under unsewered areas and a falling water table under sewered areas. The availability of waste-water effluents offers a means of supplementing the natural supply and preventing salt-water intrusion. Methods of waste-water renovation for various ultimate uses are described. Recharge wells are compared with recharge basins, and preliminary results on the Riverhead, N.Y., injection-well research project are given. (From Abs. of North Am. Geology.)

Balch, W. T.

1957. (and Jans, Melvin). Water-spreading activities of the Kern County Land Company and North Kern Water Storage District, *in* Conf. on water spreading for ground-water recharge, Proc.: California Univ. Water Resources Center Contr. 7, p. 57–60.

Two aspects of water spreading are briefly discussed. The first is the effect of spreading on ground water and the second is the development of operation criteria. (WK)

Banks, H. O.

1957. (Richter, R. C., and Harder, James). Sea water intrusion in California: Am. Water Well Assoc. Jour., v. 49, no. 1, p. 71–88.

The paper discusses sea-water intrusion and its control by maintenance of a fresh-water ridge above sea level along the coast. Previous investigations by the California Division of Water Resources are reviewed, and the West Coast Basin project operated by the Los Angeles County Flood Control District near Manhattan Beach in Los Angeles County is discussed. Recharge operations, including data on recharge injection rates and results of the injection, are presented. Laboratory and model studies are cited. (DCS)

Barraclough, J. T.

1966. Waste injection into a deep limestone in northwestern Florida: Ground Water, v. 4, no. 1, p. 22–24.

During a 3-month trial period, 10 million gallons of industrial wastes were successfully injected at moderate pressures into a deep limestone in the westernmost part of Florida. (From author's abs.)

Barksdale, H. C.

1955. (and Remson, Irwin). The effect of land-management practices on ground water: Internat. Assoc. Sci. Hydrology Pub. 37, v. 2, p. 520–525.

Artificial recharge as effected by land-management practices and infiltration is briefly mentioned. Examples of waste-water spreading at Seabrook, N.J., are described. (WK)

Baumann, Paul

1955. Ground water phenomena related to basin recharge: Am. Soc. Civil Engineers Proc., Hydraulics Div. Jour., v. 81, Paper 806, 25 p.

The artificial recharge of ground-water basins, which in Los Angeles County has been practiced for almost 60 years, has proved to be most beneficial as a conservation measure. From June 1915 to January 1955, the Los Angeles County Flood Control District has added some 1,200,000 acre-feet of potable water to the ground-water supply by percolation from basins in off-channel spreading grounds and injection through wells. (From author's synopsis.)

1957. Basin recharge, *in* Ground-water development—A symposium: Am. Soc. Civil Engineers Trans., v. 122, Paper 2869, p. 458–474.

Recharge through strip basins and basins whose shape is approximately circular is discussed. Growth and dissipation of ground-water mounds are discussed in relation to the original ground-water surface, movement, control, and pumping.

Recharge through wells in the Manhattan Beach area, Los Angeles County, Calif., to stop salt-water encroachment is cited. Data are given showing the fresh-water barrier at various stages and the injection rates through wells. (DCS)

1963a. Theoretical and practical aspects of well recharge: Am. Soc. Civil Engineers Trans., v. 128, Paper 3442, p. 739–754.

A comparison between water wells and recharge wells as concerns the cone of depression and ground-water mound is made based on theoretical aspects. Control of native ground water by recharge wells in confined and unconfined aquifers is treated. Utilization of a spreading strip as opposed to recharge wells for ground-water control is discussed for both open aquifers and those with impervious surficial layers. An analysis of fresh-water barriers to salt-water encroachment is presented including performance information on the fresh-water barrier of the Los Angeles County Flood Control District in the West Basin aquifer of Los Angeles County, Calif. Practical aspects of recharge well operation are given. (DCS)

1963b. Hydraulics of ground-water mounds, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground Water Recharge Center, 4 p.

Observations on ground-water mounds developed under spreading operations and pressure ridges developed by well recharge in the control of salt-water encroachment are discussed. (DJG)

1965. Technical development in ground-water recharge, *in* Chow, V. T., ed., Advances in hydroscience, v. 2: New York, Academic Press, p. 209–278.

A comprehensive discussion of ground-water recharge is presented with a review of the historical background of artificial recharge in California. The author presents a mathematical treatment of two-dimensional flow under steady and unsteady flow conditions based on an idealized aquifer. Theoretical aspects of the two- and three-dimensional mound phenomenon are presented with model test results for two-dimensional flow for comparison. Empirical formulae and operational aspects are discussed in relation to recharge from strip basins and circular spreading grounds, as well as theoretical and practical aspects of recharge through wells. (WK)

Bear, Jacob

1965. (and Jacobs, Martin). On the movement of water bodies injected into aquifers: Jour. Hydrology, v. 3, no. 1, p. 35–57.

The paper deals with artificial replenishment through wells and with the movement of water bodies injected into confined aquifers. Two cases have been investigated: (1) Injection through a single well under steady flow, and (2) the movement of injected water bodies under nonsteady flow conditions. The recovery ratio of injected water to native ground water in the water pumped through the same well and the extent of mixing in the pumped water were determined. (From authors' abs.)

1966. (and Braester, Carol). Flow from infiltration basins to drains and wells: Am. Soc. Civil Engineers Proc., Hydraulics Div. Jour., v. 92, no. HY–5, p. 115–134.

Theoretical derivations of flow rates, and their dependence on geometry and boundary conditions which would apply to the design of a floodwater interception recharge plant are made. Two types of plants are considered: (1) Infiltration basins in the form of long parallel channels with drains parallel to and midway between the channels leading to recharge wells, and (2) drainage wells used to collect the infiltering water. Characteristics of the flow pattern for both systems and the underlying assumptions of the analysis are enumerated. Three cases are treated under each of two flow situations, two dimensional flow and axisymmetric flow. The cases are: (1) With heavy clogging, the infiltration rate is small and the mound is created under the basin, (2) with little clogging, the infiltration rate is high and the water table reaches the basin's bottom, and (3) at intermediate infiltration rates the mound rises and touches part of the basin's bottom. The analysis is to be applied to an area in Israel where previous material is situated on an impervious stratum above the main aquifer. (DCS)

1967a. (and Bachmat, Y.). A generalized theory on hydrodynamic dispersion in porous media [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 7–16.

The phenomenon of hydrodynamic dispersion occurs in problems of underground mixing of waters of different quality. In these problems, any identifiable solute may serve as a tracer whose concentration distribution indicates the mixing.

A review is given of the microscopic and macroscopic factors of the medium and the liquid, which affect the mixing phenomenon. The paper presents a generalized macroscopic dispersion theory based on the hydrodynamics of the microflow through a porous medium model and on statistical averaging procedures. The macroscopic parameters appearing in the averaged transport equations and their interrelations are analyzed. The problem of determining the tracer concentration distribution, under field conditions encountered in the practice, is stated mathematically in the form of a set of equations and boundary and initial conditions. (Authors' abs.)

1967b. (and Levin, O.). The optimal yield of an aquifer [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 401–412.

The proposed approach is introduced through the analysis of a simple model, representing a homogeneous strip of coastal aquifer, perpendicular to the coast, which already includes pumping and recharge installations. The problem of the optimal operation of this system during a given number of time units (seasons) is presented as a conditional planning problem. The solution requires the formulation of an optimal operation policy for each of the seasons; that is, it requires the determination of the functional dependence of the decision variables (quantities of water pumped and recharged) on the state of the system (quantities of water stored in the aquifer) at the beginning of the season. This solution defines the optimal yield of the considered aquifer. (From authors' abs.)

Berend, J. E.

1962. Seepage tests for spreading grounds: Tel Aviv, Tahal—Water Planning for Israel, Ltd., Pub. 267, 20 p.

Spreading-ground seepage rates are important factors in planning groundwater replenishment projects. The report deals with the soil's natural infiltration capacity. Types of soil underlying spreading grounds, the flow phenomena in uniform and layered systems, and horizontal seepage are treated. Seepage-testing methods designed to determine the suitability of sites for the purpose of spreading grounds are compared. In the conclusions, it was pointed out that seepage tests in small ponds have been found to be the most suitable testing method. (DCS)

1967a. An analytical approach to the clogging effect of suspended matter: Internat. Assoc. Sci. Hydrology Bull., v. 12, no. 2, p. 42–55.

Suspended mineral matter was found to be the dominant factor in reducing infiltration rates in floodwater spreading operations, through the creation of an impervious film on the soil surface. Although concentration of a few thousand milligrams per liter is conducive to almost complete clogging after several hours, even a few tens of milligrams per liter generally has a greater influence than the other clogging factors (biological and chemophysical). Desilting of floodwaters prior to spreading is therefore essential, if the effectiveness of spreading grounds is to be kept on a high level.

In carrying out research and planning of floodwater utilization in Israel, analytical tools for the evaluation and prediction of the clogging process have obviously been required. Observations and theoretical considerations have led to the development of formulas and to the determination of their constants.

The formulas obtained not only fit laboratory experiments and field observations remarkably well but can be applied to forecast seepage rates of irregularly shaped spreading systems fed irregularly from detention reservoirs. A system optimization method, highest average seepage rate for spreading and treatment cycles, was also evolved. (From author's summ.)

1967b. (Rebhun, M., and Kahana, Yona). Use of storm runoff for artificial recharge: Am. Soc. Agr. Engineers Trans., v. 10, no. 5, p. 678–684.

Artificial recharge into the ground has been found to be the only feasible method of utilizing flood runoff water in Israel. A wide program of studies has been undertaken concerning artificial recharge, the more important of which referred to in the paper are: (1) quality of waters and their response to treatment, (2) infiltration capacity of spreading grounds, site selection, and analysis of infiltration phenomena, and (3) the process of clogging, its prevention and corrective measures. The paper contains a comprehensive presentation of the study areas enumerated containing data and analyses. It was concluded that the sediment load is the most serious problem to be considered in the utilization of storm runoff by artificial recharge. Future investigations were discussed and the elements of a proposed pilot plant located at the Shiqma Project in southern Israel were enumerated. (DCS)

Bernard, G. C.

1955. Effect of reactions between interstitial and injected waters on permeability of rocks: Producers Monthly, v. 20, no. 2, p. 2[illegible]–32.

Various waters were injected into Berea sandstone which were incompatible with the interstitial waters that had been used to saturate the sandstone. In no case was a change in permeability of the rock observed. It is concluded that there is no danger of plugging a rock by injecting into it a water which is incompatible with the interstitial waters in the rocks. (Author's abs.)

Berry, W. L.

1962. Ground water in California's future, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 14 p.

The role of underground storage in developing California's water resources in the most economical manner is discussed, together with the physical, engineering, and legal problems that will be encountered with utilization of underground storage. (DJG)

Bianchi, W. C.

1959. A broad view of ground-water replenishment by recharge irrigation *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 100–102.

The process of replenishment by recharge irrigation is broadly categorized into factors of: (1) diversion, (2) transportation and distribution, (3) application, and (4) percolation. From the factors involved, a regional recharge index is defined to allow comparisons of potential recharge capacities of different regions. The idea of an index is extended to a seasonal basis. If other factors are not limiting, recharge irrigation potential is controlled by the percolation rate. (DCS)

1964. (and Haskell, E. E., Jr.). Field measurement of soil water movement during artificial ground-water recharge: Am. Soc. Agr. Engineers Trans., v. 7, no. 3, p. 341–343.

Two experimental plots above an alluvium profile in Fresno County, Calif., were instrumented with a neutron meter access tube and an observation well. Piezometers were jetted to the top of fine-textured soil layers and perching layers. The value of the observations was in their use in predicting how layered profiles react if flow is limited within the profile or at the surface.

Nuclear scattering methods for moisture content and wet density determinations coupled with the piezometers provided sufficient information to define flow limiting zones and to make approximations of vertical recharge rate. Estimates of the area over which the vertical recharge rate is effective at the water table can be calculated. The recharge rate and its associated area are important conditions in evaluation of ground-water-mound shape theory. (DCS)

1966. (and Haskell, E. E., Jr.). Air in the vadose zone as it effects water movements beneath a recharge basin: Water Resources Research, v. 2, no. 2, p. 315–322.

The shape of the advancing wet front beneath an experimental recharge area can be attributed to the distribution of entrapped air above it. The apparent rise of the water table prior to the arrival of the wet front results from a localized response of observation wells to pressures associated with air movements between the water table and wet front. The curvature of the wet front and the premature response of the observation wells make it difficult to determine, from observation well hydrographs, the initial position of the "static" water table and the time that recharge commences. (Authors' abs.)

Biemond, C.
1957. Dune water flow and replenishment in the catchment area of the Amsterdam water supply: Inst. Water Engineers Jour., v. 11, no. 2, p. 195–213, table.

To prevent further salt-water intrusion into the dune area from which Amsterdam draws its water supply, recharging of Rhine River water by means of infiltration canals is anticipated. The highly polluted Rhine River water is expected to undergo natural purification during recharge. Mathematical calculations are being continued in an attempt to define the boundary between fresh and salt water resulting from recharge. (DJG)

1965. Enkele speciale vraagstukken van ondergrondse voorraad vorming [Some special problems of subterraneous storage] [in Dutch with English summ.]: Water [Netherlands], Sept., p. 281–286.

Storage of water for public supply is common practice to variable degrees. Its normal purpose is equalization of transmission. The capacity of recharged gathering grounds for storage is very great. If, however, there enter into the picture not only quantity aspects but also quality aspects, the degree to which subterraneous reservoirs are exploited to even out differences in quality is still much more important. If the source from which the raw water is abstracted is temporarily unusable, the storage capacity in the gathering grounds may serve for long periods. Special problems for the system, based upon abstractions of polluted water from the Rhine River recharged in dune areas, are formed by the high degree of mineralization which makes the river water temporarily unfit for direct distribution. Levels of 400 ppm chlorides and 1,000 ppm total solids may be reached in dry years during periods of considerable length; examples are demonstrated showing that under these circumstances water can be supplied with maximum levels of 150 ppm chloride and 500 ppm total solids. (From abs. in Water and Water Eng.)

Biggar, J. W.

1959. Leaching of soil salines in relation to ground-water recharge, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Ft. Collins, Colo., Western Soil and Water Management Research Br., p. 22–31, tables.

Soils through which recharge water infiltrates should be investigated due to the salinity characteristics that can be imparted to the recharge water. Leaching curves are prepared and discussed for Yolo loam top soil mixed with various salt combinations. (DJG)

1962. Considerations in the use of chloride and tritium in ground-water recharge operations, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 3 p.

The tracer-medium interaction results in serious error when estimating the velocity and volume of flow in the medium. Furthermore, reliable dispersion coefficients for a medium can be obtained only when the investigator considers spreading of the tracer by molecular diffusion as well as velocity dispersion and the interaction of these two processes. (Author's conclusion.)

Billingsley, Ray

1960. How much does recharge water cost: Cross Section, v. 6, no. 11, p. 4, table.

The author considers several variable factors in the cost of a recharge well operation in the High Plains of Texas. A table summarizes the compounded costs per acre-foot of water recharged for playa lakes of various sizes and the time periods for a recharge installation costing $2,000. The author concludes that artificially recharged water can be the source of an attractive return on investment. (WK)

Bittinger, M. W.

1962. Ground-water recharge research in Colorado, 1961, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 9 p.

Research summaries, including purpose, procedures, and status of current projects dealing with artificial recharge are presented. (DJG)

1965. (and Trelease, F. J.). Development and dissipation of a ground-water mound: Am. Soc. Agr. Engineers Trans., v. 8, no. 1, p. 103–104, 106.

The equation developed in the paper describes the variation, with time, of the shape of the ground-water mound which forms beneath a spreading basin. The development is based on the usual assumptions common to ground-water theory plus assumption of: (1) a circular spreading basin with uniform infiltration rate over the entire area, (2) a mound formed by periodic instantaneous releases of disks of ground water, and (3) a mound top that does not come into contact with the bed of the spreading basin. The equation was used to compute the expected rise in water levels in northeastern Colorado

in observation wells located near a spreading basin for which field measurements were available.

Comparison between field observations and computed water table rises due to artificial recharge show that influences of recharge may be predicted. Knowledge of aquifer characteristics is required. It was also found that for distances of observation greater than 2.5 times the radius of the spreading basin, the Theis nonequilibrium equation may be used. (DCS)

Blair, J. F.

1959. Recharge system offers hope for irrigation wells: Land Improvement, v. 6, no. 11, p. 16.

One of the most promising methods of saving water for irrigation farmers in west Texas is a combination irrigation-recharge well that the farmer drills on the edge of a wet-weather (playa) lake. When the lake is full of runoff water, a valve is opened, and the water drains into the well via a constructed ditch. Water from rainy seasons, previously left to evaporate, now can recharge the partially exhausted aquifer. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

Bliss, E. S.

1957. (and Johnson, C. E.) Water-spreading research and research needs in the Soil and Water Conservation Research Division, *in* Conf. on water spreading for ground-water recharge, Proc.: California Univ. Water Resources Center Contr., no. 7, p. 67–77.

Objectives and results of studies in water-spreading research by the Agricultural Research Service, Soil and Water Conservation Research Division, at Bakersfield, Calif., are discussed. (WK)

Blyth, F. G. H.

1958. The use and conservation of underground water: Chemistry and Industry, no. 37, p. 1182–1184.

Artificial replenishment or recharge of aquifers is presented for consideration as a method of conserving ground-water sources in England. The difficulties and considerations in recharge activities are discussed and recharge operations cited. Some data are presented that describe replenishment of the Chalk Formation below east London. (DCS)

Boggess, D. H.

1962. (and Rima, D. R.). Experiments in water spreading at Newark, Delaware: U.S. Geol. Survey Water-Supply Paper 1594–B, 15 p., table.

Two experiments in water spreading were made at Newark, Del., to evaluate the prospect of using excess storm runoff to recharge the shallow water table aquifer serving the community. Although slightly more than 65,000 cubic feet of water were spread in an infiltration ditch and allowed to seep into the subsurface, no appreciable gain was recorded in the producing aquifer because of the presence of an impermeable bed above the main water table. (From authors' abs.)

Boniface, E. S.

1959. Some experiments in artificial recharge in the Lower Lee Valley: Inst. Civil Engineers Proc., v. 14, p. 325–338.

Artificial recharge operations are described at three neighboring well stations in the London Basin. Potable water was passed into the Chalk Formation and Tertiary sands during the winter, and this augmented the yield during the succeeding summer and autumn. The procedure adopted is explained and the effects of the recharge on the quality of ground water is discussed. The economics of recharge are considered. (Selected Bibliog. of Hydrology, United Kingdom, 1955–59.)

Bookman, Max

1957. California's water resources and plans for their development, *in* Industrial uses of water in California: California Univ. Water Resources Center Contr., no. 3, p. 11–23.

The overall water-supply picture and plans for developing the State's water resources are summarized. Artificial recharge, consisting of the injection of reclaimed sewage and flood water is mentioned as a part of this plan. (WK)

1959. Waste water role in meeting water requirements: Am. Soc. Civil Engineers Proc., Sanitary Eng. Div. Jour., v. 85, no. SA–6, paper 2255, p. 111–125, tables.

In the water deficient area in the southern part of California, the recharging of ground-water basins by spreading or injection is the most promising market for reclaimed water. This indirect use of reclaimed water would serve all prevailing beneficial uses to which water secured by pumping from ground-water basins is put. (WK)

Boot, U. S.

1967. (Ljalko, U. I., and Falovsky, A. A.). Electromodelling as an effective method of prognosticating resources of underground water during their replenishment [with French abst.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 17–22.

Underground water resources replenishment is successfully being evaluated by an electromodeling method.

The corresponding devices for artificial underground water recharge and for their following captation are established on electroconductive models of explored territory.

Determined tensions (the strength of the current) given on recharging devices and measured on modeled captation allow to evaluate the effectiveness of different ways of replenishment.

This method is used for prognoses of underground water replenishment on Donbas drafts. (Authors' abs.)

Bosch, H.

1965. Constructie van infiltratie en winningsmiddelen [Constructional outlines for artificial recharge schemes] [in Dutch with English summ.]: Water [Netherlands], July, p. 205–211, 224–230.

Problems involved in an average scheme for artificial recharge of an aquifer and some of their solutions are discussed. Special attention is paid to artificial recharge practiced on a large scale in the Netherlands coastal area where the dune catchment areas are recharged with pretreated surface water from the Rhine River. Thus, these catchment areas constitute fresh water sources for many Dutch communities. (From abs. in Water and Water Eng.)

Bouwer, Herman

1962a. Analyzing ground-water mounds by resistance network: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 88, no. IR-3, pt. 1, p. 15-36.

A technique for predicting quantitative behavior of ground-water mounds below recharge areas is presented. The technique is applicable to stable or moving mounds, two-dimensional or radial flow systems, and uniform or nonuniform soils. Equations are derived for estimating rate of rise or fall of the center of the mound. (Author's synopsis.)

1962b. Cylindrical devices in investigations of seepage, recharge, infiltration, and hydraulic conductivity [abs.]: Jour. Geophys. Research, v. 67, no. 9, p. 3531.

The flow systems occurring in saturated soil which is below a body of free water, when a cylinder is pushed a certain distance into the soil and when the water level inside the cylinder differs from that outside the cylinder, were analyzed with an electrical resistance network and characterized by means of dimensionless "flow factors." Application of these flow factors was then made in the development of: (1) a falling-head technique for measuring seepage and hydraulic conductivity of bottom material in canals, reservoirs, recharge pits, etc., with cup-type devices, (2) a double-tube method for measuring saturated hydraulic conductivity in situ above a water table with two concentric tubes in an auger hole, and (3) an analysis of the error in the infiltration rates determined with buffered cylinders if the water levels in cylinder and buffer are not the same. The more significant features of these developments were discussed. Examples of application of the methods were presented. (Abs. in Jour. Geophys. Research.)

1962c. Measuring soil permeability above a water table, and analyzing ground-water mound behavior with a resistance network analog, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div, Southwest Br., Ground-Water Recharge Lab., 3 p.

This contribution reports on two projects in progress at the U.S. Water Conservation Laboratory, Tempe, Ariz., which relate directly to ground-water recharge, particularly to planning and executing research or investigation type programs in this field. The two projects are: (1) measuring soil permeability above a water table, and (2) analyzing ground-water mound behavior with a resistance network analog. (DJG)

1963a. The flow system below a water spreading basin [with French abs.]: Internat. Comm. Irrig. and Drainage Cong., 5th, Tokyo, Japan, Trans., v. 6, question 18, p. 89-106.

The flow system between a recharge basin and the lower mound may consist of a number of perched mounds and percolation zones. The flow conditions governing formation and recession of individual mounds can be of considerable complexity. With a resistance network analog, nonuniformities and complexities in soil and boundary conditions can be taken into account. Solutions may be obtained regarding rise, fall, or equilibrium state of mounds above original water tables and perching layers for two-dimensional or axial symmetric flow systems. (From author's summ.)

1963b. (and Rice, R. C.). Seepage meters in seepage and recharge studies: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 89, no. IR–1, pt. 1, p. 17–42.

A falling-head theory and field procedures are presented for measuring seepage and hydraulic conductivity of bottom materials in canals or ponds with seepage meters. Manometer techniques are used for measuring falling head. The method is applicable to uniform bottoms and to material that is underlain by much more, or much less, permeable soil. In addition, hydraulic impedance of thin, slowly permeable layers can be measured. Examples are presented showing the application of the technique to investigation of seepage and recharge, and in field evaluation of artificial soil sealants for reducing seepage. (Abs. in Am. Soc. Civil Engineers Trans.)

1967. Field measurement of saturated hydraulic conductivity in initially unsaturated soil [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 243–251.

The paper discusses recent developments for measuring essentially vertical hydraulic conductivity, *K*, in the zone between soil surface and the water table. Seepage meters are suitable for measuring *K* of bottom material (including impedance of clogged surfaces) and local infiltration rates and gradients in spreading basins. A newly developed permeameter-type device enables relatively rapid field measurement of *K* and the negative soil-water pressure whereby *K* undergoes its first reduction. The method is applicable to surface and subsurface soil layers and data are obtained for sorption as well as for desorption. Field experiences with the double tube method will be summarized and certain desirable design and operational features will be presented. Relatively deep *K*-measurements can be made by determining infiltration rates and gradients at the bottom of auger holes and wells. Fast-reacting piezometers which enable pressure measurement shortly after insertion were developed for this purpose. The paper concludes with a brief discussion how the *K*-data obtained can be used in analytical, analog, or digital models for predicting total flow system below spreading basins, including infiltration rates, or transmission losses from ephemeral streams. (Author's abs.)

Brewer, Elijah

1959. Ground-water replenishment in the San Joaquin Valley, Central Valley Project, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 53.

Results of surface spreading of imported water from Millerton Lake are discussed. (DJG)

Broadhurst, W. L.

1955a. (and Willis, G. W.). Rains activate recharge experiment: Cross Section, v. 1, no. 12, p. 1.

In the High Plains a recharge well experiment using runoff accumulation in a playa lake for injection is described. Injection rates ranged from a high of 1,050 gpm to a low of 200 gpm. After 8 days about 13 acre-feet were recharged. (WK)

1955b. (and Willis, G. W.). Recharge experiment successful: Johnson Natl. Drillers Jour., v. 27, no. 5, p. 5–6.

See Broadhurst, W. L., 1955a.

1957a. Experiment recharge well taking over one million gallons of water per day: Cross Section, v. 3, no. 11, p. 3.

Artificial recharge tests through a well with surface-water runoff from a playa lake in the High Plains of Texas are described. Injection rates decreased as the formation clogged with sediment. Pumping only once a day to remove sediment indicated that a recharge rate of 920 gpm could be maintained. (WK)

1957b. Another recharge well does the job: Cross Section, v. 4, no. 2, p. 2–3.

Playa-lake water near Lubbock, Tex., was used in recharging 210 acre-feet of water through a recharge well in a 41-day period. Variation in injection rate is illustrated. (WK)

1960a. Practices on the High Plains of Texas *in* Ground-water recharge and conservation: Am. Water Works Assoc. Jour., v. 52, no. 12, p. 1491–1492.

The situation concerning water supply and natural recharge ir the High Plains of Texas was described. Artificial recharge tests through wells from surface-water runoff in a playa lake were discussed as were reports on the sediment problem encountered with playa-lake water and the use of chemicals to flocculate suspended solids in the water. (DCS)

1960b. Recharge well used in conducting flocculating chemical test: Cross Section, v. 7, no. 2, p. 1.

A recharge well which took 1,153,000 gallons of playa-lake water during a 49-hour test in Lubbock County, Tex., is described. Aerial application of a liquid flocculant prior to recharge did not significantly affect the suspended-sediment concentration—apparently as a result of calm wind conditions. (DJG)

1962. High Plains Water District tries centrifuge in artificial recharge studies: Cross Section, v. 9, no. 3, p. 1.

A mechanism for removing all suspended matter from playa-lake water prior to recharge in the High Plains of Texas was tested. The results of the tests indicated the centrifuge-like mechanism was inadequate. (WK)

Brown, P. G.

1965. Potential uses of reclaimed municipal waste water *in* Bienn. microbiology symposium, 2d, Anaheim, Calif., 1964, Proc.: Am. Petroleum Inst., Paper 18, p. 144–155.

A need is stated for closer working relationships between petroleum engineering and sanitary engineering personnel, particularly as to use of reclaimed domestic sewage and industrial waste for industrial purposes, including oil-field repressurization. Listed potential uses of reclaimed sewage and domestic wastes which are described include agricultural reuse, recreational reuse, industrial reuse, and indirect general reuse. Emphasis is placed on necessary quality and treatment of such reclaimed water for artificial injection into aquifers supplying water for general purposes. A description is given of a proposed project in Orange County, Calif., similar to the successful demonstration in Los Angeles County, to create a ground-water mound and trough to halt a dangerous intrusion of ocean water into the valuable ground-water basins underlying the coastal plain of Orange County. (Tulsa Univ., Inf. Services Dept.)

Brown, S. G.

1963. Problems of utilizing ground water in the west-side business district of Portland, Oregon: U.S. Geol. Survey Water-Supply Paper 1619–O, 42 p., tables.

Water from the Troutdale sand and gravel aquifer and the underlying Columbia River basalt aquifer is being used for cooling and heating purposes and for industrial uses. Water levels are declining even though some of the water is recharged through wells.

In some places, cooling water withdrawn from the Troutdale aquifer is recharged to the basalt aquifer, while in other places just the opposite is practiced. As a result of these practices and from leakage of connate water from underlying marine beds, the water quality of the aquifers has been impaired.

The data presently available indicate that with continued uncoordinated increases in pumping and artificial recharge, the problems mentioned above probably will increase. (DJG)

Bruington, A. E.

1959a. Progress on barrier to sea water intrusion: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 85, no. IR–3, pt. 1, p. 89–96.

The west coast barrier project in the area of Manhattan Beach, Calif., was described. Geologic and engineering studies, water supply, and proposed facilities were discussed. (DCS)

1959b. The west coast barrier project and spreading in the Montebello Forebay, Los Angeles County, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 71–76.

Tentative plans resulting from a geologic and hydrologic investigation in the Redondo Beach area call for using untreated Colorado River water and possibly reclaimed Hyperion effluent injected through wells into the permeable "Gardena zone" to create a fresh-water barrier. Water-spreading operations in the Montebello Forebay area using imported and local water are described. (DJG)

1965. (and Seares, F. D.). Operating a sea water barrier project: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 91, no. IR–1, pt. 1, p. 117–140.

A 1.5-mile section of fresh-water barrier protecting a part of a coastal ground-water basin in Los Angeles County, Calif., has successfully been in operation for 10 years. Several modifications have evolved in the basic design of recharge wells and appurtenant facilities. The existing facilities, and proposed changes for new works, were described. Cost information was included on the drilling of recharge and observation wells. Maintenance of barrier facilities has presented problems regarding corrosion of metallic materials and clogging of recharge wells. The methods of alleviating or dealing with these situations, or both, were examined and specific applications of nonmetallic materials were described. Cost of maintenance was presented. The amount of supplemental chlorination required for continuous operation of the wells has been determined to be on the order of 2 mg/l. Factors contributing to clogging of the wells are examined and results of studies to evaluate the interrelationships of these factors were presented. (Abs. in Am. Soc. Civil Eng. Trans.)

1967. The amelioration or prevention of salt water intrusion in aquifers—experience in Los Angeles County, California, *in* Salt-water encroachment into aquifers, pt. 2, Baton Rouge, Louisiana, 1967, symposium: Louisiana Water Resources Research Inst., Louisiana State Univ., 12 p.

The uncompleted pressure ridge systems in Los Angeles County are creating barriers against sea-water intrusion as they were planned to do. The cost of such protection is high but is partially offset by the return of the injected water for use in the ground-water basin. The success of such a system depends upon a thorough knowledge of the aquifer geology, the availability of a firm supply of good quality water for injection, and the cooperation and control of those who pump from the basin. Equipment, maintenance, and costs are covered in detail. (From author's conclusions.)

Brune, Gunnar

1966. Recharge of the Edwards limestone reservoir, Texas; presented at the annual meeting of the Association of Engineering Geologists, Anaheim, Calif., October 19–23, 1966: Fort Worth, Tex., Soil Conserv. Service, South Regional Tech. Service Center, 26 p.

The Edwards limestone ground-water reservoir in southwest Texas is divided into two parts: an unconfined reservoir and an artesian reservoir. The Balcones fault zone has an important effect upon the movement of the ground water.

Recharge structures such as dams, wells, shafts, and natural openings which have been built are described. The Corps of Engineers' presently recommended program of six large recharge reservoirs would put an additional 63,900 acre-feet annually into the reservoir.

The Soil Conservation Service has assisted with installation of 75 floodwater retarding and ground-water recharge structures in the area. These are estimated to have increased the annual recharge by 17,000 acre-feet. A complete SCS program would increase this figure to 215,000 acre-feet.

Values of $7 to $10 per acre-foot are believed realistic for water recharged into the unconfined reservoir. In the artesian reservoir, because of the dwindling supply, a value of $38 per acre-foot is justified. (From author's abs.)

Buchan, Stevenson

1955. Artificial replenishment of aquifers: Inst. Water Engineers Jour., v. 9, no. 2, p. 111–141.

Experiences of the following countries in using artificial replenishment to supplement ground-water resources are reviewed: Australia, Canada, Great Britain, Germany, Holland, Sweden, Switzerland, and the United States of

America. Possibilities of using artificial recharge in England are discussed. (DJG)

1957. Increase of ground-water resources by artificial recharge: Jour. Sci. Food and Agriculture, v. 8, p. 616–624.

The author discusses the advantage of artificial recharge, the geological factors to be considered before an aquifer is replenished, the sources of recharge water and the preliminary treatment to be used for recharge. Methods of infiltration and abstraction of artificial ground water are described. The Rivers Thames, Trent, and Severn are considered as sources of water for recharge. (Abs. in Selected Bibliog. of Hydrology, United Kingdom, for the years 1955–59.)

1958. Replenishment of aquifers by artificial methods, *in* Symposium on ground water, Calcutta, India, 1955, Proc.: India, Central Board of Geophysics, Pub. 4, p. 327–334.

Considerations in artificial recharge such as preliminary hydrogeological investigations, sources and pretreatment of recharge water, methods of recharge, and derived benefits from artificial recharge practices are reviewed. (DJG)

1964. The problem of ground-water recharge—artificial recharge as a source of water: Inst. Water Engineers Jour., v. 18, no. 3, p. 239–246.

Practices and results of recharge operations in the United States are reviewed. Recharge operations in England with emphasis on the natural purification effects of some geological formations when being recharged with sewage are discussed. Future recharge programs utilizing the Bunter Sandstone of Nottinghamshire and the Chalk Formation are considered. (DJG)

Buhler, H. V.

1958. The importance of modern large water-supply plants for water supplies of the lower Rhine industrial region—hydrological knowledge and experience: Deutsche Gewasserkundliche Mitt., "Special No.", p. 34–40.

The author discusses water requirements and ground-water conditions in the industrial region of the lower Rhine, with special reference to the Moers district. Types of wells are described giving details and diagrams of three recently introduced types. An account is given of an investigation made to chemically determine the proportions, at different levels of the Rhine, of Rhine water reaching wells. (Abs. in California Univ. Water Resources Center Archives Rept. 13.)

Buras, Nathan

1964. Conjunctive operation of a surface reservoir and a ground-water aquifer: Internat. Assoc. Sci. Hydrology Pub. 63, p. 492–501, tables.

A conceptual framework was developed for the problem of operating surface storage facilities in conjunction with ground-water aquifers. The complex physical system was reduced to a simplified mathematical model, which was cast as a problem in sequential decision-making. This problem was analyzed using the method of dynamic programming and indicating the form of the computational solution. (From author's summ.)

California Assembly Interim Committee Reports, 1961–63

1962. Ground-water problems in California—a report of the Assembly Interim Committee on water to the California Legislature: Assembly of the State of California, v. 26, no. 4, 48 p.

This report is partially an educational document intended to explain ground-water management problems for the legislature and the public by evaluating the ground-water management tools now available in California and by synthesizing the various technical disciplines involved into a comprehensive, integrated treatment of all facets of ground-water management. From its 2-year study, the committee concludes that local, basinwide districts can best replenish overdrawn ground-water basins by using revenues collected through replenishment assessments to: (1) finance purchase of water for spreading, (2) equalize the burden of using high-cost imported surface supplies with low-cost ground water, and (3) transport surface supplies of water whenever ground-water basins have inadequate transmission capacity. The objective is maximum utilization of the low-cost ground-water basins without destroying the basins. (From letter of transmittal.)

California Department of Water Resources

1958. Reclamation of water from sewage and industrial wastes—progress report, July 1, 1953–June 30, 1955: California Dept. Water Resources Bull. 68, 24 p.

The report presents basic data concerning sewage treatment facilities and the status of reclamation projects. Proposed waste-water reclamation projects include using reclaimed water to supply injection wells to prevent sea-water intrusion and spreading basins to recharge the San Luis Rey ground-water basin. (DCS)

1959. Orange County land and water use survey, 1957: California Dept. Water Resources Bull. 70, 57 p.

Ground-water recharge was discussed in a general way within the text as concerns overdraft of supplies, imported water, and waste-water reclamation. (DCS)

1961a. Feasibility of reclamation of water from wastes in the Los Angeles metropolitan area: California Dept. Water Resources Bull. 80, 155 p.

The bulletin contains detailed descriptions of methods and procedures followed in the investigation. Artificial ground-water recharge by spreading, including areas where it can be accomplished, pollution considerations, recharge capacities of spreading grounds, and other aspects, was discussed. Appendix A contains a bibliography, and appendix B contains examples of waste-water reclamation projects which include artificial recharge. (DCS)

1961b. Clear Lake-Cache Creek Basin investigation: California Dept. Water Resources Bull. 90, 267 p.

The bulletin includes a discussion of planned operation of ground-water storage involving conservation of runoff by diverting surplus winter flows in Cache Creek for ground-water replenishment by artificial spreading basins, infiltration from canals and laterals, or winter irrigation. (DCS)

1961c. Water supply conditions in southern California during 1959–60: California Dept. Water Resources Bull. 39–60, v. 1, 87 p., table.

This report on southern California summarizes artificial recharge data. During the 1959–60 water year, a total of approximately 273,000 acre-feet of local and imported water was reported as being spread or injected at 51 projects. Approximately 211,000 acre-feet of this amount, or about 77 percent consisted of imported Colorado River water. (WK)

1964. Water supply conditions in southern California during 1961–62: California Dept. Water Resources Bull. 39–62, v. 1, 92 p., tables.

This report contains a summary of artificial recharge for the water year 1961–62 when approximately 520,000 acre-feet of local and imported water were reported as being spread or injected at 40 ground-water recharge projects. Of this total amount, about 398,000 acre-feet or 77 percent consisted of imported Colorado River water. This represented approximately a 100 percent increase over the amount spread during the previous year. Most of this imported water was spread in the Montebello Forebay area of the Anaheim Basin in Orange County.

The artificial recharge activities played an important role in retarding the decline of water levels in the basins. The measured or estimated amounts of water spread during 1961–62 are tabulated. (WK)

1966. Planned utilization of ground-water basins: California Dept. Water Resources Bull. 104, 435 p., app. C, tables.

The planning of artificial recharge by spreading and injection is discussed in this comprehensive report. Operational-economic information on a wide range of plans that will assist agencies to achieve the maximum utilization of ground-water basins in coordination with surface storage and transmission facilities is presented. Imported water will be used in injection projects which will assure continued protection of the ground-water basins by the maintenance of fresh-water barriers in the coastal plain. This imported water will also be used for spreading and placing the water in storage for transmitting it through the ground-water basin to the point of ground-water use. Details of these techniques and tabulations of data are presented. (WK)

1967. Ground-water measurements, appendix C, *in* Hydrologic data, 1965—Southern California: California Dept. Water Resources Bull. 130–65, v. 5, 477 p.

Appendix C tabulates ground-water measurements taken in the Central Coastal, Los Angeles, Lahontan, Colorado River Basin, Santa Ana, and San Diego Drainage Provinces from July 1, 1964, through June 30, 1965. The tabulations list water surface elevations at wells, along with State well numbers, ground surface elevation at wells, depth to water from ground surface, date of measurement, and name of agency supplying the data.

Recharge activities for the 1964–65 water year are given. Foldout maps depict drainage provinces, boundaries of hydrologic areas, and areas of water-bearing sediments. (Author's abs.)

California Department of Water Resources, Division Resources Planning

1958. Sea-water intrusion in California: California Dept. Water Resources Bull. 63, 91 p., 31 plates, tables.

The bulletin contains a comprehensive report and review of the aspects of salt-water encroachment. A description of areas of known sea-water intrusion in California was presented. Methods of intrusion control were enumerated including direct recharge of overdrawn aquifers and maintenance of the resulting fresh-water ridge above sea level along the coast. Experimental studies pertinent to the subject of recharge of ground-water through injection wells and surface spreading were reviewed. Operations of the West Coast Basin experimental project in Los Angeles County were presented. Laboratory experiments performed by the University of California, Berkeley, were reported as well as a review of other experimental studies on ground-water recharge in other States. Appendixes to the report were: (1) "Status of sea-water intrusion," (2) "Report by Los Angeles County Flood Control District on Investigational work for prevention and control of sea-water intrusion," West Coast Basin experimental project, Los Angeles County, (3) "Laboratory and model studies of sea-water intrusion," and "An abstract of literature pertaining to sea-water intrusion and its control," and "Review of formulas and derivations for the equilibrium rate of seaward flow in a coastal aquifer with sea-water intrusion," (4) "An investigation of some problems in preventing sea-water intrusion by creating a fresh-water barrier," and (5) "Preliminary chemical quality study in the Manhattan Beach area, California." (DCS)

California Division Water Resources

1955. Water conditions in California: California Division Water Resources, 1955.

This report is one of a series that summarizes water conditions in California. It contains a table in the appendix listing basic data or artificial recharge of ground-water basins—South Coastal area. The table includes such information as spreading-ground areas, source of water supply, agency operating the facility, and the quantity of water spread. (WK)

California State Water Resources Board

1955. Water utilization and requirements of California: California State Water Resources Board Bull. 2, v. 1, 227 p.

Artificial recharge of fresh water by well injection to prevent salt-water intrusion along the coast of California is mentioned briefly. (WK)

California University Sanitary Engineering Research Laboratory

1954. Investigation of travel of pollution: California State Water Pollution Control Board Pub. 11, 218 p.

This study of travel of pollution from direct recharge used a well field consisting of a 12-inch gravel-packed recharge well and 23 6-inch observation wells located in Richmond, Calif. The wells penetrate a confined aquifer, about 5 feet thick, overlain by about 90 feet of overburden. Both fresh water and water degraded with settled sewage were injected at various rates. Rates of travel of recharged water were determined by chemical, bacteriological, and radiological means. The nature of well clogging was determined, and methods of well redevelopment were studied. (WK)

1955a. Report on laboratory and model studies of sea-water intrusion: California Univ. Sanitary Eng. Research Lab. Tech. Bull. 11, 44 p.

Theoretical relationships were derived which give the distances above sea level to which the piezometric surface must be raised in order to halt intrusion, as well as the amount of seaward fresh-water leakage to be expected under these conditions for an aquifer of known characteristics. Also, a theory was developed which shows that a line of injection wells required for aquifers under different hydraulic conditions can be predicted.

To confirm the theories, a model aquifer was constructed. The salt water was distinguished from the fresh by fluorescent dyes, and the interface could be observed both in a plane through an injection well and in a plane midway between injection wells. Experimentally, the sea water was observed to enter the aquifer as a wedge along the lower boundary and to move to an equilibrium position which depended on the seaward rate of fresh-water flow. The position and movement of this intruded sea-water wedge were recorded for various rates of seaward fresh-water flow and also for various rates of overdraft. Later the effect of injecting fresh water into the zone of intrusion and into the aquifer inland from the sea-water interface were observed. Preliminary studies were also made of a pumping trough, using the model wells to extract water from the aquifer in amounts sufficient to intercept all the intruding sea water. (From author's summ.)

1955b. An investigation of sewage spreading on five California soils: California Univ. Eng. Research Lab. Tech. Pub. 12, 53 p., tables.

Infiltration data were obtained for both water and sewage spreading on five permeable California agricultural soils under lysimeter conditions. The bacterial and chemical quality of the effluents from 3-foot columns of each soil were determined. Additional information was secured on the mechanism of soil clogging, the nature of bacterial buildup in soil, and the effect of a commercial soil conditioner on infiltration rates. (From author's summ.)

1955c. Studies in water reclamation: California Univ. Sanitary Eng. Research Lab. Tech. Bull. 13, 65 p., tables.

This report attempts to bring together and evaluate the pertinent studies conducted in water reclamation, primarily through the procedure of artificial recharge. The methods and some statistics of recharge by spreading and injection are reviewed; tabulated data of infiltration rates and pollution travel are cited. The report concludes with an appraisal of the engineering and economic aspects. (WK)

California Water Pollution Control Board

1955. A survey of direct utilization of waste waters: California Water Pollution Control Board Pub. 12, 80 p.

The paper presents a general survey concerning utilization of waste water and includes a section on its use for recharge in the United States. (DCS)

1957. Third report on the study of waste-water reclamation and utilization: California Water Pollution Control Board Pub. 18, 102 p.

Various aspects of waste-water reclamation and use are presented including artificial ground-water recharge. Recharge of sewage effluent at Victorville, Calif., and activities of the Los Angeles County Flood Control District concerned with recharge by water spreading are discussed. (DCS)

California Water Quality Control Board

1966. Waste-water reclamation at Whittier Narrows: California Water Quality Control Board Pub. 33, 100 p.

A comprehensive study directed toward determining the effects of intermittent percolation through soil in the Whittier Narrows area on the quality of ground water is reported. Wells were monitored, test spreading basins were constructed, and soil columns were studied in the laboratory. A review of ground-water recharge literature is included. (DCS)

Charmonman, Srisakdi

1967. (Carstens, M. R., and May, G. D.). A fresh-water canal as a barrier to salt-water intrusion [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 374–382.

The seepage flow pattern is determined for flow from a fresh-water canal which parallels the sea. Numerical results are presented for cases in which the fresh-water seepage from the land is a small fraction of the fresh-water seepage from the canal. In other words, the fresh-water flow from the canal acts as a dam forcing the interface between the sea water and the fresh water down to a lower elevation. The solution of Laplace's equation is obtained by numerical methods for this flow situation with the boundary conditions involving a water table and a density interface. The possibility of using a fresh-water canal for agricultural reclamation of sea-water intruded deltas and marshes is discussed. (Authors' summ.)

Chase, R. W.

1955. California ground-water replenishment bill: Am. Water Works Assoc. Jour., v. 47, no. 4, p. 383–388.

A bill (Assembly bill 2699) of the California Legislature intended to provide legal machinery for creation of districts or zones to implement artificial ground-water recharge is discussed. (DCS)

Chun, R. Y. D.

1967. (Weber, E. M., and Mido, K. W.). Planned utilization of ground-water basins—studies conducted in Southern California [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 426–434.

The methods and significant findings of the Los Angeles study on planned utilization of ground-water basins are presented in the paper. Use was made of a nonlinear mathematical model to simulate the dynamic behavior of the ground-water basin which was tested utilizing geologic and hydrologic data from other studies. Formulation of alternative plans of operation for a ground-water basin include consideration of the controllable factors of location, amounts and timing of extractions, and artificial recharge. Cost analyses were made for each plan of operation, and the results were discussed. It is stated that the techniques presented are adaptable for use in studies in any area of the world. (DCS)

Clarke, F. E.

1962. Industrial re-use of water: Indus. and Eng. Chemistry, v. 54, no. 2, p. 18–27, table.

The requirements of water for industrial use are discussed, and it is suggested that every industry and most individual plants can reduce their primary water needs by process improvement, water conservation, and return water reuse. One special type of return water reuse, ground-water recharge, is considered. Methods and problems of artificial recharge are briefly described, and examples for specific areas are given. (WK)

Clarke, J. H.

1959. Ground-water recharge activities in Santa Clara Valley, Calif., *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br. p. 77–81.

As provided in the seventh bond issue of 1957, 400 acres of spreading grounds are to be acquired in addition to the 100 acres now receiving recharge water via canals and pipelines from reservoirs designed to store 140,400 acre-feet of winter flood water. Considerations in the selection of these new spreading grounds are discussed, and results of percolation tests are given. Problems encountered during recharge operations and limited work with inverted wells are also discussed. (DJG)

1962. Problems and their solutions in ground water recharge activities in Santa Clara Valley, Calif., *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 7 p.

Selection of 315 acres of new spreading ground was guided by percolation measurement records and well log data. The increased efficiency of the present transmission lines and recharge facilities accomplished by concrete lining of the canals, elimination of aquatic vegetation by use of the chemical Aquilan, and suspended-sediment removal by use of Separan AP–30 is discussed. (DJG)

Clendenen, F. B.

1957a. Conjunctive use of surface- and ground-water reservoirs, *in* Conf. on water spreading for ground-water recharge, Proc.: California Univ. Water Resources Center Contr. 7, p. 61–68.

Artificial recharge is included in the general discussion of the conjunctive use of surface- and ground-water reservoirs in California. (WK)

1957b. Ground water problems—physical and economic, *in* Conf. on legal problems in water resources: California Univ. Water Resources Center Contr. 9, p. 143–151.

Part of the paper deals with artificial recharge. It is discussed in conjunction with utilization of ground-water storage reservoirs. Deliberate and incidental artificial recharge occurrences are defined. (DCS)

Clyma, Wayne

1960. (and Jensen, M. E.). Flocculent used to remove sediments from playa lake water used for ground-water recharge: Texas A&M College, Texas Agr. Expt. Sta. Prog. Rept. 2144, 7 p.

By using a commercial flocculent, Separan AP–30, the amount of silt plus clay entering a recharge well in a 24-hour period was reduced 49 percent. The quantity of silt plus clay removed from the well during the 1-hour pumping cycle after recharge was 2.4 percent of the amount that entered the well. The combination of the flocculent and pumping cycle resulted in 50.2 percent less sediment in the well compared with 7–10 percent removed using the pumping cycle alone. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1961. (and Broadhurst, W. L.). Clarification of playa lake water by aerial application of a flocculating agent: Texas A&M College, Texas Agr. Expt. Sta. Prog. Rept. 2168, 6 p.

Dusting playa lakes with a nontoxic, synthetic, organic flocculent removed 43–93 percent of the silt and clay in the water. Wave action caused by wind

mixed the flocculent, and settlement of the sediments resulted. The clarified lake water is used for ground-water recharge. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1963. Ground-water hydrology: Agr. Eng., v. 44, no. 2, p. 82–83.

A summary of papers on ground water is presented. Included are papers concerned with an analysis of two-dimensional ground-water mounds created by artificial recharge from surface basins, a study of the effect of pit geometry on outflow from recharge pits, and a discussion of problems faced by public districts in managing artificial recharge programs. (DCS)

1964. Artificial recharge by a multiple-purpose well: Texas A&M Univ., Texas Agr. Expt. Sta. Misc. Pub. 712, 4 p.

A study of runoff-water recharge through a modified irrigation well was reported. Untreated water from a playa lake, excepting one test, was injected through the well, and pumping tests were carried out to determine the quantity of sediment removed by pumping and the effects of sediment on well yield. Prior to one test, the lake was dusted with a flocculant. Specific capacity of the well was reduced to 10 percent of its original value and subsequent redevelopment returned the well yield to one-third its original value. (DCS)

Coe, Jack

1957. Water-spreading activities of the California Department of Water Resources, *in* Schiff, Leonard, ed., Conf. on water spreading for ground-water recharge, Proc.: California Univ. Water Resources Center Contr. 7, p. 8–13.

A very brief description of projects in California dealing with artificial recharge by water spreading is presented. (WK)

Cohen, Philip

1966. (and Durfor, C. N.). Design and construction of a unique injection well on Long Island, New York, *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–D, p. D253–D257, table.

An injection well of unique design and construction recently completed on Long Island, N.Y., will be used in making a series of artificial recharge experiments with highly treated sewage-plant effluent. The well, about 500 feet deep, consists of two adjacent fiberglass casings (18 inches and 4 inches in diameter) and seven auxiliary pipes, four of which are made of fiberglass and three of polyvinyl chloride. Fiberglass was used because of its advantageous chemical and strength characteristics. A stainless-steel well screen, 62 feet long, is attached to the bottom end of each casing. Water will be injected into the aquifer through the large casing and screen, and hydraulic-head changes will be measured at several points within the well and filterpack. Geochemical reactions related to the head changes will be monitored by means of instruments in each screen. (Authors' abs.)

1967. (and Durfor, C. N.). Artificial-recharge experiments utilizing renovated sewage-plant effluent—a feasibility study at Bay Park, New York, U.S.A. [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 193–199.

The U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works, is conducting a series of artificial-recharge experiments on Long Island, N.Y. The experiments are designed to obtain scientific and economic data needed to evaluate the feasibility of injecting highly treated sewage-plant effluent into a proposed network of "barrier" injection wells that are intended to prevent or retard the landward movement of salty water from the Atlantic Ocean into major aquifers beneath Long Island.

A tertiary sewage-treatment process has been developed to upgrade the quality of the effluent so that it meets the requirements that are commonly accepted for potability in the United States. In addition, a uniquely designed experimental injection well and injection plant have been completed. The injection-well complex, which is about 500 feet deep, consists of two adjacent fiberglass casings that surmount stainless-steel screens and of seven auxiliary plastic pipes. The casings and pipes, equipped with remote-sensing down-hole geochemical probes, permit the measurement of hydraulic-head changes and related geochemical changes at several points within the injection well and the filterpack.

Data from the experimental injection well and from 13 nearby observation wells are providing information regarding several aspects of the proposed artificial recharge, most notably: (1) the design and hydraulic characteristics of injection wells, (2) hydraulics of the leaky artesian aquifers, and (3) geochemical controls on artificial ground-water recharge through wells. (Authors' abs.)

Columbus, Nathan

1966. The design and construction of Hele-Shaw models: Ground Water, v. 4, no. 2, p. 16–22.

This paper deals with the model most frequently used in ground-water studies, the vertical Hele-Shaw model. Both the water table and the piezometric surface may be observed visually and recorded with photographic equipment whether the problem involves the steady or the unsteady state. Since the model is transparent, the progressive movement of stream lines can be studied with the use of injected dye. The Hele-Shaw model has recently been used in place of sand models because of some of the advantages listed. One such important advantage of the Hele-Shaw model is in studies involving two liquids with two differing viscosities and specific weights. By dyeing the liquids, the movement of the interface can be studied and problems of salt-water intrusion solved satisfactorily. Although a variety of flow situations can be studied with a Hele-Shaw model, it is most advantageous with problems involving two-phase flow. Sea-water intrusion, tidal fluctuations, and recharge through variable permeabilities are some of the problems that can be studied effectively. (Tulsa Univ., Inf. Services Dept.)

Committee on Ground-Water, Irrigation and Drainage Division, American Society of Civil Engineers

1961. Ground-water basin management, Chapter IV—Recharge and withdrawal: Am. Soc. Civil Engineers Manual of Eng. Practice No. 40, p. 72–98.

A comprehensive presentation of the considerations in planning, site selection, method selection, design, operation, and maintenance of artificial recharge operations is given. Costs and benefits are discussed. An appendix is included containing a tabulation of information pertaining to selected research studies undertaken between 1950 and 1958. (DCS)

Cooper, H. H.

1966. (Bredehoeft, J. D., and Papadopulos, I. S.) Response of a finite-diameter well to an instantaneous charge of water [abs.]: Am. Geophys. Union Trans., v. 47, no. 1, p. 86.

A solution is presented for the change in water level in a well of finite diameter after a known volume of water is suddenly injected or withdrawn. A set of type curves computed from this solution permits a determination of the transmissibility of the aquifer. (Tulsa Univ., Inf. Services Dept.)

Costa, J. A. da

1960. (and Bennett, R. R.). The pattern of flow in the vicinity of a recharging and discharging pair of wells in an aquifer having areal parallel flow [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 52, p. 524–536.

A theoretical analysis of the flow patterns in the vicinity of recharging and discharging wells is presented. The relationships describing the flow patterns are important because of the need to dispose of various liquid contaminants, such as some types of radioactive waste, and the return of ground water after it has been warmed from use in air conditioning. (DCS)

Cox, E. R.

1967. Geology and hydrology between Lake McMillan and Carlsbad Spring, Eddy County, New Mexico: U.S. Geol. Survey Water-Supply Paper 1828, 48 p., table.

In a section concerning dam sites, the possibility of using 45,000 acre-feet of storage in the Seven Rivers Formation between Lake McMillan and Major Johnson Springs in conjunction with a low dam appears to be the most favorable means of increasing terminal storage for the Carlsbad Irrigation District. Pumping from wells in the area would supply water while inducing recharge by the Pecos River through sinkholes under Lake McMillan and through the openings of Major Johnson Springs. (DJG)

Crawford, P. B.

1966. Importance of chemical composition of the injected water on effective permeability: Producers Monthly, v. 30, no. 6, p. 11–12.

According to F. O. Jones, Jr. (Pan American Petroleum Corp.), the influence of the chemical composition of water on flooding is a most important item. The cation exchange state of a clay mineral has a strong bearing on its capability to disperse and affect permeability. Clays in the sodium exchange state resist dispersion upon exposure to fresh water. Owing to phenomena related to ordinary mass-action behavior, calcium and magnesium are accepted more readily than sodium by the clays. The result is that comparatively small portions of divalent cations are able to maintain clays in a substantially divalent cation exchange state in the presence of large excesses of sodium ion on the solutions bathing the clays. The laboratory work has shown that as little as a tenth of the salt solutions being divalent cation salts is sufficient to prevent trouble. Often as little as a twentieth suffices. Consequently, potentially sensitive cores can be exposed to fresh water with little significant change in permeability if the required proportions of divalent cation are present in both native and invading waters. (Tulsa Univ., Inf. Services Dept.)

Cronin, J. G.

1961. A summary of the occurrence and development of ground water in the Southern High Plains of Texas: Texas Board of Water Engineers Bull. 6107, 104 p.

See Cronin, J. G., 1964.

1964. A summary of the occurrence and development of ground water in the Southern High Plains of Texas with a section on Artificial recharge studies, by B. N. Myers: U.S. Geol. Survey Water-Supply Paper 1693, 88 p., tables.

Artificial recharge experiments have been conducted in many parts of the High Plains using the water that collects in the playa lakes during the periods of high rainfall. The method of recharge has been injection through wells drilled near the lakes. Experiments have shown that perhaps as much as 80 to 90 percent of the water caught in the lakes can be injected through wells to be stored in the ground-water reservoir for future use. (From author's abs.)

Crooke, H. W.

1958. A method of financing ground water replenishment: Am. Soc. Civil Engineers Proc., Irrigation and Drainage Div. Jour., v. 84, no. IR–4, pt. 1, Paper 1860, 14 p.

A program of financing ground-water replenishment by a dual tax structure in which a replenishment assessment or charge for each acre-foot of water extracted from the ground-water basin provides the major source of revenue. This program has provided the necessary funds to import sufficient water to stop the continued depletion of the underground water basin in Orange County, Calif., and to start replenishment of the historical accumulated overdraft. The legal and practical procedures used to institute and administer the program are outlined in the paper. (Author's synopsis.)

1959. Success from pump tax program to replenish underground basin: Western City, v. 35, no. 3, p. 24–25,27, tables.

This article describes the results of artificial recharge in the Orange County Water District. During the past 2 years, 267,500 acre-feet of Colorado River water was imported some 275 miles into the district. More than 185,500 acre-feet of this water was used for artificial recharge; as a result the average water levels in 3,200 wells have been raised 10.5 feet. (WK)

1961. Ground water replenishment in Orange County, California: Am. Water Works Assoc. Jour., v. 53, no. 7, p. 831–838.

The development and management operation of ground-water recharge by spreading is described. Recharge of imported water from the Colorado River was accomplished, in an expanded program, to halt the decline of ground-water levels and salt-water encroachment. Water spreading operations are carried out in the Santa Ana River channel and other smaller spreading sites outside the river channel. Water levels have risen substantially in a part of the area but near the coast there was no appreciable change. (DCS)

1962. (and Toups, J. M.). Ground water basin management and artificial recharge in Orange County California, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.:

Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 8 p.

The three main areas of activity for protection of the Orange County Water District's ground-water supply are discussed in detail and consist of: (1) protecting the rights of the inhabitants and land owners of the district to the natural waters of the Santa Ana River watershed, (2) obtaining maximum importation and use of water outside the watershed for both direct use and ground-water replenishment to supplement the deficient supply of local water and repel sea-water intrusion, and (3) encouraging maximum beneficial use of the present water supply. (DJG)

1963. Financing a ground water replenishment program as part of ground water basin management in the area of Orange County Water District, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 6 p.

The water management program of the Orange County Water District and financing of water acquisitions for replenishment program are described against the background of the great transition which has been taking place in the economy of the area. (DJG)

1965. (Toups, J. M., and Aley, T. J.). Ground water recharge means "Progress Insurance" in Orange County, California: Water and Sewage Works, v. 112, no. 7, p. 257–261, table.

This is a popularized article in which the authors discuss financing, operating procedures, and future problems of ground-water recharge. (WK)

1966. Ground water replenishment in Orange County Water District, *in* Doneen, L. D., ed., Symposium on agricultural waste water, Davis, Calif., 1966, Proc.: California Univ. Water Resources Center Rept. 10, p. 222–230, table.

Major problems in the extensive ground-water replenishment program of the Orange County Water District are briefly discussed. Of considerable interest is the description of the recharge facility, known locally, as the Crill Pit. This recharge pit covers 65 acres and is being excavated to an ultimate depth of 50 feet and is planned to accept 300 cfs of water for recharge. Flooding of this incompleted facility with imported water has produced problems of decreased infiltration rates because of the building of fine-grained sediments on walls and floor of the pit and the establishment of a ground-water mound that extended to the base of the pit. (WK)

1967. Planning and providing an adequate supply of water for Orange County, California, *in* Salt-water encroachment into aquifers, pt. 2, Baton Rouge, Louisiana, 1967, symposium: Baton Rouge, Louisiana State Univ., Louisiana Water Resources Research Inst., 18 p., tables.

A comprehensive account of the Orange County Water District activities, historical and present, is given. A major activity is artificial recharge for both supply storage and prevention of salt-water encroachment. (DCS)

Cullinan, T. A.

1960. Preliminary study on the movement of silt and clay in a water-bearing formation: Compass of Sigma Gamma Epsilon, v. 37, no. 4, p. 297–314.

One of the problems connected with artificial recharge through wells in the High Plains of Texas is the clogging of the aquifer by suspended particles in the recharge water. The study investigated movement of these particles and their effect on the water-bearing formation. (DCS)

Cullinan, T. A.

1961. (and Reeves, C. C., Jr.). Aquifer clogging by silt and clay in recharge water: Water Well Jour., v. 15, no. 5, p. 14–15, 26, 51, 56–57, 64–65, tables.

The purpose of this investigation was to determine the movement of suspended sediments in recharge water into and out of the Ogallala aquifer in the southern High Plains area, Halfway, Tex. Recharge through a multipurpose well was conducted for 24 hours at an average input rate of 762 gpm. Approximately 40 percent and 20 percent of the original silt and clay respectively was removed by 6 hours of pumping with hourly surging. Results of a comparison of data reveal a decrease in permeability of 10–15 percent over a 14-month period. (DJG)

Curry, R. B.

1962. (and Beasley, R. P.). Flow of colloidal suspensions through porous media as related to reservoir sealing: Am. Soc. Agr. Engineers, Trans. v. 5, no. 2, p. 160–164.

Relationships of porous media particle size, colloidal suspension concentration, and hydraulic gradient were investigated. The porous media was composed of carborundum and the colloidal suspensions of Wyoming bentonite and distilled water. The electrokinetic property of the zeta potential using the Helmholtz-Smoluchowski equation was determined. Particle sizes of the carborundum ranged from 63 to 775 microns; hydraulic gradient ranged from 0.10 to 2.00 inch per inch; and suspension concentrations of 0.10 and 1.00 percent were used. Conclusions included: (1) Mechanical filtering is the main process by which the bentonite particles are removed from suspension by the carborundum column, (2) degree of sealing increased with decreasing particle size, increasing hydraulic gradient, and increasing concentration of the suspension, (3) the shape of the particles of the media had a considerable effect on the sealing process, and (4) the calculated zeta potential of the carborundum can be correlated with the degree of sealing. (DCS)

Dagan, G.

1967. Linearized solutions of free-surface ground water flow with uniform recharge: Jour. Geophys. Research, v. 72, no. 4, p. 1183–1193.

The movement of the water table caused by uniform recharge (spreading) is considered here. The flow is saturated and the aquifer is unconfined and underlain by an impervious bottom. For a two-dimensional flow the recharge applies to a finite interval, and for a three-dimensional flow it applies to a circle and a rectangle. The solutions are derived by an expansion in a small parameter which linearizes the exact equations of flow. Solutions of different cases are obtained by numerical integration. (From author's abs.)

Davis, G. H.

1959. (Green, J. H., Olmstead, F. H., and Brown, D. W.). Ground-water conditions and storage capacity in the San Joaquin Valley, California: U.S. Geol. Survey Water-Supply Paper 1469, 287 p., tables.

Water spreading with surplus water to augment natural recharge in the

Kaweah-Tule, White Poso, and Kern River ground-water storage units is mentioned. (DJG)

1964. (Lofgren, B. E., and Mack, Seymour). Use of ground-water reservoirs for storage of surface water in the San Joaquin Valley, California: U.S. Geol. Survey Water-Supply Paper 1618, 125 p., tables.

Withdrawal of ground water from storage by heavy pumping not only provides a needed irrigation water supply, but it also lowers the ground-water level and makes storage space available in which to conserve excess water during periods of heavy runoff. Infiltration studies made by various agencies along stream channels, canals, and irrigation ditches are summarized as are infiltration measurements made during this study.

Artificial recharge of the ground-water reservoir by deliberate spreading of excess surface water has been effective in five districts. Most of the water is spread in stream channels, canals, and spreading ponds and is dependent principally on the availability of low-cost water. In the North Kern Water Storage District, as much as 63,500 acre-feet of surface water was recharged into the ground-water reservoir in 1 year at infiltration rates ranging from 0.24 to 1.71 acre-feet per acre per day. (Authors' abs.)

Dean, B. T.

1965. The design and operation of a deep-well disposal system: Water Pollution Control Federation Jour., v. 37, no. 2, p. 245–254.

At Pensacola, Fla., a deep injection well is being operated by Chemstrand Co. for the disposal of aqueous process wastes from the manufacture of nylon. The design criteria (especially the casing program), the construction, and operation of this system are described in detail. The geological formations involved in this disposal system are shown in a cross-section map. Disposal is into the lower limestone of the Floridian aquifer. In this aquifer, the direction of flow of formation water is from the surface outcrop in southern Alabama to some subsurface discharge in the Gulf of Mexico. The presumed flow of waste as it is ejected into the well is along this course. Protection is offered by clay layers to the surface strata of sand and gravel, from which potable water supplies are drawn. (Tulsa Univ., Inf. Services Dept.)

Deutsch, Morris

1962. Controlled induced-recharge tests at Kalamazoo, Michigan: Am. Water Works Assoc. Jour., v. 54, no. 2, p. 181–196.

A comprehensive presentation of an induced-artificial-recharge test at Kalamazoo, Mich., was made. Water from a creek that flowed in quantities greater than that which could be recharged naturally was artificially recharged by forming recharge channels and pumping from a lower aquifer inducing water in an upper aquifer above an intervening aquitard to enter the lower aquifer subsequently inducing the surface-water recharge. The data may be used as a guide in other areas where continental glacial drift aquifers are important sources of water supply. (DCS)

1967. Artificial recharge by induced interaquifer leakage [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 159–172.

The Geological Survey and the city of Kalamazoo, Mich., conducted tests to demonstrate the feasibility of recharging an artesian glacial-drift aquifer by inducing leakage to it from a surficial sand aquifer.

Three tests were run by pumping from the lower aquifer under different conditions of recharge: In the first test the head in a small recharge channel replenishing the upper aquifer was allowed to decline; in the second test the head in the channel was maintained by diversion from the creek; and in the third test the channel was greatly enlarged, and the head was maintained at a relatively constant stage. Each succeeding test resulted in higher water levels in the upper aquifer and increased head differences between the upper and lower aquifers, a situation which increased the rate of leakage and raised water levels in the lower aquifer. The rates of leakage from the upper to lower aquifer at the end of the three tests were 1,600, 1,800, and 1,900 gpm, respectively. After 6 years of pumping at the well field under recharge conditions, water levels are in effect the same as at the time of the tests. Through 1965, the quantity of water recharged to the lower aquifer has been at least equal to the amount pumped. (From author's abs.)

De Wiest, R. J. M.

1963. Replenishment of aquifers intersected by streams: Am. Soc. Civil Engineers Proc., Hydraulics Div. Jour., v. 89, no. HY–6, p. 165–191.

The interrelation between surface water and ground water for certain aquifers that are intersected by streams and subjected to water withdrawal by trenches or wells is studied. The presence of relatively thin clayey lenses in these aquifers creates flow conditions similar to those of leaky aquifers.

In Part I, the estimated yield of a proposed ground-water recharge project in the vicinity of Princeton, N.J., is evaluated numerically. It is found that the yield of a pilot trench, as predicted by the author of the recharge project, is a reasonable estimate compatible with calculations made for a mathematical model derived from idealized conditions.

To arrive at this model, a short description is given of the geohydrology of the watershed for which the recharge project is proposed. The parameters entering the model are examined and the use and construction of Green's functions to solve the problems is explained.

In Part II, the same mathematical techniques are extended to solve the problem of the flow to one well or to a group of wells in aquifers with different boundary conditions. The latter solutions will be useful in evaluating alternatives to the proposed project.

Only steady flow is treated herein. (Author's synopsis.)

1965. Geohydrology: New York, John Wiley & Sons, Inc., 336 p.

A section of this volume contains a discussion of artificial recharge and includes a brief history, purposes, methods, and references. Specific data are tabulated for a recharge project in Sweden. (WK)

1967. Artificial recharge through augmented bank storage [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 53–68.

Nonsteady flow is examined for a ground-water recharge project in which rainfall runoff is returned to a water-table aquifer in the vicinity of Princeton, N.J. The recharge is accomplished by damming a river and its tributary and by reversing the hydraulic gradient between the river and its connected ground-water basin.

The increased water level in the rivers would automatically decrease the hydraulic gradient from the ground-water reservoir to the rivers and hence limit the effluent discharge. Simultaneously, the ground-water reservoir would be pumped, and this would make available more storage space for retention of a higher percentage of the winter-spring rainfall or for quick recharge from flash summer runoff. A geohydrologic description of the watershed is given and various physical parameters entering the study are discussed. Use is made of Green's functions to arrive at the solutions.

The steady-state study of the project has been made before. However, it was felt, especially in view of the severe drought conditions in the area during the last few years, that a study of nonsteady flow conditions was necessary to complete the evaluation of the project. (From author's abs.)

Dickason, O. E.

1966. Status and needs in ground water quality management, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, development, and management, 5th, California Univ., Los Angeles, 1965, Proc.: Fresno, Calif., U.S. Dept. Agriculture, 5 p.

The water-quality problems in the field of ground-water development are discussed. In the field of artificial recharge the author suggests that different treatment criteria for renovated water need to be established depending on the recharge methods (deep well injections or surface spreading), nearness of the recharge site to the potential users of the recharged water, and the type of formation being recharged. (WK)

Dolcini, A. J.

1962. Comments on the Porter-Dolwig ground water basin protection law (Senate bill 1440) approved by the 1961 Legislature, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 4 p.

The study of California's ground-water basins at a level of intensity such that competent plans can be formulated for their continued and greater future use in conjunction with developed surface-water supplies is anticipated. (DJG)

Doneen, L. D.

1956. Water quality problem in the Central Valley, *in* Conf. on California ground-water situation, Proc.: California Univ. Water Resources Center Contr. 2, p. 138–145.

The author considers some of the water-quality problems or impact of recharging imported water. The influence these waters may have on the quality in the ground-water basins is unknown. (WK)

Dutcher, L. C.

1966. General geological control for water spreading and disposal activities, *in* Doneen, L. D., ed., Symposium on agricultural waste water, Davis, Calif., 1966, Proc.: California Univ. Water Resources Center Rept. 10, p. 198–202.

Alluvial fan deposits are generally poorly sorted and hence not ideally suited for water spreading; deposits beneath large rivers at the valley margins can best be used for large-scale spreading operations. Such ideal sites are being rapidly put to use and geologic and hydrologic principles must be applied in efforts to find additional suitable sites. (From author's abs.)

Dvoracek, M. J.

1963. (and Scott, V. H.). Ground-water flow characteristics influenced by recharge pit geometry: Am. Soc. Agr. Engineers Trans. v. 6, no. 3, p. 262–265, 267.

The evaluation of geometry of recharge pits and the correlation of its effect upon flow from such pits were studied. Investigation of flow characteristics from 29 model pits was conducted and reported. The flow characteristics included the determination of the division of flow, that is side or bottom, the location of the free water surface, and the amount of flow from each of the simulated recharge pits. The determination of the division of flow was through the use of a dye stream which resulted in a flow line dividing the flow between the side and bottom of the pit. Results obtained should assist in designing recharge pits where geometric proportions will be influenced by economic considerations. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

Edward E. Johnson, Inc.

1966. Ground water and wells: St. Paul, Minn., Edward E. Johnson, Inc., 440 p.

Artificial recharge in connection with conservation and utilizing ground-water resources is reviewed. A brief description of artificial recharge operations in Illinois, New York, California, and Holland is presented. (WK)

El-Rahman Zohdy, A. A.

1964. Earth resistivity and seismic refraction investigations in Santa Clara County, California: Palo Alto, Calif., Stanford Univ. Ph. D. thesis, 142 p.; abs. in Dissert. Abs., 1965, v. 25, no. 7, p. 4087.

The purpose of this study is the location of permeable strata for ground-water artificial recharge. The results of resistivity and a few seismic refraction investigations are reported from five different areas in Santa Clara County, Calif. The refraction profiles at Penitencia area show that the alluvial strata, within the depth of interest, lack a good elastic differentiation. Both Schlumberger and Wenner configurations were used in all areas for resistivity measurements. At Penitencia and San Tomas areas, resistivity measurements indicate buried stream channels. The delineation of an underground brackish-fresh water interface was sought in the Evergreen area; however, due to a thick clay cover, the results of the resistivity study were of limited use. The investigation in the Tully Road area furnishes a field example, the first of its kind, showing the higher resolving power and other advantages of the Schlumberger configuration as compared with the Wenner. (Tulsa Univ., Inf. Services Dept.)

Engler, Kyle

1963. (Bayley, F. H., 3d, and Sniegocki, R. T.). Studies of artificial recharge in the Grand Prairie region, Arkansas; environment and history: U.S. Geol. Survey Water-Supply Paper 1615–A, 32 p., tables.

This report, the first of a series, presents general information about the Grand Prairie region, as related to studies of artificial recharge, and describes the development of the region that has caused it to become a water-problem area. (From authors' introd.)

Esmail, O. J.

1967. (and Kimbler, O. K.). Investigation of the technical feasibility of storing fresh water in saline aquifers: Water Resources Research, v. 3, no. 3, p. 683–695, tables.

Preliminary studies indicate that the underground storage of fresh water in saline aquifers may be feasible from a technical viewpoint. Such a process would involve injection of fresh water, storage until needed, and subsequent production from the same well. This work, based upon theoretical considerations and model studies, leads to a computer technique by means of which the recovery of stored fresh water may be estimated. Calculations involving five hypothetical aquifers indicate recoveries ranging from 25 to 85 percent, depending upon aquifer and fluid properties. Loss of fresh water as a result of both dispersion (mixing) and gravitational segregation was considered. (From authors' abs.)

Esmaili, H.

1966. A solution for determination of aquifer characteristics and unsteady flow through injection wells by numerical methods: Davis, California Univ., D. Eng. thesis, 112 p.; abs. in Dissert. Abs., 1967, v. 27, no. 11, p. 3923–B.

The problem considered in this study is to determine aquifer characteristics and obtain a solution for unsteady flow through injection wells in unconfined and confined aquifers. In order to solve this problem, the basic differential equations of flow are set up and boundary and initial conditions are specified. These equations are nondimensionalized by introducing appropriate dimensionless parameters. The resulting dimensionless differential equations are solved numerically or analytically depending on whether they are nonlinear or linear. From these solutions the volume of revolution created by the area under the piezometric head distribution curve is obtained by numerical or analytical integration. Since the accumulative volume of flow at any time is this volume multiplied by the storage coefficient, the average rate of flow can be calculated. (Tulsa Univ., Inf. Services Dept.)

Falovsky, A. A.

1967. The present state of the study of the problems of ground-water "enrichment" in the Ukrainian S.S.R.: Internat. Assoc. Sci. Hydrology Pub. 72, p. 101–108.

The paper presents a general review of artificial ground water in the Ukranian S.S.R. and is concerned primarily with induced recharge. A map showing the objectives of a ground-water recharge scheme and a table containing tentative distribution of ground-water recharge projects within hydrogeological regions of the Ukranian S.S.R. are included. (DCS)

Farvolden, R. N.

1963. The Driedmeat Lake artificial recharge project *in* Early contributions to the ground-water hydrology of Alberta: Research Council Alberta Bull. 12, p. 76–87.

The paper reports on geologic and hydrologic investigations of the aquifer to be recharged and experimentation with surface spreading and shallow pits. Surface spreading was not feasible but shallow recharge pits over clean gravels gave good results. Artificial recharge of lake water has been carried out since 1958. Economics of the project are presented. (DCS)

Fazold, A.

1967. (Biro, Z., Takacs, S., and Schiefner, K.). Investigations on water quality at artificial recharge of ground water [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 271–277.

The authors carried on research during 5 years on the chemical, biological, and bacteriological changes during artificial recharge of ground water.

They stated that the periodical operation of a new recharge basin has a harmful effect on the water quality and in coarse sandy-pebble ground, the minimal distance between the wells and recharge basins has to be 50 meters.

In the case of short retention of recharge water in the ground, the free carbonic acid, the total hardness, the iron, and manganese are decreasing; the quantity of the dissolved oxygen and the pH value are increasing. During long retention the free carbonic acid and iron content will increase; however, the quantity of dissolved oxygen will not vary and the pH value will decrease.

With biological growth in the recharge water, undesirable biological organisms appear in well water and the consumption rate of potassium permanganate increases.

According to bacteriological research, initial ground-water extractions from period operation of recharge basins reveal a deterioration of water quality. (From authors' abs.)

Ferris, J. G.

1959. Ground water *in* Wisler, C. O., and Brater, E. F., Hydrology: New York, John Wiley & Sons, Inc., p. 184–186.

Recharge methods and considerations are discussed briefly. Examples of spreading and well recharge are cited. (DCS)

Feuerstein, D. L.

1963. Activities of the Sanitary Engineering Research Laboratory, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 3 p.

Studies of tracer investigations, recovery ratio of recharged water, and paths and rates of flow of sewage and surplus water during recharge are described. (DJG)

Fink, B. K.

1961. (and Reddell, D. L.). Gravel-filter system and new recharge well completed by High Plains Underground Water Conservation District: Cross Section, v. 8, no. 2, p. 2–3.

A gravel-filtering system to clarify recharge water in the High Plains of Texas is described. Costs of constructing the recharge-filtering system, exclusive of the well, are tabulated. (WK)

Fletcher, J. E.

1965. (and Bender, G. L., eds.). Ecology of groundwater in the southwestern United States—Symposium, Arizona State Univ., 1961: Tempe, Ariz., Am. Assoc. Adv. Sci., Southwest and Rocky Mtn. Div., and Ariz. State Univ. Bur. Pubs., 74 p., tables.

Five chapters by separate authors give a perspective of ground water in the southwest, its natural recharge, analog computing in arid-zone hydrology, geophysical studies, and artificial recharge which, except for the latter, are cited separately. (From Abs. of North Am. Geology.)

Forkasiewicz, J.

1967. (and Guillaume, M.). Experience d'exploitation de la reserve de la nappe sous-alluvialle et sous-fluviale de la Meuse, au nord de Verdun [Exploitation test on the suballuvial and subfluvial Meuse ground water to the north of Verdun] [in French with English summ.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 143–158.

To provide for increasing water needs of the north and Lorraine industrial areas, we have thought to regulate the seasonal overflows of underground waters in the Jurassic and karstic limestones in the area of Verdun and a survey and tests have been made, the results of which are presented.

Because it is impossible to create a surface reservoir by an elevated dam, it is necessary to utilize the natural subfluvial and suballuvial reservoir constituted of limestone under the valley level. The storage reservoir of the winter overflow will be created by pumping in summer (discharge = 1 million cu m per day) without overdrawing river and alluvial water resources, thanks to natural damping between ground water and surface water and to an adequate disposition of testing wells.

Research work has been carried out for 5 years (1960–65). A punctual and continuous pumping test has been made during 200 days with selective observation of superposed aquifers. (From authors' summ.)

Fowler, L. C.

1962. Electronic analog computers and ground water management in Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 11 p.

The development and theory of an electric analog model of the Coastal Plain of Los Angeles County is explained. Alternate plans of operation which can be coordinated with available imported supplemental sources of water to reach an optimum utilization of the basin's resources are being prepared using information derived from the analog model. (DJG)

1964. (and Valantine, V. E.). The coordinated use of ground-water basins and surface water delivery facilities [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 64, p. 376–383.

Local water resources can be increased by coordinating use of ground-water basins and surface-water delivery facilities. Where pumping has left more available storage space in ground-water reservoirs than that needed for storage of local runoff, the space can be used to store and distribute water imported from other areas and, depending on the storage capacity and aquifer transmissibility, to regulate rates of water deliveries to seasonal, daily, and even hourly peak periods. (Abs. of North Am. Geology.)

Foxworthy, B. L.

1967. (and Bryant, C. T.). Artificial recharge through a well tapping basalt aquifers at The Dalles, Oregon: U.S. Geol. Survey Water-Supply Paper 1594–E, 55 p., tables.

The object of this study was to develop techniques applicable to a municipal program of artificial recharge. A total of 81.4 million gallons of surplus water from the city's treated surface-water supply was injected under pressure into one of the municipal wells during four periods ranging from 8 hours to more than 25 days at an average injection rate of 1,500 gpm. The wells' specific capacity decreased primarily due to viscosity effects produced by colder recharge water and bubbles of air coming out of solution. No buildup of water levels resulted, but geologic and hydrologic conditions preclude escape of substantial amounts of recharge water from the ground water subbasin. (From authors' abs.)

Frank, W. H.

1965. Neve ergebnisse zur verbesserung der kunstbicken grundwasseranrecherung [New findings in the improvement of artificial recharge of ground water] [in Dutch with English summ.]: Water [Netherlands], August, p. 249–253, September, p. 268–271.

The main objective of technological progress should be to adjust the unwelcome disparity of the $O_2:CO_2$ proportion and to prolong the filter run of the various filters in favor of both quantity and quality. Through experiments with the ground-water pilot plant of the Dortmunder Stadtwerke AG, the chemical and bacteriological progress in the sand layers of the filters has been closely analyzed for some years. On account of the recent results, the Dortmunder Stadtwerke AG have developed their system of artificial recharge with prefiltration, in which the water is passed through a biologically reactive sand filter and then intensively aerated on cascades before passing to the infiltration sand bed. Thus a filter effluent with a raised O_2 content and a lower CO_2 content is possible with but a single infiltration. Moreover, the efficiency of elimination from being polluted with oil, filthy waste, and so forth (even radioactivity) has been intensified. The suspended solids in the river water will be removed by a settling chamber which is installed after entrance cascades. To reduce the growth of algae, the filtration basins will not be completely submerged. In addition, the $O_2:CO_2$ proportion will also be improved by an exchange between the pore air of the filter material and the atmosphere. Permanent experiments showed the good effect at a ground-water plant with intermittent aeration in the preliminary filter and periodical feed of the main infiltration basin. (From abs. in Water and Water Eng.)

Frankel, R. J.

1967. Economics of artificial recharge for municipal water supply [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 2°9–301.

A research project was undertaken to determine whether or not waste reclamation could be economically competitive with other water sources for municipal water supply. Numerous advanced waste treatment systems and recycle schemes were evaluated. Waste-water renovation through ground-water recharge proved to be the most feasible solution to reclamation of the effluent of any type treatment plant today.

Further study has evaluated the chemical and physical limitations of artificial recharge using municipal wastes, the economic trade-offs between additional treatment prior to recharge and greater land utilization, and the break-even point for land values as a function of economies of scale. Finally the economics of a particular case study in the arid West of the United States is discussed as well as a proposed scheme for converting the Nation's

Capitol, Washington, D.C., in the humid East from using solely surface-water supplies to using artificial recharge of undeveloped aquifers for future expansion of water supplies. (From author's abs.)

Frink, J. W.

1967. (and Fulcher, M. K.). Effective use of upper Snake River water resources: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 93, no. IR–1, p. 99–112.

Nearly 2,500,000 acres are irrigated in upper Snake River basin. Of these, 1,000,000 have a deficient water supply. An additional 3,000,000 acres of arable land have no water supply. Yet nearly 7,000,000 acre-feet of which 60 percent is ground-water discharge flow out of the area annually. Surface holdover storage sufficient to supply the above lands cannot be identified, and the abundant ground-water supply is mostly beneath presently irrigated lands. Therefore, further development must depend on coordinated surface- and ground-water use, exchange of sources of supply, and artificial recharge. Numerous hydrologic and geographic factors establish limiting parameters within which detailed planning may proceed. Studying the possible layouts and operations of such projects is being undertaken by analog studies of the ground-water reservoir and computer studies of the river system. (Abs. Am. Soc. Civil Engineers Trans.)

Garraud, J.

1965. Conditions d'exploration du dispostif de realimentation de la nappe le long du canal de fuite de Donzere-Mondragon [Operating conditions for the ground-water recharging system along the Donzere-Mondragon plant tailwater canal] [in French with English summ.]: La Houille Blanche, May–June, p. 253–258.

The layout of the diversion works for the Donzere-Mondragon scheme on the Rhone made it necessary to run a 10-km-long tailwater canal through a very fertile alluvial plain. In order to compensate for the estimated fall of 4 m in water-table levels throughout the plain, due to this canal acting as a drain, the Compagnie Nationale du Rhône had ground-water recharging systems provided along both sides of the canal.

A justification of the method adopted by the Compagnie Nationale du Rhône is followed by a summary description of the arrangements provided and the results achieved during the first 12 years of operation, with a few words about the technical and financial condition. (From abs. in Water and Water Eng.)

Garrett, A. A.

1962. Artificial recharge of basalt aquifers, Walla Walla, Washington, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 450–C, p. C116–C117.

Owing to a high air content in the recharge water of Mill Creek, an injection schedule of short period recharge was followed. Results of 11 such short-term runs are presented and discussed with the tentative conclusion being that replenishment of this type offers a successful means of injecting water containing air into basalt aquifers without loss in yield or well efficiency. (DJG)

Garza, Sergio

1959. (and Wesselman, J. B.). Geology and ground-water resources of Winkler County, Texas: Texas Board of Water Engineers Bull. 5916, p. 23.

Artificial recharge of waste water from earthen disposal pits occurred in several parts of the county. The fresh water supply was being polluted by the recharge. The area most heavily recharged was near Kermit, Tex. (DCS)

Glazunov, I. S.

1967. Artificial formation of fresh ground water lenses by means of wells [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 237–242.

In this report, the problems of artificial formation of new fresh ground-water lenses as well as replenishment of existing ones by means of a system of fully penetrating recharge and pumped wells are discussed. The developed technique allows formation of the lateral boundary of a lens to be calculated in time. The calculation relationships have been obtained for the constant and exponentially changing flow of recharge wells. In this case, piston-like displacement of saline water by fresh water is assumed. (Author's abs.)

Glover, R. E.

1967. (Fink, J. W., and Philips, H. B.). Snake Plain analog studies: Am. Soc. Civil Eng. Proc., Irrig. and Drainage Div. Jour., v. 93, no. IR–4, Paper 5670, p. 97–110.

Design, construction, and operation of an electric analog to correlate existing geologic and hydrologic data and to guide future exchange pumping and recharge operations in the Snake River Plain area in Idaho are described. Beneath this plain, fissured lavas form an aquifer of exceptional permeability covering an area of about 12,000 square miles. Ground-water discharge accounts for 4,500,000 acre-feet of the 7,000,000 acre-feet now flowing uncontrolled out of the area each year. The analog will be used to study the possibilities of developing this ground-water reservoir to supply pumped irrigation water and to store excess surface flows as recharge. (Authors' abs.)

Gong-Guy, Georges

1963. Disposal of storm water by ground-water recharge, *in* Schiff, Leonard, ed., Bienn, conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 10 p.

Owing to the absence of natural drainage channels, excavated pit-type recharge basins are used by the California Division of Highways to dispose of storm drainage from depressed roadways in the Fresno to Bakersfield area.

Basins are also being provided for roadways at grade interchange areas to store the increased runoff from added impervious surfacing. Although basin recharge is preferable, well recharge of the storm runoff has also been used extensively. (DJG)

Goot, H. A. van der

1957. Water reclamation experiments at Hyperion: Sewage and Indus. Wastes, v. 29, no. 10, p. 1139–1144.

The paper presents a progress report on water reclamation experiments by the Los Angeles County Flood Control District at the Hyperion treatment plant of the city of Los Angeles. Studies at Whittier and Azusa concerning waste-water reclamation conducted since 1948 were reviewed. A comprehensive account is presented of reclaiming treated sewage by percolating water through filter beds and subsequently collecting the filter-bed effluents for injection into the aquifer through a test recharge well. The effluent from the Hyperion sewage-treatment plant is one of the possible sources of water to supply the requirements of an 11-mile fresh-water barrier to prevent sea-water intrusion. (DCS)

Gray, D. H.

1966. (and Rex, R. W.). Formation damage in sandstones caused by clay dispersion and migration, *in* Conf. on clays and clay minerals, 14th, Berkeley, Calif., 1963, Proc.: London and New York, Pergamon Press (Internat. Ser. Mon. Earth Sci., v. 26), p. 355–366, table.

Severe water sensitivity or loss of permeability was observed in a suite of experimentally flooded sandstones in spite of almost total absence of montmorillonite or swelling mixed layer clays. X-ray diffraction and electron microscopy analysis showed displacement of submicroscopic natural clay crystals of needle-shaped mica and hexagonal-shaped kaolinite, dislodged by change in water chemistry combined with water movement. Flooding sandstone with alkaline metal brines triggered clay dispersion upon subsequent flooding with fresh water; flooding with divalent calcium brine prevented water sensitivity. A double layer expansion effect is suggested as the dispersion mechanism. (From Abs. of North Am. Geology.)

Green, M. G.

1965. Artificial recharge to the Edwards limestone aquifer in south Texas: [abs.] Symposium on hydrology of fractured rocks, sponsored by United Nations Educ., Sci., and Cultural Organization, Internat. Assoc. Sci. Hydrology, Internat. Hydrol. Decade, in Dubrovnik, Yugoslavia, Paper 16.

A plan to artificially recharge the fractured Edwards limestone aquifer of Texas is described. From extensive studies it has been concluded that additional recharge can best be provided in the drainage area by a system of dams on the principal streams that contribute to the Edwards limestone aquifer. From gauge records, it has been estimated that the infiltration rate along the streams in the Nueces River basin where they cross the Balcones fault zone ranges from about 500 to more than 1,000 cfs, which is a contribution of about 64 percent of their flows to the natural recharge of the aquifer. About 128,000 acre-feet per year pass the lower edge of the loss zone. In the San Antonio River basin only about 8 percent or 15,900 acre-feet per year of the average annual resources pass the lower edge of the loss area. In the Guadalupe River basin only one stream is a major contributor to the underground reservoir. This stream has an annual average of only 8,400 acre-feet passing the loss area.

Surface-water reservoirs constructed upstream from and in the Balcones fault zone would provide regulation of the recharge to the underground reservoir. The water would be released from the surface reservoirs at rates not to exceed the infiltration rates along the streams and would be allowed to enter the aquifer through existing natural recharge channels downstream from the dams. (From author's abs.)

Greenberg, A. E.

1955. (McGauhey, P. H.). Chemical changes in sewage during reclamation by spreading: Soil Sci., v. 79, no. 1, p. 33–39.

A study of chemical changes in sewage during the reclamation of water from sewage by spreading is reported. The spreading operation was conducted on Hanford fine sandy loam. Samples were collected and analyzed to a depth of 13 feet. The results indicate that quantitative changes in the liquid were few. The concentrations of calcium, magnesium, sodium, and chloride ions remain the same. Potassium decreased by about 50 percent. Ammonia and phosphates were completely removed within the first 4 feet of vertical water travel. Sulfates and bicarbonates increased by about 200 percent. Explanations for the changes, which were largely due to biological activity in the soils, are proposed. (Authors' summ.)

Grodzensky, V. D.

1967. Formation of fresh ground-water lenses as a result of percolation from canals and pits [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 360–364.

If saline unconfined ground water is of deep occurrence and if the sides and bed of a canal or pit are composed of less permeable rocks as compared with underlying ones, the rocks under the canal or pit are not fully saturated.

For possible conditions of formation of fresh ground-water lenses in this case, analytically obtained calculation relationships are presented. They allow the process of the movement of the fresh- and saline-water interface, the different densities of these waters taken into account, to be predicted. The solutions obtained are analyzed and their validity is verified by using a model similar to a Hele-Shaw model. (Author's abs.)

Groot, C. R.

1960. Feasibility of artificial recharge at Newark, Delaware: Am. Water Works Assoc. Jour., v. 52, no. 6, p. 749–755.

Spreading of water in shallow basins appeared to be the most practical method of ground-water recharge in the area of Newark, Del. The paper reports on a study to obtain infiltration rates utilizing double-ring infiltrometers directed toward determining the feasibility of artificial recharge. (DCS)

Haile, H. H.

1966. Ground water recharge experience in Los Angeles County, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, development, and management, 5th, California Univ., Los Angeles, 1965, Proc.: Fresno, Calif., U.S. Dept. Agriculture, 3 p.

The experiences and problems of the Los Angeles County Flood Control District with spreading and well-injection facilities for recharge are discussed. The major effort of this organization is involved with the surface spreading of local, imported and reclaimed water and the development and operation of barriers to sea-winter intrusion. The writer states that new barrier facilities placed in operation in the past year and a half increased the injection rate to 70 cfs which is 10 times the previous rate.

Problems to be resolved include the handling of silt in local storm waters, reducing land areas required for spreading grounds, elimination of biological nuisances, and well clogging. (WK)

Hall, W. A.

1955. Theoretical aspects of water spreading: Agr. Eng., v. 36, no. 6, p. 394–399.

Effects of variable permeability of the soil with depth on the prolonged submergence infiltration rates are discussed from a theoretical point of view. A method for analysis of a prospective location for water spreading is proposed. One-dimensional infiltration, infiltration into stratified soils, perched water tables, and infiltration with lateral flow are included in the analyses. (DCS)

1957a. (Hagan, R. M., and Axtell, J. D.). Recharging ground water by irrigation: Agr. Eng., v. 38, no. 2, p. 98–100.

Excessive irrigation on alfalfa plots was studied cooperatively by the University of California, Davis, and the Kern County Land Co. It was concluded that excessive irrigation did not affect plant mortality for the treatments imposed and that, subject to the conditions of the study, a considerable volume of water can be returned to underground storage. The continuously flooded plot absorbed 31 acre feet per acre, an average of 4.5 acre feet per acre per week, while for all treatments the average intake was 6.4 acre feet per acre per week. (DCS)

1957b. Perched water tables under an artificial ground-water recharge system: Am. Geophys. Union Trans., v. 38, no. 3, p. 346–347.

Hydrostatic pressure measurements were made at 14 depths below the surface of a large ground-water recharge system. These measurements show the nature of the growth of the perched water tables resulting from the spreading operation. They demonstrate the importance of knowing subsurface stratigraphy for a considerable depth with respect to treatment of the surface soil to improve permeability. These factors also limit the potential capacity of a recharge area. (Author's abs.)

1957c. Water-spreading research by the University of California Agricultural Experiment Station, *in* Conf. on water spreading for ground-water recharge, Proc.: California Univ. Water Resources Center Contr. 7, p. 52–56.

This paper deals with an experiment to study overirrigation of alfalfa during the dormant season. It was concluded that, with the possible exception of the continuously wet treatment, there is no apparent damage to alfalfa under the conditions of the experimental tests. (WK)

Hammad, H. Y.

1961. Seepage losses from parallel canal systems: Am. Soc. Civil Engineers Trans., v. 126, pt. 1, Paper 3102, p. 136–143.

This paper deals with the two-dimensional problem of steady seepage flow under gravity from a system of parallel, identical, and equally spaced canals into a semipervious clay layer of finite thickness underlain by a freely permeable layer of sand and gravel in which the piezometric head is very near the canal water level. Two steps of conformal mapping are used and an approximation to the canal profile is adapted. In this approximation the specified canal width and depth are not changed. (Author's synopsis.)

Hantush, M. S.
1964. Depletion of storage, leakage, and river flow by gravity wells in sloping sands: Jour. Geophys. Research, v. 69, no. 12, p. 2551-2560.

Formulae are obtained for estimating the rate, at anytime after pumping begins, and the total volume, at the end of a period of continuous pumping, of the parts of the well yield that are derived from storage, induced leakage, and induced infiltration from the river and (or) from the natural flow that would have been discharged into the river if the well had not been pumping. It is assumed that the river cuts completely through the sand and flows in a fairly straight course which extends a considerable distance on both sides from the well location. Two cases are considered: A stream cutting across the natural flow and a stream cutting along the natural flow. (From author's abs.)

1965. Wells near streams with semipervious beds: Jour. Geophys. Research, v. 70, no. 12, p. 2829-2838.

Currently used formulas for the drawdown distribution and the rate and total volume of river depletion resulting from wells pumping nearby are based primarily on the assumption that the bed of the stream is as permeable as the aquifer it completely cuts through. These formulas have been empirically modified to be approximately applicable when the stream bed is semipervious and is partially penetrating the aquifer. This modification is based on the assumption that the resistance to flow due to the partial penetration and the semiperviousness of the stream bed can be reasonably replaced by its equivalent owing to flow through a horizontal additional stretch of the main aquifer. This additional length is determined empirically by using pumping-test data in conjunction with the drawdown equation for the substitute system. In the present study, the approach to the problem is to replace the resistance to flow due to the semiperviousness of the bed of the stream by an equivalent resistance due to a horizontal flow through a semipervious layer of insignificant storage capacity which is lying between the aquifer and the channel of the stream. The conjecture is that this approach is closer to reality and, consequently, yields flow formulas that reproduce the flow conditions in the actual system more closely. Except for the unsteady drawdown equation, this approach has led to flow equations that are as easy as their counterparts now in use. Tabulation of the function involved in the unsteady drawdown equation is not difficult, and, once completed, the equation becomes as easy to use as any other simple formula. Quantitative comparison between results of the old and the new approaches are presented graphically. A procedure using the steady-state drawdown equation is outlined for obtaining the transmissivity of the aquifer, the effective distance to the stream, and the "retardation coefficient" of the channel lining. (Author's abs.)

1967a. Growth and decay of ground-water mounds in response to uniform percolation: Water Resources Research, v. 3, no. 1, p. 227-234.

In the artificial recharge of irrigation waters, the response of groundwater mounds to deep percolation is of practical interest. Where the underlying aquifer is infinite in areal extent, the solution of rise and fall of the water table for the circular recharging area is given in terms of a function easily tabulated for a practical range of parameters. Approximate solutions

in terms of already tabulated functions are presented also. For the rectangular recharging area the solution function depends on two parameters. This function is tabulated for a wide range of parameters, which affords a means for relatively simple calculation. The solutions are applicable if the rise of water table relative to initial depth of saturation does not exceed 50 percent. (Abs. of North Am. Geology.)

1967b. Depletion of flow in right-angle stream bends by steady wells: Water Resources Research, v. 3, no. 1, p. 235–240, table.

The flow of a stream hydraulically connected to an aquifer can be reduced by nearby pumping wells. Such pumping will either increase infiltration from nearby streams or decrease the natural flow of ground water into the streams or both. This depletion of stream flow increases perennial yield of the sand to much more than would have been available as ground water alone. Natural streams as well as canals can meet at right angles, such as those in a trellis drainage pattern. Formulas are developed in terms of tabulated functions for estimating rate and volume of such stream depletion by pumping wells, for both domestic and irrigation use. (Abs. of North Am. Geology.)

Harding, S. T.

1955. Statutory control of ground water in the Western United States: Am. Soc. Civil Engineers Trans., v. 120, Paper 2751, p. 490–498.

Control of artificial ground water was discussed as concerns the right to recover the water, restriction of ground-water use, and other similar points. Court decisions in California are cited. It was concluded that there does not appear to be a need for separate statutory control of artificial ground waters. If abandoned, they are subject to the same controls as natural waters, and if provided under conditions in which title to their use is retained separately from the natural supply by an agency, such title should enable their use to be controlled in the agency's interest. (DCS)

Harmeson, R. H.

1959. Pit recharge at Peoria, Illinois, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 40–43.

The two recharge pit operations at Peoria, Ill., are described. Bearing the silt accumulation of a 3-year operation, recharge rates were 35.3 feet per day at Pit No. 1 and 45.3 feet per day at the larger Pit No. 2. (DJG)

1963. (and Vogel, O. W.). Artificial recharge and pollution of ground water: Ground Water, v. 1, no. 1, p. 11–15.

In an attempt at partially counteracting the serious depletion of ground-water resources at Peoria, Ill., a method for artificial replenishment has been developed by the Illinois State Water Survey and used in two well fields. Water taken from the Illinois River is chlorinated and infiltrated into the ground-water aquifers by means of recharge pits.

Potential pollutants of physical, chemical, bacterial, and radioactive nature are present in the river at all times in varying degrees. Possible pollution of the ground water is patently inherent with the artificial recharge process.

Eight years of operating experience have proven the pit method of recharge to be effective in the Peoria area. Substantial quantities of water are recharged annually and existing standards for quality have been met. The results serve to point out problems which are encountered, to emphasize the need for control measures, and to establish trends and effects which may become important in the future. (Authors' abs.)

Harpaz, Y.

1964. (and Bear, Jacob). Investigations on mixing of waters in underground storage operations [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 64, p. 132–153.

At the more advanced stages of water development, ground-water aquifers are being used not only as sources of natural water but also as stores for water introduced by artificial means as reserves under various supply projects. During such underground storage operations, water of varying quality and composition is introduced into the aquifer, and intermixing occurs between the injected water and the indigenous water.

Displacement and mixing phenomena within the ground and in pumping wells are analyzed. Laboratory and analytical studies are described in which solutions have been found for breakthrough times and breakthrough concentrations in wells (assuming immiscible liquids) for various well arrangements as well as for various recharge and pumping regimes. A graphical solution for complex systems is developed and demonstrated.

First results of dispersion studies performed on a sectorial sand model are presented.

Results of recent mixing experiments conducted in productive well fields exploiting limestone and sandstone aquifers are described and analyzed. The effect on the mixing process produced by several factors such as hydrodynamic dispersion, natural ground-water flow, and downward percolation of fresh replenishment water is discussed and evaluated.

The testing of a proposed field technique for determining the mixing characteristics of aquifers (and dispersivity) is reported. (Authors' abs.)

1965. Field experiments in recharge and mixing through wells: Tel Aviv, Tahal—Water Planning for Israel, Ltd., Tech. Rept. 17, Pub. 483, 54 p.

Up to 1964, an extensive program of recharge and mixing experiments was carried out in more than 20 production wells, drilled in sandstone, limestone, and basalt formations. The experiments were aimed at determining: (1) the capacity of the formations and the wells to absorb recharge water, (2) the shape a recharged body of water takes in the aquifer and the way it spreads, and (3) the mixing process that takes place when water which is different from the native ground water is recharged. Injection was found to sustain rates of between 300 and 800 cu m per hr in sandstone wells and of between 1,000 and 2,000 cu m per hr in ordinary limestone wells. Conclusions as to the planning of a controlled underground storage and mixing project are presented. (From author's abs.)

1967. (and Schwarz, J.). Operating a limestone aquifer as a reservoir for a water supply system: Internat. Assoc. Sci. Hydrology Bull., v. 12, no. 1, p. 78–90.

An aquifer can be used not only as a water source but also as a regulating reservoir linked to a water-supply system. Planning the operation of such reservoirs calls for a good knowledge of the characteristics and limitations of the aquifer, an estimate of its natural replenishment and outflows, as well as the determination of a program for pumping and artificial recharge.

A limestone aquifer of karstic nature, heavily exploited and artificially recharged, has been studied recently with respect to its storage capacity and responses to a planned scheme of operations established for the national water-supply systems.

The physical characteristics of this aquifer—its inflows, outflows, and dynamic behaviour—were first determined by geological and hydrological investigations. The dynamic model obtained was then verified and improved by use of a resistor-capacitor electric analog constructed for this purpose. Later on, several operational alternatives were tested on the same analog. An optimization analysis was performed on a simplified single cell model representing the aquifer system. The methodology of such integrational operation is discussed in light of the results obtained. (Authors' abs.)

Hart, D. H.

1957. Feasibility of recharging basalt aquifers in the Walla Walla area, Washington: U.S. Geol. Survey, open-file rept., 35 p., tables.

An experimental artificial recharge program for the Walla Walla area, Washington, is proposed. Water available from Mill Creek is to be injected into a basalt aquifer at an initial rate of about 500 gpm and varied depending upon the evaluated results. The chemical compatibility and biological suitability of the water are discussed as well as the problems of dissolved and entrained air, temperatures, and sediment concentration. (WK)

1958. Artificial recharge to ground water in Oregon and Washington: U.S. Geol. Survey, open-file rept., 55 p., tables.

Nine installations in Oregon and Washington have been used to recharge ground water to replenish the supply, to conserve physical characteristics of the water, or to dispose of excess uncontaminated water. Five of these installations are in Oregon; four are in Washington.

Each year about 100 acre-feet of field drainage is recharged into irrigation wells at Pine Flat, about 200 acre-feet of river water is recharged to augment the pumpage from nearby wells of the Springfield public-supply system, and about 311 acre-feet of exhaust water from two heat-pump installations is recharged at Portland. For several years 43 acre-feet of excess spring water was recharged annually to a public-supply well at St. Helens. Nearly 384 acre-feet of exhaust water is recharged each year from a heat pump at Tacoma and 160 acre-feet at Vancouver. About 160 acre-feet of cooling water is recharged annually to two wells at the Snohomish substation. The Richland city system annually utilizes about 12,000 acre-feet of recharge water of which 2,200 acre-feet is pumped from the Columbia River and the remainder is diverted by canal from the Yakima River. The Richland system uses recharge ponds whereas the other uses injection wells. Artificial recharge has been essentially successful except in one well. (From author's abs.)

Haskell, E. E., Jr.

1963. (Bianchi, W. C., and Pomeroy, C. R.). Low intake rates and rising perched water tables hinder ground water recharge in southwestern Fresno County: California Agriculture, v. 17, no. 9, p. 2–3.

Water intake rates of the soils in southwestern Fresno County are low for recharge purposes. However, extending the period of flooding will allow the movement of considerable depths of water through their profiles to a

perched water table. Pumping from this shallow water table is now limited, and water-table elevations are continuing to rise. This threatening water-table situation, together with the poor quality of the perched water at these sites, makes the practice of surface spreading for artificial recharge undesirable. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1965. (and Bianchi, W. C.). Development and dissipation of ground water mounds beneath square recharge basins: Am. Water Works Assoc. Jour., v. 57, no. 3, p. 349–353.

An experiment is described in which square basins instrumented with observation wells were subjected to continuous water aplication. Buildup and dissipation of ground-water mounds were measured. Permeability below the existing water table was determined from pump tests, and its directional distribution for the plots did not correlate with the center of the mound at equilibrium. (DCS)

Hauser, V. L.

1966. Hydrology, conservation, and management of runoff water in playas on the Southern High Plains: U.S. Dept. Agriculture, Agr. Research Service, Conserv. Research Rept. 8, 26 p.

The paper contains conservation and management plans for runoff water which include artificial ground-water recharge. Discussion in the report concerns, to a large degree, artificial ground-water recharge as a management practice. (DCS)

1967a. (and Lotspeich, F. B.). Artificial ground-water recharge through wells: Jour. Soil and Water Conserv., v. 22, no. 1, p. 11–15, tables.

Surface runoff that accumulated in a playa lake was used to recharge the Ogallala Formation in the southern High Plains area near Bushland, Tex. Before injecting the raw water, 90 percent of its suspended material was removed by flocculation and settling after treatment with a cationic polyelectrolyte and alum. Recharge wells that became clogged were successfully redeveloped by bailing. Sixty-one acre-feet of treated water was recharged in 1965 through 6-inch wells.

Data showed that ground-water recharge is not likely to pollute an aquifer more than a few feet from a recharge well. (DJG)

1967b. (and Signor, D. C.). Water conservation and ground-water recharge research in the Texas High Plains, *in* West Texas water conf., 5th, Lubbock, Tex., 1967, Proc.: Lubbock, Texas Technol. Coll., West Texas Water Inst., p. 41–74; condensed in 1967 in Texas A&M Univ., Texas Agr. Expt. Sta. Misc. Pub. 850, 10 p.

Hydrology and water conservation considerations of the High Plains of Texas were reviewed. Past research on ground-water recharge through wells and current research concerning hydrogeology, water clarification, and recharge through shafts, wells and pits was discussed. An experimental field recharge system utilizing surface runoff water in a playa lake consisting of clarification and injection through wells was described. (DCS)

Havens, J. S.

1966. Recharge studies on the High Plains in northern Lea County, New Mexico: U.S. Geol. Survey Water-Supply Paper 1819–F, 52 p., tables.

Data obtained during this study indicate that about 100,000 acre-feet of water collects in closed depressions on the surface of the High Plains in

years of normal precipitation. Studies of water losses from ponds in selected depressions indicate that between 20 and 80 percent of this runoff recharges the ground-water body and the balance is lost to evapotranspiration, chiefly evaporation. Artificial recharge facilities constructed in the depressions could put at least 50,000 acre-feet of water underground annually that otherwise would be lost to evaporation. Recharging through pits or spreading ponds would cost less per unit volume of water than recharge through wells. Results of well recharge experiments are described. (From author's abs.)

Hazan, R.

1961a. (Chapond, G.). Hydrodynamique des captages s'influençant mutuellement (cas de l'injection) [in French with English summ.]: Internat. Assoc. Sci. Hydrology Pub. 56, p. 321–331.

A study of artificial recharge in the Sais water table (Morocco, Fez region) using two wells is discussed. A hydrodynamical study of the injection in each single working well and of the interaction of the two wells in case of simultaneous injection was made. (Authors' summ.)

1961. Nappes de Berrechid et du Charf el Akab mechanisme d'alimentation et evaluation des resources en eaux souterraines. Recharge artificielle [French with English summ.]: Internat. Assoc. Sci. Hydrology Pub. 57, p. 542–546.

Among other things an application of artificial recharge in the Charf el Akab area is discussed. (DJG)

Hedger, H. E.

1956. Contamination by and control of sea water intrusion, *in* Conf. on California ground-water situation, Proc.: California Univ. Water Resources Center Contr. 2, p. 98–105.

The use of storm runoff and imported Colorado River water for artificial recharge by spreading and well injection in Los Angeles County is described. The present off-channel spreading grounds have a combined percolation capacity of about 1,100 cfs. Off-channel spreading grounds have conserved approximately 1,300,000 acre-feet of local water during the period 1920–55. During the last 3 years 125,000 acre-feet of imported water has been recharged to ground-water basins, and since 1953 about 10,000 acre-feet of imported water has been recharged to ground-water basins, and since 1953 about 10,000 acre-feet has been injected into recharge wells to form a fresh-water pressure ridge to prevent intrusion of salt water. (WK)

Hem, J. D.

1960. Chemical equilibrium diagrams for ground-water systems [with French abs.]: Internat. Assoc. Sci. Hydrology Bull. 19, p. 45–53.

Chemical equilibrium in water in contact with calcite is expressed by means of a pH grid overlay on a log-log plot of activities of bicarbonate versus calcium ions. Solubility of ferrous iron and the solid-phase minerals that would be stable in a solution containing activities of 10 ppm of sulfate and 100 ppm of bicarbonate or related species is expressed by means of a stability-field diagram with pH as abscissa and redox potential as ordinate.

The diagrams can be used to tell whether water injected in recharge wells may form precipitates that could plug the aquifer and have other uses in studies of natural water chemistry. (Author's abs.)

Hennessy, P. V.
1967. (Williams, L. R., and Lin, Y. S.). Tertiary treatment of trickling filter effluent at Orange County, California: Water Pollution Control Federation Jour., v. 39, no. 11, p. 1819–1833.

A pilot program for reclamation of waste water for injection into fresh-water aquifers is in progress in Orange County, Calif. Facilities consist of a full-size injection well and a pilot-scale plant comprising flocculation-clarification procedure and gravity filtration for advanced treatment of secondary effluent before injection. (From abs. in Water Pollution Control Federation Jour.)

Hirshleifer, Jack
1960. (De Havin, J. C., and Milliman, J. W.). Water supply economics, technology, and policy: Chicago, Univ. of Chicago Press, 378 p.

Artificial recharge of ground waters is discussed in appropriate chapters in this book in relation to specific topics of economics, law, and technology. (WK)

Hoffman, J. F.
1956. This diffusion well won't flood: Eng. News-Record, v. 156, no. 10, p. 55–56.

This article describes a "leaching-type" diffusion well which was developed for installation at new buildings of the New York Telephone Co. in Patchogue, Long Island, N.Y., where the requirements were to return 52 to 260 gpm of air-conditioning water in an area having a water table 11 feet below the land surface. It was designed by use of Hazen's formula, relating permeability to grain size, and the Thiem formula. Tests indicate that a 7.5-foot diameter, rock- and gravel-packed well, penetrating 4.5 feet below the water table will return 260 gpm into stratified glacial outwash sand with a water-level buildup of only 8.5 feet—without flooding of the recharge well. (DCS)

Holsinger, Henry
1956. (Murray, A. N., McSwain, Kenneth, Eversen, Burrham, and Harding, S. T.) Factors to be considered in establishing a ground-water policy for California, *in* Conf. on California ground-water situation, Proc.: California Univ. Water Resources Center Contr. 2, p. 177–207.

This panel discussion presents opposing views on the need for legislation in relation to the protection and preservation of the utility of ground-water sources. Artificial recharge is discussed. (WK)

Hoopes, J. A.
1967a. (and Harleman, D. R. F.). Dispersion in radial flow from a recharge well: Jour. Geophys. Research, v. 72, no. 14, p. 3595–3607, table.

The recharge and disposal of treated and untreated waste waters in ground-water aquifers results in a mixing of these waters with the natural groundwater. The distribution and boundaries of the ensuing mixture are determined by the combined mechanisms of convection, dispersion, diffusion, and sorption. In this study, the mass conservation equation for a dissolved substance in two-dimensional ground-water flow is developed. An analytical solution and a numerical solution of this equation are obtained for the radial and temporal distribution of a conservative dissolved substance, which is

injected into a homogeneous isotropic confined aquifer by a single recharging well. Experimental measurements of the concentration distributions of a dilute salt-water tracer support the theoretical considerations. It is found that, for homogeneous media, the dispersed or mixed region may be less than 1 percent of the volume of fluid recharged at distances of only 30–60 m from the well. Finally, from the experimental results it is shown that the dispersion coefficient along the streamlines is the same for both uniform and nonuniform flows at the same velocity. (Authors' abs.)

1967b. (and Harleman, D. R. F.). Wastewater recharge and dispersion in porous media: Am. Soc. Civil Engineers Proc., Hydraulics Div. Jour., v. 93, no. HY–5, p. 51–71.

For steady flow between a recharging and a pumping well, in an infinite confined aquifer of homogeneous, isotopic media, theoretical expressions were developed for the spatial and temporal distributions of a conservative substance, introduced at the recharge well. From these expressions, the relative influences of convection, dispersion, and diffusion on the substance distribution were deduced. To test the analytical results experimental measurements of the distribution of a dilute salt-water tracer on a sand model were presented. The model tests and field problem show that lateral dispersion has a negligible influence on the substance distribution, and molecular diffusion, while not important in the model tests, may be important in field problems. Longitudinal dispersion is important in determining the shape of the tracer distribution within the aquifer, but it has a significant influence on the concentration in the pumping well only for small times when the concentration ratio is less than 0.1. (Abs. in Am. Soc. Civil Engineers Trans.)

Huisman, L.

1965. Hydrologische aspecten van kunstinatige grondwateraanvulling [Hydrological aspects of artificial increase of ground water] [in Dutch with English summ.]: Water [Netherlands], p. 131–138, 143–148.

When more ground water is needed than the safe yield of the catchment can provide, the amount of water entering the aquifer must be artificially increased. This may be accomplished indirectly by local wells and galleries as close as practicable to surface streams with pervious banks (induced recharge) or directly by converging water from another source to points from which it percolates into a body of ground water (artificial recharge). With both methods of artificial ground-water replenishment, care must be taken to prevent a rapid clogging of the area of infiltration and an excessive lowering of the ground-water table. To effect an improvement in the quality of the recharge water to the standard of the ground water, a minimum length of travel and a minimum retention period underground are required. In this paper a mathematical analysis is given of these requirements and the resulting limitation in recharge capacity is formulated. (From abs. in Water and Water Eng.)

1967. Artificial recharge for public water supplies in urbanized regions [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 200–212.

In the field of drinking water, artificial recharge has already been applied for a long time, the main purpose being to transform surface water with varying characteristics into ground water of more constant quality, which will be safe for public supply. In reality, however, the utmost stress is put on the removal of bacteriological pollutions, for which purpose the recharge and recovery works are designed and operated in such a way as to avoid short-circuiting as much as possible. This results in a more or less constant detention period for all the water abstracted, and consequently, variations in physical and chemical characteristics of the raw water are propagated with little or no damping.

Nowadays other reliable means for assuring the bacteriological safety are available, while in densely populated, highly industrialized regions surface streams often carry a large artificial load of chemical pollutants, resulting in a variable composition from high to low flows. This variation, as well as the fluctuation in water temperature, could be smoothed out by a different design of the artificial-recharge system, promoting a strong variation in detention time and, if necessary, even accepting short-circuiting.

The paper tries to outline the problem and gives a few suggestions for possible solutions. As an example, the use of water from the river Rhine for public drinking-water supplies in the Netherlands is considered. (Author's abs.)

Hunziker, L. T.

1964. Aquifer recharging: Water and Sewage Works, v. 3, no. 4, p. 203–205.

This article is one of a general series on ground water and contains a review of artificial recharge programs in various parts of the country. (WK)

Imbertson, N. M.

1959a. Reclaiming the Los Angeles River: Water Works Eng., p. 1089–1091, 1106, 1113.

High turbidities in the Los Angeles River are no longer a deterrent to its diversion into reclamation spreading grounds and its use to supplement the water supply of the city of Los Angeles, nor are stormflows, which formerly swept away wooden diversion dams. Los Angeles has found solutions for both of these problems. Turbidities will be overcome by the use of a flocculating chemical which will preclarify the water and prevent rapid clogging of the recharge basins; floodflows will be saved by use of a deflatable-inflatable rubber dam across the Los Angeles River.

The article describes initial tests made of a product known as Separan 2610, a new synthetic organic polymer to flocculate the colloidal material in storm water and settle it to the bottom of a collecting basin in a matter of minutes, the equipment installed for dosing the water with this polymer, and a 22-day test run of this equipment. (From abs. in Water and Water Eng.)

1959b. Replenishment of ground water with desilted storm water, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 66–70.

After experiments revealed that suspended sediment of storm runoff could be economically and efficiently removed by application of Separan 2610, a collapsible dam was built on the Los Angeles River flood-control channel to divert storm runoff for treatment and replenishment on a 30-acre spreading tract. With no silt restriction, greater quantities of water are now available for recharge. Increasing infiltration rates by pumping out the air from soil beneath water-spreading areas is discussed. (DJG)

1960. Collapsible dam aids Los Angeles water supply: Civil Eng., v. 30, no. 9, p. 42–44.

A giant inflatable nylon bag coated with neoprene is used as a dam to back up water in the Los Angeles River. It thus directs water to a 30-acre spreading ground for recharging the underlying aquifer. (WK)

Jacob, C. E.

1960. Ground-water mounds in two-layered aquifers [abs.]: Jour. Geophys. Research, v. 65, no. 5, p. 1634.

This is a study of flow in systems of two layers, a top one of low permeability and high storativity and a bottom one of high permeability and low storativity, coupled hydraulically across their common interface. Partial differential equations are obtained for nonsteady flow in such a two-layered system into which water is recharged at nonuniform and varying rates over all or part of the aquifer. Various lateral boundary conditions are specified for both linear and radial systems. Finite difference equations are obtained as approximations of the differential equations. Solutions are obtained in certain illustrative cases by electric analog computer. Examples of actual ground-water mounds were studied in light of this theory. (Abs. in Jour. Geophys. Research.)

Jacobsen, J. C., Jr.

1959. Ground water recharge on the Jacobsen Ranch, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 85–86.

A water-spreading operation consisting of seven basins within a 12-acre spreading site receiving diverted river water is described. (DJG)

Jans, Melvin

1959. North Kern Water Storage District spreading activities, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 54–57.

Water-spreading experiments carried out through 1956 resulted in the discontinuing of any further soil disturbance practices such as cultivation or treatments to increase infiltration rates. Flooding on alternate basins, when spreading over an extended period of time to take advantage of rapid infiltration rates of dried basin surfaces, has proven successful. Operation, maintenance, and costs are discussed for the operations since 1957, as is redesign of the operations on the basis of accumulated experience in this field. (DJG)

1962. North Kern Water Storage District recharge activities, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 4 p.

General conclusions resulting from spreading studies are presented. Investigation of alternative methods of ground-water replenishment, such as using natural stream channels as recharge areas, is emphasized. (DJG)

Jenkins, Merchant, and Nankivil, consulting engineers
1955. A program to replenish water resources of the greater Peoria area in Peoria and Tazewell Counties, Illinois: Springfield, Ill., Jenkins, Merchant, and Nankivil, consulting engineers, 279 p.

After study and interpretation of the data developed in this report, construction and operation of a new recharge pit is recommended to solve the immediate water-supply problem in the greater Peoria water area. One of two alternative permanent solutions calls for recharging fully treated Peoria Lake water through horizontal collecting wells operated in reverse. (DJG)

Jensen, M. E.
1959a. Ground water recharge in the High Plains of Texas, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 88–92.

Problems of aquifer clogging due to suspended material, mostly clay, in playa-lake water used for recharge are discussed. Research, with an objective to preserve the performance of multipurpose wells, has resulted in a field-scale model filter now being evaluated as is the use of chemicals to flocculate the sediment. (DJG)

1959b. (and Clyma, Wayne). What happens to sediments in playa lake water when used for underground recharge in wells: Cross Section, v. 5, no. 8, tables, p. 2–4.

Measured quantities of sediment entering a recharge well are compared with measured quantities of sediments removed during the pumping cycle in Hockley County, Tex. (WK)

Johnson, A. H.
1955. Conservation of ground water on Long Island: Am. Water Works Assoc. Jour., v. 47, no. 4, p. 348–354.

Problems of a declining water table and saltwater encroachment on Long Island, N.Y., are described. Diffusion wells have been required to return water from new cooling and air-conditioning wells. Diffusion wells are described and data are given on pumpage and recharge. Open basins and effects of artificial recharge on ground-water temperature are mentioned. (DCS)

Johnson, A. I.
1963. (and Kunkel, Fred). Some research related to ground-water recharge—a progress report from the U.S. Geological Survey, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 17 p.

A model study of infiltration in layered and nonlayered porous material is described. De-aired tap water was introduced through small "cribs" simulating infiltration pits or recharge basins.

Also as part of a continuing study in cooperation with the California Department of Water Resources, appraisal of the geology and hydrology as they relate to various possibilities for recharge of the ground-water reservoir and to the use of the reservoir for cyclic ground-water storage are being investigated in the San Joaquin Valley. (DJG)

1966. (Moston, R. P., and Versaw, S. F.). Laboratory study of aquifer properties and well design for an artificial-recharge site: U.S. Geol. Survey Water-Supply Paper 1615–H, 42 p., tables.

Hydrologic and physical properties of the aquifer used were determined from analyses of samples taken at the recharge well site used in the artificial recharge study at Grand Prairie, Ark., and from nearby test holes. Using laboratory-analysis data, quantitative aquifer characteristics were estimated —a coefficient of transmissibility of 60,000 gpd per foot and a specific yield or coefficient of storage of about 0.34. Laboratory data also were used to predict a specific capacity of 30 gpm per foot of drawdown for the proposed recharge well. (From authors' abs.)

1967. (and Sniegocki, R. T.). Comparison of laboratory and field analyses of aquifer and well characteristics at an artificial recharge well site [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 182–192.

Research on artificial recharge of alluvial deposits by means of recharge wells was carried out in the Grand Prairie region of Arkansas. Extensive test drilling and construction of observation wells within the 24-square-mile research site provided detailed information on the geology and hydrology of the deposits of Quaternary Age.

Aquifer characteristics were determined by means of laboratory analysis of samples collected from the pilot test holes for the recharge wells and by conventional pumping tests in the field. On the basis of the laboratory analyses, a transmissibility of 60,000 gpd per foot, and a storage coefficient of 0.34 was predicted for the recharge test site.

Later pumping tests and recharge tests in the field confirmed that the values of transmissibility predicted from laboratory analysis were comparable to those obtained by the field test. Slow drainage from the fine-textured portions of the aquifer resulted in a change of storage coefficient with time. However, the field data showed that the storage coefficient probably would have reached the value predicted by laboratory analyses if the field tests had been run for a much longer period of time.

The authors conclude that laboratory analysis of water-bearing materials can and should be used in conjunction with field tests in developing design and operational criteria for recharge wells. A more thorough understanding of the hydrologic system under injection conditions will result. (Authors' abs.)

Johnson, C. E.

1957. Utilizing the decomposition of organic residues to increase infiltration rates in water spreading: Am. Geophys. Union Trans., v. 38, no. 3, p. 326–332.

Percolation rates of soil mixed with organic residues varied with the amount of material applied, decomposition rate of the material, and the length of the incubation period. These studies indicate that initial decomposition at a moisture content near field capacity followed by decomposition at saturation may produce the highest infiltration rate for a given amount of organic residue. Infiltration rates on 0.005-acre test ponds are presented. The use of organic residues to increase infiltration rate of water spreading areas is discussed. (From author's abs.)

1959a. (and Schiff, Leonard). Activities of the ground water recharge research project, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 11–17.

During experiments on infiltration rates in ponds, the authors found that ground water of 7.5 to 10.0 me/l total salts infiltrated 2 to 2.5 times as fast as Kern River canal water with 1.2 to 2.5 me/l total salts. While addition of gypsum or sulfuric acid did not increase the infiltration rate of the low salinity Kern River water, additions of ferric sulfate at concentrations of 3 me/l or 7 me/l were very effective in increasing infiltration when applied continuously.

Experimental results of well recharging with river water filtered through flumes containing aquifer sand ≤ 0.5 mm in size were compared with control models recharging unfiltered river water during the same period. (DJG)

1959b. Recharge research plans of the Soil and Water Conservation Research Division, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 103–105.

In a broad investigation concerning replenishment and utilization of underground storage, particularly in the San Joaquin Valley, objectives include: (1) characterization of sites as to their suitability for recharge, (2) study of ground-water replenishment by irrigation, and (3) concern with the quality of the water reaching the water table. A combination laboratory-field approach will be used. (DJG)

Johnson, Michael

1967. (Lundeen, E. W.). Alamitos barrier project—Resume of geohydrologic investigation and status of barrier construction: Eng. Geology, v. 4, no. 1, p. 37–49.

To prevent sea-water intrusion into ground-water aquifers in the Alamitos Gap area, Long Beach, Calif., a fresh-water barrier is being constructed. This consists of recharging the aquifer and developing a fresh-water mound by a line of injection wells inland from the zone of exposure of Recent fluvial deposits, which are in contact with the aquifer and with tidal waters, and by lowering the Recent zone water level, seaward of the injection well alignment, by a series of pumping wells. The barrier was placed across Alamitos Gap in an arc from the most inland margin of the exposure zone into the Seal Beach fault, a natural barrier, at each end. Recharge line operation, though incomplete, has resulted in a pressure rise at all observation wells and considerable freshening in all intruded zones of the aquifer. (From Abs. of North Am. Geology.)

Johnson, Philip

1967a. (Crawford, D. A.). An investigation of the effect on the mechanism of hydraulic formation fracturing in water injection of a sandface filter cake deposited from water carrying high colloidal and solid suspensions of organic and/or inorganic origin: Lubbock, Tex., Texas Technol. Coll., Dept. Petroleum Eng. Research Rept., Research Proj. 191–5408, 71 p.

This report describes an investigation of surface-water recharge into sand of the Ogallala Formation of the southern High Plains of west Texas. Theoretical and laboratory investigations were carried out to determine the mechanics of sand-plugging and fracturing in porous media. A research well was drilled and instrumented. Two recharge operations were performed and reported. (DCS)

1967b. (Crawford, D. A.). An investigation of the effect on the mechanism of hydraulic formation fracturing in water injection of a sandface filter cake deposited from water carrying high colloidal and solid suspensions of organic and/or inorganic origin: Lubbock, Tex., Technol. Coll., Dept. Petroleum Eng. Research Rept. 2, Research Proj. 191–5408, 18 p.

A recharge well previously utilized for gravity recharge experiments was modified to provide for pressure injection of water into the Ogallala formation to cause fracturing or disperse accumulations near the well bore in order to improve water intake rates. Pressure injection was performed with a 400 gpm flow rate at 40 psi. No fracturing was evident. Almost 2000 gpm recharge was obtained at 85 psi and the pressure subsequently reduced to a stable level of 50 psi.

Laboratory investigations pertaining to the use of chemical flocculents were made. Conclusions included that: (1) the Ogallala Formation was not fractured but that the colloidal material was removed from the well bore into the formation, and (2) colloidal or suspended material in playa-lake water may be successfully pumped into highly permeable and porous sections of unconsolidated sand formations. (DCS)

Kahana, Yona

1964. Coastal groundwater collectors as a means of intensifying exploitation of groundwater: Internat. Assoc. Sci. Hydrology Pub. 64, p. 182–193.

A method is described of increasing the yield of coastal aquifers by groundwater collectors installed close to the sea coast. These collectors are to intercept fresh water escaping into the sea above the interface between salt and fresh water. A suitable form of collector is that of a series of closely spaced shallow wells.

The intensified exploitation of ground water is achieved with no significant additional intrusion of sea water inland. The interrelation between rate of pumping, distance of collector from coastline, and depth of filters is examined.

The optimum utilization of coastal aquifers including the utilization of one-time reserves and artificial recharge for the underground storage of water are analyzed and discussed. (Author's abs.)

1966. Some aspects of ground water management, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, development, and management, 5th, California Univ., Los Angeles, 1965, Proc.: Fresno, Calif., U.S. Dept. Agriculture, 4 p.

Ground-water management to protect the fresh-water aquifer from sea-water intrusion in the coastal area of Israel is discussed. (WK)

Katz, D. L.

1968. (Coats, K. H.). Underground storage of fluids: Ann Arbor, Mich., Ulrich's Books, Inc.

The book is written primarily for engineers, geologists, and managers, who are engaged in studies preparatory to developing storage projects, for those

who have responsibilities in designing the facilities, and for personnel who operate facilities for storing fluids, either liquids or gases. Many ideas or concepts involved in storage operations are presented at the layman's level prior to engaging in the more technical material. The book brings together many pieces of information needed for those who wish to understand the development, design, and operation of storage projects. The book does not pretend to be a treatise on the subject, but rather a representation of the experiences and interests of the authors. (From authors' preface.)

Katzer, M. F.

1959. Data reveal flocculating chemical clears lake water of most suspended matter: Cross Section, v. 6, no. 1, p. 2–3, tables.

A flocculating chemical, when mixed properly with playa-lake water near Hart, Tex., caused the suspended clay and silt particles to redeposit. Relatively free from sediment, the treated lake water is more suitable for artificial recharge through wells. (WK)

Kaufman, W. J. (ed.)

1961. Conference on ground disposal of radioactive wastes: Berkeley, California Univ., Sanitary Eng. Research Lab., 168 p., tables.

This series of papers reviews progress made in research and development studies related to ground disposal of radioactive wastes over the past few years, both in the United States and abroad. Major subjects include: (1) operating practices, experiences, and problems at Hanford; Oak Ridge National Reactor Testing Station; the Savannah River Plant; Chalk River, Ontario Canada; Saclay, France; and Mol, Belgium; (2) research on ion exchange and adsorption in natural media; and (3) current investigations of hydrodynamic problems of flow through porous media.

Methods of waste disposal discussed include spreading, well injection, and the use of pits, trenches and cribs. Disposal rates are tabulated. (WK)

Kazmann, R. G.

1958. Problems encountered in the utilization of ground-water reservoirs: Am. Geophys. Union Trans., v. 39, no. 1, p. 94–99.

Ground-water reservoirs are compared to surface-water reservoirs and the similarities and differences are pinpointed. The differences give rise to social and engineering problems which are not duplicated elsewhere in the field of water-resources development. Examples of problems encountered in utilization of ground-water reservoirs are cited. As case histories, problems of industrial ground-water supply in the area of East St. Louis and of municipal ground-water supply in the area of Canton, Ohio, are discussed. (From author's abs.)

1967. Perspectives in artificial recharge *in* Marino, M. A., ed., Symposium on ground-water hydrology, San Francisco, Calif., 1967, Proc.: Urbana, Ill., Am. Water Resources Assoc., Proc. Ser. 4, p. 188–192.

The paper outlines the opportunities and obstacles of artificially recharging partially depleted aquifers to provide permanent water supplies that are safer and more reliable than most now in operation.

Aquifers are independent sources of water that can be "mined," but also they are functional for the natural filtration, distribution, and storage of water. Surface storage is discussed in the light of sedimentation considerations, and it is concluded that the loss of surface reservoir capacity will affect

the water economy of an area in the same manner as depletion of an aquifer. The uses of surface storage volume indicates that the least important reason for the "mining" of reservoir sites has been the storage of water for municipal and industrial use. Flood control, hydroelectric power, and irrigation account for 90 percent of all surface storage. From the long-range viewpoint presented, that men will always have to store water in times of plenty for use in periods of drought, a reexamination of the potentialities of aquifers as reservoirs is required.

The advantages of aquifers as reservoirs for cyclic storage are enumerated and present day technology is discussed. (DCS)

Kehr, Dietrich

1957. The sewage of Mexico City [abs.]: Technique de l'Eau, v. 11, p. 36.

The problems of land subsidence in Mexico City due to ground-water pumpage could be eased by recharging with treated effluent. (Abs. in Texas Water Devel. Board Rept. 8)

Kelly, T. E.

1967. Artificial recharge at Valley City, North Dakota, 1932 to 1965: Ground Water, v. 5, no. 2, p. 20–25, table.

Valley City obtains a daily average of 750,000 gallons of water from wells in partly confined gravel deposits in the Sheyenne River Valley; deposits have a maximum thickness of over 50 feet and areal extent of about 1 square mile. Since 1932 the aquifer has been artificially recharged by diversions of water from the river to an abandoned gravel pit, during which time the piezometric surface in the aquifer has been raised more than 22 feet with a gradual increase in quality of water. Prior to 1958 the recharge system was operated from January to June, discontinued when the piezometric surface rose to within 8 feet of the surface; following which it declined as ground water was withdrawn. Annual fluctuation was 10 feet, the change in storage about 1,000 acre-feet. Since 1958 the recharge system has been operated throughout the year. (Abs. of North Am. Geology.)

Kemper, W. D.

1967. Evaluating methods of ground water recharge: Colo. Agr. Exp. Sta., Colorado State Univ., Fort Collins, Colo., Prog. Rept. PR211, 2 p., table.

The paper is a description of the progress achieved in the study of sand and gravel mulches which reduce evaporation and allow more of the incident rainfall to percolate to the ground-water reservoir. Evaporation was reduced to less than 5 inches per year, a fact indicating that under a 17-inch-per-year rainfall, a foot of water could be recharged. If plant growth were prevented and a gravel mulch treatment lasted for 20 or 30 years, the cost of recharging the ground water might be in the vicinity of $10 per acre-foot. On gravelly soils, where the gravel could economically be extracted and left on the surface, ground-water recharge would be immediately practical. (DCS)

Key, A.

1957. The recharge of ground water—problems and dangers: Jour. Sci. Food and Agriculture, v. 8, p. 605–610.

This paper points out that although the artificial recharge idea is simple in principle, it is not so simple in practice but requires the most careful thought and investigations. (WK)

Klaer, F. H., Jr.

1963. Bacteriological and chemical factors in induced infiltration: Ground Water, v. 1, no. 1, p. 38–43.

The lowering of ground-water levels by pumping from horizontal or vertical wells near a surface stream may cause water to move from the stream into the water-bearing materials by the process known as induced infiltration. In such cases, the natural deposits of sand and gravel serve as large natural filter beds effectively removing or reducing turbidity, organic matter, and pathogenic bacteria. This paper discusses the general processes by which such removal is accomplished as well as the significance of certain changes in chemical characteristics of the water as it passes from a surface source to an underground point of collection. By a better understanding of the processes involved, the bacteriological and chemical quality of infiltrated water supplies can be improved. (Author's abs.)

Knézék, M.

1964. (and Zajícék, V.). Realisation de l'exploration hydrologique dans la problematique de l'infiltration et l'accumulation artificielle des eaux souterraines [Utilization of hydrological research in problems of artificial recharge and artificial storage of ground water] [with French summ.]: Internat. Assoc. Sci. Hydrology Pub. 64, p. 414–423.

The paper reports on the importance of correct determinations of hydraulic conductivity and effective porosity in the evaluation of infiltration areas for artificial recharge. Laboratory and field methods for determining hydrogeologic conditions suitable for artificial recharge as well as storage of ground water are presented. Method verification was carried out by research on the watershed of the Jizera River through means of a pilot plant infiltration system. Time of retention as it concerns removal of organic matter was investigated. (DCS)

Korver, John A.

1966. Fluid flow from nuclear chimneys: Water Resources Research, v. 2, no. 2, p. 297–310.

To assess the feasibility of using nuclear explosives to create large underground rubble chimneys into which liquid wastes can be injected, a predictive capability has been developed by matching laboratory model studies with mathematical analogs. The effects of varying permeability, porosity, input flow rates, and chimney dimensions were examined; variations between laboratory and methematical model results were less than 10 percent. This paper describes the laboratory model studies of two hydrologic environments, the development of the mathematical models, and the numerical solutions obtained with the latter. Also summarized are two examples of potential applications of nuclear explosives to the field of waste disposal; results indicate that for many selected hydrologic conditions, it is feasible to use the rubble chimney in permeable but unsaturated formations. (Abs. of North Am. Geology.)

Kramer, M. C.

1963. Vector control considerations in ground-water spreading, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 4 p.

Vector control methods, particularly in the case of mosquitoes and gnats, require slight modification of water spreading practices and are described. (DJG)

Krieger, J. H.

1955. Progress in ground water replenishment in southern California: Am. Water Works Assoc. Jour., v. 47, no. 9, p. 909–913.

Water rights, The Water Replenishment District Act (Assembly bill 2,908) and an act to compel the recording of water extractions and diversions (Senate bill 1,557) of the State of California are discussed. (DCS)

Krone, R. B.

1957a. McGauhey, P. H., and Gotaas, H. B.). Direct recharge of ground water with sewage effluents: Am. Soc. Civil Engineers Proc., Sanitary Eng. Div. Jour., v. 83, no. SA–4, Paper 1335, 25 p., tables.

Mixtures of settled raw sewage and water were used to recharge a 5-foot thick confined aquifer located 95 feet underground. Observations of pressure and of pollution travel were made in 23 sampling wells surrounding the recharge well. The bacterial pollutants traveled a maximum of 100 feet in the direction of normal ground-water movement even though steep gradients were imposed. The maximum distance of travel was quickly reached, but intensity of pollution regressed as the aquifer face in the recharge well became increasingly clogged. An injection rate (8.4 gpm per foot of aquifer) equal to the best reported for fresh-water recharge was found to be practical. With mixtures of fresh water and 20 or 27 percent primary sewage, recharge well redevelopment was necessary after 7 to 9 days of recharge. About half a day was required for redevelopment and a maximum of 4 percent of the recharged water was returned to the surface in the process. After a brief settling period this water was suitable for re-injection. (WK)

1957b. Water spreading research by the Sanitary Engineering Research Laboratory, University of California, *in* Schiff, Leonard, ed., Conf. on water spreading for ground-water recharge, California Univ., Berkeley, 1957, Proc.: California Univ. Water Resources Center Contr. 7, p. 21–25.

When a suspension is applied to a water-bearing medium, the travel of bacteria through porous media with ground-water flow is limited by straining developed in the clogged zone, and beyond the clogged region, by straining and sedimentation in the soil pores. The infiltration rate is determined by the permeability of the clogging solids at the soil surface. The penetration of these solids into the soil surface depends on the pressure difference applied across the clogged region. (Author's summ.)

Landon, R. A.

1967. Geologic studies as an aid to ground-water management: Illinois Geol. Survey Environmental Geology. Note 14, 9 p.

Geologic studies of areas suitable for natural and artificial ground-water recharge have been conducted in the Chicago region on regional and local scales, based on maps, well records, and borings filed with the State Survey. Sand and gravel bodies in glacial deposits and underlying Silurian dolomite were the principal aquifers considered, with the former acting as a recharge medium for the latter. Selected sand and gravel deposits occurred in stream valleys and were at least 20 feet thick, with 15 feet below stream level. The Park Forest-Chicago Heights study is given as an example. (From Abs. of North Am. Geology.)

Larson, T. E.

1957. (Suter, Max, and Vogel, O. W.). Recharge of ground water at Peoria, Illinois: Water and Sewage Works, v. 104, no. 11, p. 488–491.

During experiments in recharge of chlorinated Illinois River water through infiltration pits, observation shows that most of the recharge takes place through the sides of the pit. Construction of an adjacent pit interfered very little, and changing to a pea-gravel lining increased the recharge rate. Success of this experimental pit has stimulated the construction of two other pits in the Peoria area by private industry. Findings from 6 years of study are discussed. (DJG)

Laverty, F. B.

1955. (Goot, H. A. van der). Development of a fresh-water barrier in southern California for the prevention of sea water intrusion: Am. Water Works Assoc. Jour., v. 47, no. 9, p. 886–908.

A comprehensive review of the fresh-water barrier project to halt salt-water encroachment at Manhattan Beach in the West Coast Basin, Los Angeles County, Calif. is given. Recharge-well construction and operation are described and results are presented. (DCS)

1957. Water spreading activities of the Los Angeles Flood Control District *in* Schiff, Leonard, ed., Conf. on water spreading for ground-water recharge, California Univ., Berkeley, 1957, Proc.: California Univ. Water Resources Center Contr. 7, p. 14–20.

A general review of the water spreading and conservation activities of the Los Angeles Flood Control District is given. (WK)

1958. Recharging ground water with reclaimed sewage effluent: Civil Eng., v. 28, no. 8, p. 49–51.

To combat sea-water intrusion in California, injection wells are used for recharge and to maintain fresh-water ridges above sea level along the coast. Aside from imported water, effluent from waste treatment plants is being used as a supplementary source of supply for injection. Various tests show that, where enough land of proper infiltration characteristics is available, trickling-filter plant effluent can be spread economically so as to create no pollution to the ground water when the latter is more than 7 feet below the surface and that high-rate activated-sludge effluent can be sufficiently treated through spreading techniques to furnish a percolate which, when chlorinated, can be injected into a well with no important maintenance problem. (WK)

1961. (Stone, Ralph, and Meyerson, L. A.). Reclaiming Hyperion effluent: Am. Soc. Civil Engineers Proc., Sanitary Eng. Div. Jour., v. 87, no. SA–6, Paper 2985, p. 1–40.

The reclamation of high-rate activated sludge type sewage effluent by means of normal practices of continuous surface spreading on well-sorted dune sand was unsuccessful because of gradual sealing off by anaerobic slimes. Neither chlorination of the effluent before spreading or increased water depth resulted in practical improvement of percolation rates. Continuous spreading accompanied by raking of the test basin surfaces permitted operation at average percolation rates of 0.6 cfs per acre to 1.0 cfs per acre for several months but demanded excessive maintenance. Injection well tests demonstrated that a suitable water could contain about 6 ppm suspended solids and 2 ppm BOD, provided the solids were of suitable particle size, fully oxidized, and contained a minimum of inert clay or silt. Chlorine dosage sufficient to maintain a free chlorine residual of 0.1 ppm at the injection well appeared suitable for efficient injection operation, while at the same time affording adequate protection against contamination of ground water. Standard-rate activated sludge containing 25 ppm suspended solids was entirely unsatisfactory for direct recharge into an injection well. (From authors' conclusions.)

1962. Ground water recharge conference, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 5 p.

The recharge program involves spreading of local and imported water, preservation of existing fresh-water supplies by prevention of sea-water intrusion, and reclamation of waste water.

Studies have determined the areas affected by salt-water encroachment in the Alamitos and Dominguez gap areas; plans are being developed for stemming this intrusion by using well recharge to create a fresh-water barrier.

The "Whittier Narrows Demonstration Waste Water Reclamation Project" and other activities of the District are also described. (DJG)

Léczfalvy, S.

1961. Hydraulic analysis of some simple cases of artesian water recharge: Hidrologiai Kozlony [Hungary], Aug., p. 317–325.

The first part of this paper is devoted to problems relating to recharge to artesian waters, while temperature variations of the water gained are discussed in the second. In the last section practical examples are described, where water was recharged to artesian layers.

A single inverted well and a single yielding well, as well as two inverted wells and a single yielding well, were investigated, and a computation method valid for several wells is derived therefrom. In several inverted wells, the paper applies only to well arrangements where the yielding well is located at the center of a ring of inverted wells. The theoretically possible highest yield is attained by a gallery concentrically surrounding the yielding well. The water quantity yielded in one, two, and so forth inverted wells (Q_1) is related to the highest possible yield (Q_2) by the coefficient (B). The formulas given were derived by summing the velocity potentials. The validity of the Darcy law and a constant influence range ($R =$ constant) has been assumed, which is deemed justified for this case. The elasticity of the layers has been neglected.

The problem of several wells can be approached by summing up the velocity potential. In such a problem a linear set of equations must be solved, in which the number of available equations always exceeds by one the number of wells. Finally, temperature variations of the withdrawn water are discussed. An equation, included for the gallery surrounding the centrally located yielding well, gives a fair degree of approximation. (From abs. in Water and Water Eng.)

Leeflang, K. W. H.

1965. Kwaliteits verandering door infiltratie [Changes in quality by artificial ground-water replenishment] [in Dutch with English summ.]: Water [Netherlands] June, p. 167–170, 177–183.

The changes in quality by infiltration are discussed on the basis of the infiltration of Rhine water in the dunes. The smoothing out of temperature and salt content is dealt with. As to the chemical amelioration, the importance of free oxygen and nitrates is amply described. Stress is laid upon the denitrification to free nitrogen under anaerobic conditions. The bacteriological purification and the removal of radioactive isotopes are found to be highly satisfactory. No pollution of the soil by badly assimilated organic substance has as yet been observed. The conditions of infiltration as to duration of flow through the soil, the accessibility of oxygen, and the need of periodical cleaning of the infiltration basins are discussed in detail. (From abs. in Water and Water Eng.)

Leggat, E. R.

1957. Geology and ground-water resources of Lamb County, Texas: Texas Board of Water Engineers Bull. 5704, p. 18–19.

Three methods of artificial recharge of playa-lake water in Lamb County, Tex., are briefly described. These are a single-purpose drainage well, a dual-purpose well (irrigation and drainage), and a drainage trench. The wells had not been tested to any extent but the trench was reported to have drained a small quantity of water and subsequently failed. It was estimated that playa accumulation was equivalent to only about 15 percent of the well discharge in 1950 and artificial recharge of all the playa-lake water would be relatively small compared to irrigation pumpage. (DCS)

1962. Development of ground water in the El Paso district, Texas, 1955–60, Progress Rept. 8: Texas Water Commission Bull. 6204, 56 p., tables.

Injection of treated water through wells is probably the most satisfactory method of artificially increasing the recharge to the aquifer underlying the Hueco Bolson. (From author's abs.)

LeGrand, H. E.

1965. Environmental framework of ground-water contamination: Groundwater, v. 3, no. 2, p. 11–15.

Methodology of managing contamination problems calls for appropriate classification of the hydrogeologic environment; these classifications include aspects of interdependent factors such as permeability, sorption, hydraulic gradient, position of water table relative to some base, and distance from source of contamination. Ways of contamination and pertinent parts of the physical environment include: waste-disposal practices (at or near land surface and in deep formations), artificial recharge (at land surface and in aquifers), accidents, and salt-water contamination of aquifers (shallow depth from salty surface water and at variable depths from subjacent salty aquifers). Evaluation of waste-disposal problems calls for appreciation of two opposing tendencies—the tendency of wastes to move with groundwater and the tendency to be attenuated near disposal sites by decay or inherent decrease in potency, by chemical and physical sorption, and by dilution through dispersion of ground water. Mixed wastes of differing attenuation habits represent special complex problems. (Tulsa Univ., Inf. Services Dept.)

Lehr, J. H.

1964. Relation of shape of artificial recharge pits to infiltration rate: Am. Water Works Assoc. Jour., v. 56, no. 6, p. 699–702.

Sand tank models of two configurations of recharge pits, wedge-shaped and rectangular-shaped, were tested to determine the difference in performance due to shape. Average flow paths from the rectangular pit model were only 3 percent greater than from the wedge model with corresponding differences in recharge rates. (DCS)

Linsley, R. K.

1958. (Kohler, M. A., and Paulhus, J. L. H.). Hydrology for engineers: New York, McGraw-Hill Book Company Inc., 340 p.

Artificial recharge methods are briefly discussed in general terms in this book on hydrology. (WK)

1964. (and Franzini, J. B.). Water resources engineering: New York, McGraw-Hill Book Co., Inc., 654 p.

A short section of the book is devoted to artificial recharge methods and considerations. Salt-water intrusion and development of a fresh-water barrier by artificial recharge are also discussed. (DCS)

Lofgren, B. E.

1957. Infiltration and percolation rates in valley sediments *in* Schiff, Leonard, ed., Conf. on water spreading for ground-water recharge, California Univ., Berkeley, 1957, Proc.: California Univ. Water Resources Center Contr. 7, p. 46–49.

A brief description of infiltration rate measurement in specially constructed spreading areas made in conjunction with studies of land subsidence in the San Joaquin Valley is presented. The surface infiltration rate at one test plot was between 0.75 and 0.25 foot per day; percolation rates were about 5 feet per day near the surface, 2.1 feet per day at a 50-foot depth, 1.0 foot per day at a 75-foot depth, and 0.4 foot per day at a 100-foot depth. (WK)

Longenbaugh, R. A.

1966. Artificial ground-water recharge on the Arikaree River near Cope, Colorado: Fort Collins, Colorado State Univ., Civil Eng. Dept., Eng. Research Center, no. CER 66 RAL 35, 12 p.

Water-spreading structures were constructed on the Arikaree River near Cope, Colo., in 1964 and 1965. The structures consisted of low earthen dams designed to retard the flow and spread water on the adjacent permeable areas for recharge. Floodflows provided recharge and the benefits exceeded the cost of the construction. Recharge amounts were computed from observation-well measurements. A floodflow destroyed the structures, but they were rebuilt and the study is continuing. (DCS)

McDonald, C. K.

1967. (and Sasman, R. T.). Artificial ground-water recharge investigations in northeastern Illinois: Ground Water, v. 5, no. 2, p. 26–30, table.

Rapidly increasing development of ground-water resources in northeastern Illinois has created regional and local problems of supply and interest in the feasibility of artificial recharge. Five systems now in operation in this primarily metropolitan region recharge annually from 25,000 to 395,000 gpd; an initial study in the Park Forest-Chicago Heights area indicates that recharge to the Silurian dolomite aquifer is feasible. This study provides guidelines to aid in additional studies of artificial recharge in northeastern Illinois. (From Abs. of North Am. Geology.)

McKee, J. E.

1963. (and Wolf, H. W., eds.). Water quality criteria: California State Water Quality Control Board Pub. 3–A, 548 p.

Quality considerations pertaining to recharge water are discussed. These considerations should be made before water is recharged by means of spreading grounds or recharge wells. (DCS)

McMichael, F. C.

1966. (McKee, J. E.). Waste-water reclamation at Whittier Narrows: California State Water Quality Control Board Pub. 33, 100 p., tables.

The result of a study of the effects of intermittent percolation through soil of highly treated activated-sludge effluent on the quality of ground water in the Whittier Narrows area is described. The Whittier Narrows Water Reclamation Plant has been discharging about 12 to 16 mgd of effluent since August 1962. The effluent is conveyed to spreading basins of the Montebello forebay along the Rio Hondo and San Gabriel River, where it is allowed to percolate into water-bearing strata. To determine the effect of intermittent spreading on the quality of percolating effluent, sampling pans were located at depths of 2, 4, 6, and 8 feet below the surface of each of two spreading basins. The results indicate no detrimental effect on the quality of ground water. (WK)

Maddox, G. B.

1960. (Jordan, R. M., Cluf, C. B., and Resnick, S. D.). Artificial ground-water recharge at Litchfield Ranch, Arizona: Tucson, Ariz., Inst. of Water Utilization, Agr. Expt. Sta.

Treated water was injected into an aquifer through an irrigation well. The suspended sediments were removed by treatment with a chemical flocculent. Suggestions are given for modification of procedures which would allow larger volumes of water to be recharged. (DCS)

Maddox, G. B.

1962. (and Resnick, S. D.). Artificial recharge activities in Arizona, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 7 p.

Even with the scattered, intermittent, uncontrolled type of water supply existing in Arizona, artificial-recharge programs are feasible when integrated with flood-control projects. A promising recharge method under investigation will utilize dry shallow permeable alluvial zones. Existing irrigation wells will be perforated in this zone and transmit water from spreading operations through the aquiclude to the main aquifer. Recharge activities and research in suspended-sediment removal are also described. (DJG)

Mandel, Samuel

1967. Underground water: Internat. Sci. and Technology, no. 66, p. 35–41.

The principal problem in water management is one of determining how much water can be pumped safely. To determine this the hydrologist relies on field tests, meteorological data, geophysical measurements, mathematical models, and other techniques. He may also turn to methods of artificial recharge, and he must take care to prevent accretions of impurities and to guard against intrusion of sea water. The ultimate problem, however, is securing cooperation between those who tap the water and those who are attempting to manage it. (From Abs. of North Am. Geology.)

Marino, M. A.

1967. Hele-Shaw model study of the growth and decay of groundwater ridges: Jour. Geophys. Research, v. 72, no. 4, p. 1195–1205.

Analytical expressions are available which describe the growth of a ground-water ridge in response to a uniform deep percolation occurring in a strip of infinite length but of finite width over an aquifer that is really infinite. The primary assumptions in these equations are that the aquifer is homogeneous and isotropic, the height of the water table above the base of the aquifer is approximately equal to the average head over the depth of saturation, the rise of the water table is less than 50 percent of the initial depth of saturation, and the rate of vertical percolation is small relative to the hydraulic conductivity of the aquifer. This flow problem describing the growth and decay of a ground-water ridge has been studied in a viscous-flow model in which the actual two-dimensional flow was reproduced. The experimental results confirm the theoretical equations at least when the rate of deep percolation is equal to or less than 0.2 of the hydraulic conductivity of the aquifer, a ratio that has not been exceeded in the present investigation. (From author's abs.)

Marmion, K. R.

1962. Hydraulics of artificial recharge in non-homogeneous formations: Berkeley, California Univ. Water Resources Center Contr. no. 48, 88 p.

The problem of ground-water mounds created by the artificial recharge of ground-water reservoirs was investigated for the two-dimensional case by a model analogy. Equations were developed to describe the free surface of the growing mounds and were compared to the results of the model studies and analytical studies of others. (From author's abs.)

1967. Can recharged water be recovered? *in* West Texas water conf. 5th, Lubbock, Texas, 1967, Proc.: Lubbock, Texas Technol. Coll., West Texas Water Inst., p. 79–83.

The paper describes a simple analogy to ground-water flow illustrating to the layman the effects of pumping and recharge on an aquifer. The conclusion indicated is that, for the conditions of the Ogallala Formation, recharged water can be recovered from the well through which it was recharged. (DCS)

Massoulié, G.

1961. Realimentation de la nappe de Croissy [Recharge of the Croissy aquifer]: L'Eau [France], May, p. 118–122.

Since 1959 a water distributing company has been using a 30,000 sq m abandoned sand pit to replenish the Croissy aquifer with filtered water from the Seine River. The sand pit, which previously connected with the Seine, has been isolated and the slime has been removed from it, as a result of which the gravel covering the fissured chalk was laid bare. A station previously used to tap water from the Seine was equipped with a revolving strainer and two electric motor pump sets of 400 cu m per hr capacity, the water being filtered through two batteries of sand filters providing a total surface of 260 sq m. The recharge operation resulted in a rise in water level and an improvement in the quality of the water, with total disappearance of the iron and a reduction in the ammonia content.

Studies are under way to determine optimum operating conditions, such as those for ventilation problems, the best way to prevent clogging, and the choice of recharge periods. Once the sand pit is completely equipped the operations will involve 5 million cu m of water yearly. (From abs. in Water and Water Eng.)

Matlock, W. G.

1966. Sewage effluent recharge in an ephemeral channel: Water and Sewage Works, v. 113, no. 6, p. 225–229.

The hydraulic feasibility of using sewage effluent for artificial recharge in an ephemeral stream channel such as the Santa Cruz River at Tucson, Ariz., is clearly evident from the results of this study. In the 6.3-mile reach investigated, almost two-thirds of the total flow infiltrated at a rate of about 6 acre-feet per mile of channel per day. The remaining flow below this reach infiltrated completely but at a lower rate estimated at 2 acre-feet per mile per day. (From author's conclusions.)

Mercado, A.

1965. Recharge and mixing tests at well Lod 20 (1964): Tel Aviv, Tahal—Water Planning for Israel, Ltd., Tech. Rept. 16, Pub. 485, 19 p.

Three recharge-withdrawal tests at the same well were carried out with different injected volumes of up to 500,000 cu m and different pause intervals of up to 500 hours. The recharge rate was about 1000 cu m per hr, while the pumping rate was 550 cu m per hr. The recharge water was labeled with radioactive cobalt-60. It was ascertained, as anticipated, that the time interval between the injection and the pumping phases is an important factor in the mixing process. At Lod 20, an interval of 50 days was sufficient to remove the injected water from the pumping region of the well after several million cubic meters of water were injected and the same recharge and withdrawal rates were maintained. The recharge rate capacity of the well increased threefold when the water was recharged between the casing and the column pipe. (From author's abs.)

1966a. Recharge and mixing tests at Yavne 20 well field (1963/64 and 1964/65): Tel Aviv, Tahal—Water Planning for Israel, Ltd., Tech. Rept. 12, Pub. 611, 62 p., tables.

Eight recharge-pumping tests were carried out with different injected volumes (1,000–1.4×10^6 cu m) and different pause inervals (0–290 hours), with injection rates ranging from 270 to 650 cu m per hr, and pumping rates, from 260 to 320 cu m per hr.

Several factors governing the spreading and mixing pattern of injected water bodies in aquifers were studied, particularly the natural flow and the aquifer's dispersivity.

The sanitary aspects related to the recharge of surface water into pumping wells were investigated by analyzing the quality of the pumped water.

The clogging of the well, due to injection of surface water, was investigated by carrying out several step-drawdown pumping tests. (From author's abs.)

1966b. Underground water storage study, recharge and mixing experiments in the Haifa Bay field: Tel Aviv, Tahal—Water Planning for Israel, Ltd., Tech. Rept. 18, Pub. 495, 37 p., tables, pls.

The investigation was to determine: (1) the spreading pattern of injected water bodies in two different flow nets, (2) the breakthrough curves at the pumping wells, and (3) the transition zone between injected and local water, the zone being caused by the dispersivity and the permeability distribution in the aquifer. The results of the test measurements were related to theoretical models. The experimental results are applicable to large-scale recharge and mixing operations. (DCS)

1967. The spreading pattern of injected water in a permeability stratified aquifer [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 23–36.

The paper describes an explanation of the existence of a transition zone between the injected and the aquifer's waters, the explanation being developed on the assumption of a flow through an aquifer with horizontally stratified permeability, in which it is assumed that the frequency of permeabilities follows approximately the normal distribution function. The resulting transition zone is S-shaped and similar to that caused by dispersion. Its shape depends on the permeability distribution factor.

The width of the transition zone caused by the horizontally stratified flow is directly proportional to the distance traveled, while the width of the transition zone caused by dispersion is proportional to the square root of the distance traveled. In the latter case, the width of the transition zone increases also during the return flow, whereas it decreases in the case of horizontally stratified return flow. It is believed that in nature the dispersion and the horizontally stratified flow occur simultaneously, and thus the shape and width of the transition zone is a resultant of the two processes.

A field experiment of the "injection-pumping pair" type carried out at the Haifa Bay Experimental Field is described and interpreted. The values of the permeability distribution factor as determined from the experimental breakthrough curves lie within the limits of 0.1 and 0.2.

The results of the investigations in the experimental field are applicable to large-scale underground recharge and mixing operations. (From author's abs.)

Meyboom, Peter

1963. Induced infiltration, Medicine Hat, Alberta, *in* Early contributions to the ground-water hydrology of Alberta: Research Council of Alberta Bull. 12, p. 88–97.

An investigation was carried out to determine the potential of induced recharge for an industrial plant supply. Geologic, hydrologic, and water quality considerations were made indicating an adequate source of good quality. The economic advantages to such a source were pointed out. (DCS)

Meyers, L. J.

1959. (McKillop, D. H.). A report on artificial recharge in California, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 7–10.

A detailed investigation by the Department of Water Resources of artificial recharge activities in California is described. The study is directed toward summarizing the recharge activities in California and developing a handbook for the uninitiated entering this field. The results of the investigation were summarized. (DJG)

Mikels, F. C.

1956. (and Klaer, F. H., Jr.). Application of ground-water hydraulics to the development of water supplies by induced infiltration: Internat. Assoc. Sci. Hydrology, Pub. 41, p. 232–242.

The paper describes the particular problem of developing ground-water supplies from an unconsolidated aquifer which is dependent upon induced infiltration from a nearby surface source. The discussion of ground-water hydraulics is confined to the analysis of equilibrium pumping-test methods. The Darcy law and fundamental equilibrium methods of ground-water hydraulics are utilized to develop criteria for design, construction, and development of large water supplies.

Practical application of the analysis is described and comparison of pumping-test determinations to actual results is made for various locations in the United States. (DCS)

Minton, E. G.

1955. Report and recommendations on artificial recharge in underground water basins, New Mexico: New Mexico Office of the State Engineer, Roswell, N. M., 42 p.

A review including pictures and diagrams of recharge installations in the High Plains of Texas is presented. A detailed presentation of the geology and hydrology of the High Plains of New Mexico is made. Specific areas and methods of artificial recharge are described. These include contouring to retard runoff allowing more time for infiltration and diverting water into natural openings in the San Andres limestone, and installation of recharge wells. (DCS)

Mobasheri, F.

1963. (and Todd, D. K.). Investigation of the hydraulics of flow near recharge wells: California Univ. Hydraulic Lab., Water Resources Center Contr. 72, 32 p.

Flow behavior in the immediate vicinity of a well in a confined formation was studied to determine if the hydrodynamics of flow is the same for converging and diverging conditions. Flow near a well where turbulence might exist was studied in more detail.

A porous media model representing a radial sector of a prototype confined aquifer was used. Three different types of material were used as the porous media. In addition, the effect of a gravel pack around a well was studied. A constant-head permeameter was used to determine the relation between Reynolds' number and Fanning function factor for each of the media used.

Model results indicate that for identical flow rates, the head loss in the

transition and turbulent flow regions of the porous media is larger for a recharging well than for a discharging well. The difference is small and is on the order of 4 percent or less. The head loss in the laminar region of a recharging well is equal to that of a discharging well when flow rates are identical. (From authors' abs.)

Monke, E. J.

1967. (and Edwards, D. M.). Electrokinetic measurements of colloidal-laden flow through a sand column: Indiana Acad. Sci. Proc., v. 76, p. 377–385.

The operation of a colloidal clay-silica sand system was studied by introducing a bentonite clay suspension into a 20-inch silica sand column. The purpose of this study was to investigate the effect of pH, period of operation, and depth within a column on the electrokinetic properties of the clay colloids and total colloidal clay-silica sand system.

The fact that the column zeta potential approached an isoelectric (neutral) condition quickly at a pH of 7.0 indicates its propensity for rapid clogging. This was subsequently verified in terms of head loss. The total head loss for the column at a pH of 5.1, 7.8, and 8.4 at the end of 60 hours was around 4 inches of water as compared to the head loss of nearly 18 inches at a pH of 7.0 at the end of 45 hours. Most of this difference occurred in the top 2 inches of the column. Control of pH in systems where suspensions containing colloidal particles are introduced onto porous media is very important. The control level, however, would depend on whether the system is used to promote or inhibit the rapid clogging of pores.

Perhaps the most important finding was that bacteria, at least of the type accumulating on soil surfaces, may exhibit a positive electrical charge. The positively charged bacteria may attract the net negatively charged clay colloids and bind them to the negatively charged silica sand. Electrokinetic forces thus augmented by the charge orientation of bacteria may well be the principal mechanism by which colloidal particles are retained in porous media. (From authors' summ.)

Moore, J. E.

1966. (and Jenkins, C. T.). An evaluation of the effect of ground-water pumpage on the infiltration rate of a semipervious streambed: Water Resources Research, v. 2, no. 4, p. 691–696.

A quantitative evaluation of the effect of ground-water pumpage on the Arkansas River in southeastern Colorado using both ground-water and surface-water data has shown that, in at least one reach of the valley, pumping has lowered the water table below the level of the apparently pervious streambed; thereby breaking the hydraulic connection between the stream and the water table. The river is gaining except in reaches where withdrawals of water from the valley fill are large. However, a large cone of depression has formed directly beneath the stream because of continuous withdrawal of about 10 cfs of groundwater at Lamar. The cone extends under the losing reach of the stream without appreciable distortion and has been as much as 12 feet below the streambed. In the 1-mile reach immediately upstream from the wells, the stream lost about 2 cfs during each of three sets of observations. Once the water table is lowered below the streambed, hydraulic connection is broken, and changes in depth to water table have no measurable effect on the rate of depletion of streamflow. The major control on infiltration loss, where hydraulic connection is broken, is probably the permeability of the least permeable layer of the streambed. Studies of stream reaches that have beds with wide ranges of grain size and sorting suggest that the range in maximum infiltration rates is small if the streambeds are undisturbed and depth of water in the stream is less than about 1 foot. A maximum infiltration rate of 20 gallons per square foot per day is suggested as a reasonable first approximation in the absence of observed rates. (Authors' abs.)

Motts, W. S.

1964. (and Cushman, R. L.). An appraisal of the possibilities of artificial recharge to ground-water supplies in part of the Roswell Basin, New Mexico: U.S. Geol. Survey Water-Supply Paper 1785, 85 p., tables.

The amount of recharge to the main consolidated aquifer and an alluvial aquifer probably could be substantially increased by inducing infiltration of surface water through sinkholes and through permeable sections of stream channels to halt the decline of water levels and saline-water encroachment. The area of the main aquifer is divided into seven subareas. The artificial recharge potential through wells of these areas is described. Sources of water that probably could be made available for artificial recharge are described. (From authors' abs.)

Moulder, E. A.

1957. (and Frazor, D. R.). Artificial recharge experiments at McDonald Well Field, Amarillo, Texas: Texas Board of Water Engineers Bull. 5701, tables, 34 p.

This study examines the hydraulic possibility of storing water in the McDonald well field by intra-aquifer transfer. Due to excellent well development, no clogging resulted. Wells recharged up to 1000 gpm; this rate could be doubled with modification of the recharge facilities. The water table was affected very little beyond 0.5 mile of the recharge points. (DJG)

Muckel, D. C.

1955. (and Schiff, Leonard). Replenishing ground water by spreading *in* The Yearbook of Agriculture 1955: U.S. Dept. Agriculture, p. 302–310.

A general review of water-spreading methods and operational procedures is presented. (DCS)

1956. Ground water recharge investigations, *in* Todd, D. K., ed., Conf. on California ground-water situations, Proc.: California Univ. Water Resources Center Contr. 2, p. 82–97.

A partial review of information and data on artificial recharge investigations in California is given. (WK)

1958. Artificial recharge in relation to ground water storage, *in* Ann. conf. on water for Texas, 4th, College Station, Tex., 1958, Proc.: Texas A&M Coll. System, Water Research and Inf. Center, p. 85–94.

Considerations in the selection of artificial recharge sites are listed. Methods of recharge including streambed percolation, basin, flooding, ditches or furrows, overirrigation, pits and shafts, and injection wells are discussed. Artificial-recharge operations in California, and one in the High Plains of Texas are described. (DJG)

1959a. Replenishment of ground-water supplies by artificial means: U.S. Dept. of Agriculture Tech. Bull. 1195, 51 p.

Factors that govern the use of either water spreading or recharge-well replenishment are described. The problem of decreased infiltration rates presents itself in all types of surface spreading where the water is applied for long uninterrupted periods, particularly in the case of silt-laden recharge water. In general, infiltration rates can be improved by adding organic matter to the surface soil and permitting it to decompose under moist conditions followed by a drying period. Soil surveys and well logs should be examined carefully when selecting an area for spreading. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1959b. Replenishing underground-water supplies on the farm: U.S. Dept. Agriculture Leaflet 425, 8 p.

Beneath the surface of the ground are water basins with unused storage capacity far in excess of the largest surface reservoirs. In many localities, farmers who irrigate can use these underground reservoirs as supplements to ponds and other surface basins by storing water in them for later use. Floodwater, waste water, and water above that needed for irrigation are good sources for potential underground storage. A general discussion pertaining to the location of artificial-recharge sites and the most beneficial method of recharge for an area is given. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1960. Groundwater recharge: Land Improvement v. 7, no. 2, p. 14–17.

Water-spreading practices using basins, ditches, or flooding techniques as well as recharge through shafts, pits, or wells to augment natural recharge are discussed. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1962. Artificial recharge of ground water *in* Internat. seminar on soil and water utilization, Proc.: Brookings, South Dakota State Coll., p. 31–32.

Purposes of artificial recharge of ground water are presented and considerations to be made prior to site selection are enumerated. (DCS)

Muegge, O. J.
1958. Artificial recharge of water-bearing formations: Am. Water Works Assoc. Jour., v. 50, no. 2, p. 168–174.

A general review of ground-water recharge projects in the United States is presented. Operations in Wisconsin and proposed research are discussed. (DCS)

Muir, Joe
1959. Refilling our wells: Farm Quart., v. 14, no. 1, p. 72–74, 106–114.

A historical background of agricultural development and increased irrigation in California and other areas and the resultant ground-water depletion is presented. Development in the Salinas Valley, Calif., is covered in detail. Building of the Nacimiento Reservoir to control floodflows in the influent Salinas River recharging depleted underground reservoirs is described. Recharge through wells in the High Plains of Texas and raising of water tables by construction of surface reservoirs in Utah are briefly covered. (DCS)

Muller-Feuga, R.
1965. (and Ruby, P.). L'alimentation artificielle de la nappe des alluvions de la basse-Durance [Artificial recharge of the alluvial aquifer in the lower-Durance] [in French with English summ.]: La Houille Blanche [France], May–June, p. 261–266.

The effectiveness of a suitable method of countering possible effects of the lower Durance diversion scheme on the water table in the local alluvium has been demonstrated by Electricité de France. The method is to recharge the alluvium with flows and supply points determined by theoretical methods aimed at achieving a certain effect after recharging for 1 month. In other words, the method is mainly based on Theis' formula and image procedure. Several tests were carried out in the field, three of which are described. The results obtained agreed well with predictions. (From abs. in Water and Water Eng.)

Mullnix, L. A.
1959. The interest of the Department of Water Resources in artificial recharge, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 5–6.

The California Water Plan as a guide to the solution of the distribution of available runoff water to areas of need is discussed. A significant portion of this water is intended for artificial recharge and underground conservation storage. (DJG)

Mundorff, M. J.
1964. (Crosthwaite, E. G., and Kilburn, Chabot). Ground water for irrigation in the Snake River Basin in Idaho: U.S. Geol. Survey Water-Supply Paper 1654, 224 p., tables.

In a section considering the possibility of artificial recharge in which surplus surface water is used, the author points out that extended storage is possible only if the recharge areas are remote from discharge points because of the high transmissivity of the aquifer. Areas suitable for recharge are described. (DJG)

Muravev, I. M.
1967. Determining the permissible amount of impurities in injection water: Neft. Khoz. [Russia], v. 45, no. 3, p. 47–49.

Injectivity data from 12 wells were analyzed in an effort to determine the maximum amount of suspended matter which can be tolerated in injection water. Some wells were found to be unaffected by injection of 70,000 kilograms of suspended solids, while other wells were affected by injection of 15,000–30,000 kg of solids. The data indicate that water injection rates did not decrease, as long as specific suspended-solids load was in the range 0.0035–0.0040 mg/l per square centimeter. Analysis of suspended-particle size and of pore size showed that particles 1–30 microns in diameter can readily pass through reservoir rocks. From field data, the authors developed the following equation for calculating maximum permissible suspended-matter content in injection water:

$$b = nKF$$

where b is maximum suspended matter in milligrams per liter, n is permissible amount of suspended matter per unit of formation permeability in milligrams

per liter per square centimeter per millidarcy, *K* is average permeability in millidarcys, and *F* is average formation well bore surface in square centimeters. For river water, *n* is about 0.00001, while for produced water, *n* is about 0.000025. (Tulsa Univ., Inf. Services Dept.)

Nevo, Z.

1967. (and Mitchell, R.). Factors affecting biological clogging of sand associated with ground-water recharge: Water Research [Great Britain], v. 1, no. 3, p. 231–236.

Clogging of sand beds by microbial polysaccharides during ground-water recharge of waste water appears to be correlated with a decline in measured potential in the sand, which inhibits degradation of the polysaccharides. Growth of paddy rice was found to be an effective alternative to periodic resting as a means of keeping the sand bed oxidized. Adjustment of pH could also be used to prevent polysaccharide accumulation. A correlation between water temperature and clogging was observed. Preliminary evidence that sandy soils might be used for infiltration of waste water is presented. (Authors' abs.)

Norris, S. E.

1966. (and Fidler, R. E.). Use of type curves developed from electric analog studies of unconfined flow to determine the vertical permeability of an aquifer at Piketon, Ohio: Ground Water, v. 4, no. 3, p. 43–48.

A type-curve method for determining anisotropy of unconfined aquifers, developed from electric analog simulation, is applied to drawdowns observed near a well pumping from a glacial outwash aquifer at Piketon, Ohio. The coefficient of vertical permeability, averaged 365 gpd per square foot. Computed drawdown for the pumped well, based on this value, differed by only a small amount from the observed drawdown. The coefficient of storage determined from type curves for an image well system averaged 0.20, typical of unconfined aquifers. Application of the methods required a thorough knowledge of geohydrologic controls operating at the test site. (Authors' abs.)

1967. Effects on ground-water quality and induced infiltration of wastes disposed into the Hocking River at Lancaster, Ohio: Ground Water, v. 5, no. 3.

The discharge of wastes to the Hocking River at Lancaster, Ohio, seriously retards the induced infiltration of streamflow to the aquifer and thereby lessens the available yield of the wells. (WK)

Noseda, Giorgio

1967. L'alimentazione artificiale delle falde sotterranee [Artificial recharge of ground water] [in Italian with English summ.]: L'Acqua [Italy], Jan.–Feb., p. 2–19.

In this paper a survey is presented of the more usual methods and works for artificial ground-water recharge; the operating data of several installations and the results of important research investigations undertaken in all parts of the world are discussed to develop significant criteria for the design, construction, operation and maintenance of the recharge projects and to show the advantages and the disadvantages of each method. A review of some typical plants shows the cultural, hydrologic, and geologic conditions of the sites where artificial ground-water recharge has given good results. (From abs. in Water and Water Eng.)

Ogata, Akio

1963. Effect of the injection scheme on the spread of tracers in a ground-water reservoir, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475-B, p. B199-B202.

Commonly, the dispersion of a tracer or contaminant injected into an isotropic granular medium, in which the regional flow is unidirectional, is attributed principally to microscopic velocity variations and ionic diffusion. This is true provided the injection scheme neither disturbs nor alters the preexisting flow regime. The effect on the spread of tracers, caused by injection disturbance, is discussed using two examples. The first example concerns injection from an elliptic source and the second concerns injection from a point source. These examples demonstrate that the spread of tracers caused by these methods of injection may be much larger than the spread due to diffusion. (Author's abs.)

Oldsen, C. B.

1962. (and Gutierrez, L. V.). Attractive plant reclaims waste water for a small community: Public Works, v. 93, p. 120-122.

Rancho Santa Fe, San Diego County, Calif., has recently completed a plant which recharges its effluent through a dry river bed for later agricultural and domestic well supply. (Abs. in Texas Water Devel. Board, Rept. 8.)

Ongerth, H. J.

1959. (and Harmon, J. A.). Sanitary engineering appraisal of waste-water reuse: Am. Water Works Assoc. Jour., v. 51, no. 5, p. 647-658.

Sanitary aspects of waste-water reclamation or disposal are discussed including methods of ground-water recharge by infiltration and percolation and by direct injection. (DCS)

Orlob, G. T.

1956a. Effect of water reclamation practices on quality of ground water *in* Conf. on California ground-water situation, Proc.: California Univ. Water Resources Center Contr. 2, p. 146-156.

The feasibility of waste-water reclamation by artificial recharge is largely dependent on the economics of source development. Water quality problems, although they may be formidable, particularly in the field of public health, do not appear as serious limitations on the use of either surface spreading or direct injection. (From author's conclusions.)

1956b. (and Butler, R. G.). Use of soil lysimeters in waste-water reclamation studies: Am. Soc. Civil Engineers Proc., Sanitary Eng. Div. Jour. v. 82, no. SA3, paper 1002, 25 p., tables.

In their study of the mechanism of infiltration, the writers have determined the infiltration capacities of five pervious California agricultural soils during prolonged spreading with water and primary effluent. Each of the soils exhibited time-infiltration rate curves of a characteristic shape. Infiltration rates for continuous spreading ranged from 0.6 to 40 feet per day. Spreading of primary sewage produced an abrupt decrease in the infiltration rates and surface permeabilities of two of the coarsest soils within a few hours. Little or no change occurred in the rates of infiltration into the finer soils for a period of 1 month after the onset of spreading. Sustained infiltration rates

during prolonged sewage spreading ranged from about 0.1 to 0.3 foot per day. (From authors' summ.)

1957. Assimilative capacity of receiving waters in relation to the pulp and paper industry, *in* Waste treatment and disposal aspects: California State Water Pollution Control Board Pub. 17, p. 73–100.

The author examines the particular wastes of typical pulping processes together with the characteristics of potential receiving waters with a view toward determining the general requirements for disposal of pulpmill wastes. The author discusses the underground disposal of these wastes which involves the artificial comingling of waters of widely variant quality and the resulting problems. (WK)

1958. (and Butler, R. G.). Soil lysimeters in waste-water reclamation studies: Am. Soc. Civil Engineers Trans., v. 123, Paper 2914, p. 116–136.

The behavior of five typical pervious California agricultural soils under water and sewage spreading conditions are evaluated, and a comparison is made between field and lysimeter performance of two of these soils. (From authors' synopsis.)

Owen, L. D.

1967. The challenge of water management, Orange County Water District, *in* Salt-water encroachment into aquifers, pt. 2, Baton Rouge, La., 1967, Symposium: Louisiana State Univ., Louisiana Water Resources Research Inst., 19 p., tables.

The paper presents a comprehensive overall view of water management in the Orange County Water District, Calif. Artificial recharge and ground-water basin storage are integral parts of water management and are discussed according to sources, amounts, quality, economics, and basin protection against salt-water encroachment. (DCS)

Palmquist, W. N., Jr.

1962. (and Johnson, A. I.), Vadose flow in layered and nonlayered materials, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 450–C, p. C142–C143.

Studies of downward flow of water in two porous-media models were made to demonstrate general patterns of flow and volume of wetted material beneath disposal pits. The first model consisted of homogeneous glass beads 0.47 millimeters in diameter which were initially dry. The second model consisted of three beds of glass beads 0.036 mm in diameter separated by two beds of beads 0.47 mm in diameter. In the homogeneous material, the wetted area was confined to a relatively narrow vertical column. Flow through stratified material resulted in lateral spreading. The results indicated qualitatively that pits for disposal of nuclear waste can be operated more safely where the underlying granular materials are highly stratified and have different grain sizes. These results apply chiefly to arid regions .(DCS)

Parker, G. G.

1967. (Cohen, Philip, and Foxworthy, B. L.). Artificial recharge and its role in scientific water management, with emphasis on Long Island, New York, *in* Marino, M. A., ed., Symposium on ground-water hydrology, San Francisco, Calif., 1967, Proc.: Urbana, Ill., The Am. Water Resources Assoc. Proc., ser. 4, p. 193–213.

The paper places a particular emphasis on the role of ground-water reservoirs and artificial recharge in deriving optimum benefit from water resources. A comprehensive discussion of aquifer systems and artificial recharge is presented in which problems and considerations associated with artificial recharge by various methods are dealt with.

A brief review of the advances, problems, and scope of artificial recharge and related operations in Israel, California, and the High Plains of Texas is included. A detailed account of ground-water recharge in Long Island, N.Y., includes sections on: (1) the general hydrologic situation, (2) recharge through cesspools and septic tanks, (3) recharge through basins, (4) recharge through injection wells, (5) recharge from leaky pipes and sewers, and (6) artificial recharge studies in Riverhead and Bay Park, Long Island. (DCS)

Parkhurst, J. D.

1964. (and Garrison, W. E.). Whittier Narrows water reclamation plant—two years of operation: Civil Eng., v. 34, no. 9, p. 60–63, table.

More than 1,000 acre-feet per month of effluent from the Whittier Narrows water reclamation plant in southern California has been renovated and recharged to the underlying shallow aquifer through the use of spreading techniques. Percolation rates for undiluted reclaimed water average about 2 feet per day during the wetting cycle of about 5 days. (WK)

1965. Progress in waste-water reuse in Southern California: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 91, no. IR–1, p. 79–91.

Reuse of waste water in Los Angeles County, Calif., is being accomplished through operation of the Whittier Narrows water reclamation plant. Considerations important in waste-water reuse and plans for development in the area were presented. Of the uses to which reclaimed water may be applied, recharging of underground water basins was included. Approximately 24,000 acre-feet of water was salvaged in the 2 years of operation with approximately 12,000 acre-feet being released to the flood control district's spreading facilities and returned to the underground water supply. (DCS)

Peter, Yebuda

1958. Sewage effluent into sand dunes: Water and Sewage Works, v. 105, no. 11, p. 493.

Sand dunes in the "Dan Region" of Israel are used to receive effluent from several simple primary treatment plants. Two years of experience has established that the permissible rate of application by sprinkling is 80–100 cu m per day per dunim (1000 sq m), or about 10 times the desirable rate used for agricultural purposes, and has resulted in a rise in water table by several decimeters. As the ground-water level has declined by overpumping and the aquifer is endangered by salt-water intrusion, the above method of recharge serves a dual purpose. (WK)

Peters, J. H.

1967. (and Cuming, Donald). Water conservation by barrier injection: Water and Sewage Works, v. 114, no. 2, p. 63–68, table.

An account is given of an investigation of artificial recharge by injection on Long Island, N.Y. The injection system is to establish a barrier, by utilizing renovated water, along the south shore of Nassau County that would prevent

27 mgd of fresh water from wasting to the ocean. The barrier will also maintain the fresh-water–salt-water interface and prevent salt-water intrusion. (WK)

Pettyjohn, W. A.
1967. Geohydrology of the Souris River valley in the vicinity of Minot, North Dakota: U.S. Geol. Survey Water-Supply Paper 1844, 53 p.

The Minot area of the Souris River valley in north-central North Dakota is covered primarily by late Wisconsin glacial drift averaging 100 feet in thickness. Although six glacial aquifers were studied, only the Minot aquifer was examined in detail; it is a thick deposit of sand and gravel recharged from buried glaciofluvial deposits and from the Souris River. The water level has declined more than 70 feet since 1916 and more than 20 feet in some places during 1961–63. This rapid decline could be counteracted by artificial recharge; several possible recharge sites of highly permeable sand and gravel crop out in the western Minot area. (From Abs. of North Am. Geology.)

Pickett, Arthur
1957. Industrial wastes and their relation to the re-use of water, *in* Industrial uses of water in California; California Univ. Water Resources Center Contr. 3, p. 31–36.

Artificial recharge of pretreated connate water, derived from oil-field production, is accomplished through injection wells and replaced in the oil sands from which it came. These wells are injecting more than 5,600,000 gpd under a casing head pressure in some wells of more than 2,000 psi. In some oil fields, controlled injection is being used to increase total production of oil-producing zones by 50 percent or more. (WK)

Plotnikov, N. I.
1967. Artificial control of static fissure-karst water resources in carbonate rocks [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 132–135.

Carbonate rocks are characterized by high collector properties. Given the rock thickness required and the intermittent source of runoff (streamflow), artificial recharge and static storage control of the ground water can be conducted by means of water-supply wells.

To solve the above problem, the practice is to construct water-supply wells as a contour well system in the river valley, in the zone of near-surface ground-water occurrence, at a depth of 150–200 m. Under the effect of the intensive ground-water pumping, the cone of depression is formed around the water intake at a large area. Favorable conditions are thus created for the intensive recharge by floodwater and for complete return of the static storage previously used.

Operation practice of water-supply wells in the U.S.S.R. shows that in arid regions a constant well yield up to 100,000–150,000 cu m per day may be obtained by means of artificial recharge and static storage pumping control of the ground water in carbonate rocks. (Author's abs.)

Pluhowski, E. J.
1964. (Kantrowitz, I. H.). Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1768, 119 p., tables.

In a short section on artificial recharge, the authors discuss the possibilities of recharging treated sewage effluent to retard salt-water encroachment and supplement natural recharge. (DJG)

Poland, J. F.

1956. Land subsidence and ground-water development in California, *in* Conf. on California ground-water situation, Proc.: California Univ. Water Resources Center Contr. 2, p. 106–119.

The writer speculates on the effect of land subsidence in relation to artificial recharge or cyclic storage. (WK)

1959. Notes on rate of water penetration in subsidence test plots, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Branch, p. 87.

Rates of vertical penetration beneath a test plot on the west side of the San Joaquin Valley in Fresno County were determined. Owing to the presence of fine-grained material of low permeability impeding vertical percolation, much of the applied water moved laterally. (DJG)

Price, C. E.

1961. Artificial recharge through a well tapping basalt aquifers, Walla Walla area, Washington: U.S. Geol. Survey Water-Supply Paper 1594–A, 31 p., tables.

During an experiment to determine the feasibility of artificial recharge in the Columbia lava plateau area, 71.3 acre-feet (23 million gallons) of surface water containing 2 ppm suspended sediment (and chemically compatible with the native ground water) was injected into basalt aquifers through a city well at rates ranging from 630 to 670 gpm. The water level rose, but subsequent yield and specific capacity decreased. Data obtained suggest that hydraulic boundaries limit the lateral movement of water. (From author's abs.)

Price, Don

1965. (Hart, D. H., and Foxworthy, B. L.). Artificial recharge in Oregon and Washington, 1962: U.S. Geol. Survey Water-Supply Paper 1593–C, 65 p., tables.

Natural recharge to basalt, sand, and gravel aquifers was augmented by more than 17,000 acre-feet of artificially recharged water in 1961—about 12,000 acre-feet coming from a water-spreading operation at Richland, Wash., and the rest, from 22 separate water-spreading and well-injection operations. (DJG)

Price, W. P., Jr.

1959. (and Brown, R. L.). Ground-water recharge activities of the United Water Conservation District of Ventura County, California, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 58–65.

A historical summary of studies, practices, problems, and effects of replenishment in the Peru, Saticoy, and El Rio spreading grounds is presented. Future programs are also discussed. (DJG)

1962. (Watson, R. M., and Babcock, B. A.). Problems and Programs of the United Water Conservation District of Ventura County, California, in the field of ground-water recharge with appendix, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 5 p.

Problems encountered during the past 2 years of operation were: (1) accumulation of silt in spreading basins, (2) use of existing wells as multipurpose wells in a program of well recharge, (3) desilting of stormflows, (4) reduced infiltration rates caused by mounding, (5) salt-water encroachment, and (6) iron in Fox Canyon water. Solutions to these problems are discussed. (DJG)

1963. (and Baker, C. W.). Ground-water recharge activities in the United Water Conservation District of Ventura County, California, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963 Proc.: Fresno, Calif., Ground-Water Recharge Center, 6 p.

The Ocean View Municipal Water District's injection well operation receiving treated El Rio well-field water via the United Water Conservation District's Oxnard-Port Hueneme pipeline to increase depleted ground water and retard salt-water intrusion is discussed. After recharge, the wells are used for alternate irrigations, when possible; thus they serve a redevelopment scheme. (DJG)

Prudhomme, P.

1967. Representativité des simulateurs utilises pour l'étude de la recharge artificielle des nappes [Representativity of models used for the study of the artificial recharge of aquifers] [in French with English abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 46–52.

The use of mathematical programs or of laboratory models is particularly recommendable for the determination of efficiency of devices used for the artificial recharging of underground water reservoirs.

However, in order that the results obtained are valid, it is necessary for the model to be representative of the aquifer. It is known that pump tests alone are insufficient to determine the exact distribution of transmissibilities and storage coefficients. To this difficulty, owing to the insufficient knowledge of the distribution of hydrodynamic characteristics, is added the lack of precision of the conditions at the limits.

The author explains how, in spite of the poor knowledge of certain parameters, it is possible to construct models that faithfully represent actual conditions. The demonstration is divided into two parts. The first develops the basic theories on which the possibility of constructing such models is based; the second presents how the construction phase of a model contributes efficiently to the determination of the characteristics of the aquifer—in particular, transmissibility and conditions at the limits. (Author's abs.)

Rawn, A. M.

1957. (and Bowerman, F. R.). Planned water reclamation: Sewage and Indus. Wastes, v. 29, no. 10, p. 1134–1138.

Locating a protected sewage treatment plant in the impounding area behind Whittier Narrows Dam in Los Angeles County and applying reclaimed

sewage to existing spreading basins along the Rio Hondo channel 3 miles downstream was proposed. The utility of the spreading basins, used about 2 months out of the year for recharging released storm runoff, could be extended to the entire 12-month period. (DCS)

Rayner, F. A.

1967. Artificial recharge: Cross Section, v. 13, no. 8, p. 1–4.

In addition to presenting a historical review of recharge projects in the southern High Plains of Texas, the author also discusses "the artificial recharge controversy" including mechanical and contamination problems associated with playa-lake water recharge. (DJG)

1967b. Potential for storage of water in southern High Plains of Texas: Cross Section, v. 13, no. 11, p. 1.

The economics of using imported water for recharge in the Southern High Plains of Texas is discussed. Several methods evaluated include the use of unlined canals, water spreading, and recharge wells. (WK)

1967c. Potential for storage of water in southern High Plains of Texas: Cross Section, v. 13, no. 12, p. 2–3.

The author states that because of the anticipated importation of water to the southern High Plains area, an adequate means of storing this water in the underlying Ogallala Formation must be found. Criteria to be used in the selection of recharge methods for specific areas are enumerated. (DJG)

Rebhun, M.

1967. (and Hauser, V. L.). Clarification of turbid water with polyelectrolytes for recharge through wells [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 218–228.

Storm-runoff water is a good source of additional water supply for arid and semiarid regions; however, it must be stored for later use. These waters may be stored in aquifers by artificial recharge; however, suspended solids in the water often prevent recharge. Where recharge must be done by injection through wells, removal of suspended solids must be nearly complete. Polyelectrolyte flocculents effectively clarified suspensions typical of flood-runoff water. A simple field system was built and tested, where for the first time all elements of a complete system including treatment with polyelectrolytes, a simple clarification system, and ground-water recharge through wells were combined into a successful operating unit. Seventy-five thousand cubic meters of clarified water was successfully recharged through wells. (Authors' abs.)

Reed, E. L.

1959. City of Midland—artificial recharge project, McMillen Field; report presented to the city of Midland, Tex.: 9 p., 29 plates.

The report summarizes the results of an experimental recharge project at the McMillen field during the winter of 1957–58. The experiment was to determine if water from a remote source could be injected into the ground-water reservoir and if water so injected could be contained in and recovered from the reservoir. An analysis was made of the geology of the area. Recharge was conducted for a 107-day period utilizing ground water from another area. Data are presented and analyzed. (DCS)

Reed, J. E.

1966. (Deutsch, Morris, and Wiitala, S. W.). Induced recharge of an artesian glacial-drift aquifer at Kalamazoo, Michigan: U.S. Geol. Water-Supply Paper 1594–D, 62 p., tables.

The object of three recharge tests was to observe the effects of induced recharge on the main lower aquifer by varying conditions in a recharge channel receiving diverted water from West Fork Portage Creek. Aquifer tests showed that the transmissibility of the upper and lower aquifer ranges from 50,000 to 100,000 gpd per foot with nearly 200 gpm leaking through the confining layer separating the two aquifers. The principal effect of induced recharge on the two aquifers was to reduce the amount and rate of drawdown; therefore, where water levels and artesian pressures can be maintained at high stages, the result is lower pumping costs and increased rates of withdrawal during periods of peak demand. (From authors' abs.)

Reeves, C. C., Jr.

1967. (and Parry, W. T.). Geology of water importation: Cross Section, v. 14, no. 3, p. 4.

Because of the importance of geology on any surface or subsurface storage scheme for water imported to the southern High Plains section of Texas, the authors propose complete evaluation of geological factors. (DJG)

Richards, W. P.

1958. (and Watts, B. B.). Spacing wells to control water temperatures and drawdown: Water Works Eng., v. 111, no. 5, p. 464–466.

Lincoln, Nebr., obtains its water supply from wells in gravel aquifers receiving induced water from the adjacent Platte River. Over a period of 24 years, the city has developed 33 wells, properly spaced to control water temperature and provide optimum discharge and minimum drawdown. (DJG)

Richter, R. C.

1955. Geological considerations of artificial recharge [abs.]: Geol. Soc. Am. Bull. v. 66, no. 12, pt. 2, p. 1661.

Artificial recharge to ground water is now an important technique and will become increasingly significant in the future conservation of California's water resources. Selection of recharge sites must be based on evaluation of surface material for maximum percolation rates and physical characteristics of underlying sediments for storage capacity and transmissivity of aquifers. (From author's abs.)

1959. (and Chun, R. Y. D.). Geologic and hydrologic factors affecting infiltration rates at artificial recharge sites in California, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Research Br., p. 48–52.

In the selection of a recharge site, consideration should be given to factors affecting infiltration rates such as ground shape, surface soils, and physiography as a guide to subsurface conditions. These factors are discussed and information is presented on using them as guides in obtaining an estimate of the infiltration rate. (DJG)

1961. (and Chun, R. Y. D.). Artificial recharge in California: Am. Soc. Civil Engineers Trans., v. 126, pt. 3, Paper 3274, p. 742–762.

The major types of artificial-recharge projects in California are described and the extent of artificial-recharge activities in California are summarized. Some of the important factors related to selection of artificial-recharge project sites are reviewed with particular emphasis on infiltration rate. A partial bibliography on artificial recharge is appended. (From authors' synopsis.)

Robinson, A. R., Jr.

1957. (and Rohwer, Carl). Measurement of canal seepage: Am. Soc. Civil Engineers Trans., v. 122, Paper 2865, p. 347–363.

Existing methods of measuring seepage have been investigated by the authors in an effort to develop new methods and to study the factors affecting seepage. Special studies include the effect of depth of water on seepage, the effect of depth to ground water, and the effect of temperature on the seepage rate. Seepage meters were found to indicate the order of magnitude of loss, although they do not provide accurate measurement. A method of analysis was developed for using the well-permeameter test results in forecasting seepage. (Authors' synopsis.)

Roll, J. R.

1963. (Page, L. M., and Wright, L. E.). Ground water recharge in Santa Clara Valley, California, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 17 p. tables.

New operational problems resulting from the fact that Santa Clara Valley has reached the point where it must import substantial quantities of water are discussed. Problems dealt with are changes in ground-water quality resulting from importation and sediment removal. These two problems are covered in detail, including treatment costs.

The costs associated with salvaging and importing water are presented. Pertinent data concerning the district's eight dams and each percolation area are included in tables. (DCS)

Rorabaugh, M. I.

1956. Ground Water in northeastern Louisville, Kentucky, with reference to induced recharge: U. S. Geol. Survey Water-Supply Paper 1360–B, p. 101–168, tables.

Analysis of a pumping test made during the investigations proves that infiltration supplies can be developed. It is estimated that under adverse temperature and river-stage conditions, infiltration supplies could be developed to the extent of 280 mgd in the entire 6.4 mile reach investigated; at average river stage conditions and at water temperature of 59° F, about 400 mgd could be developed. Diagrams were drawn showing the estimated yield of wells of different radii, at various distances from the river, and at various spacings. (From author's abs.)

Russell, R. H.

1960. Artificial recharge of a well at Walla Walla: Am. Water Works Assoc. Jour., v. 52, no. 11, p. 1427–1437.

Experimentally recharging a well of the public supply system at Walla Walla, Wash., is described. Water diverted from a stream was recharged into a basalt aquifer totaling 71.3 acre-feet in a 26-day period. The water was of high quality, containing a maximum of 6 ppm sediment, and chemically compatible with the ground water. Some deterioration in well performance resulted. The relative importance of three recognized factors which could cause the deterioration, namely, sediment, dissolved air, and entrained air in the recharge water, could not be determined. There was evidence of large amounts of entrained air being carried into the well. The problems are further discussed and considerations for continuing the experiments are presented. (DCS)

Salisbury, M. E.

1963. Water conservation in Los Angeles County, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 5 p.

Current activities of the Los Angeles Flood Control District including spreading of local water with emphasis on chemical treatment to remove suspended sediments; spreading of imported Colorado River water and reclaimed water from the Whittier Narrows water reclamation project which recently began operation; and sea-water barrier projects using treated Colorado River water and possibly effluent from the Hyperion treatment plant are discussed. (DJG)

Scalapino, R. A.

1955. Artificial recharge of ground water reservoirs: Am. Water Works Assoc. Jour., v. 47, no. 3, p. 230–234.

Artificial recharge tests at El Paso, Tex., are described where highly treated water was injected through a recharge well. Aquifer constants derived from pump tests worked well in computing expected rises at observation points and the well's ability to take or produce water was not impaired by long periods of recharge. Salt-water encroachment into the well field is considered. Other areas where recharge was being carried out are discussed. (DCS)

Schiff, Leonard

1955. The status of water spreading for ground-water replenishment: Am. Geophys. Union Trans., v. 36, no. 6, p. 1009–1020.

Methods of spreading water on land surfaces and by injection are reviewed and some results are given. Included are: (1) developments in vegetative, chemical, and mechanical treatments to increase infiltration rate, (2) shaft, trench, and pit injection methods which cut through less pervious soil and inject water into aquifers, and (3) operational procedures such as cultural methods, length of wetting and drying periods, and surface head. Limitations in the use of treatments based on the surface soil and stratigraphy are described. Tools to determine the suitability and characteristics of a proposed spreading area are discussed. (From author's abs.)

1955a. The Darcy law in selection of water-spreading systems for ground-water recharge: Internat. Assoc. Sci. Hydrology Pub. 41, p. 99–110.

Ground-water recharge is accomplished by surface spreading methods utilizing basins, furrows, and flooding or by injection methods employing shafts, wells, pits, and trenches. Effects of the following conditions on flow to the ground-water table are discussed on the basis of Darcy's law: (1) surface and subsurface soils which permit rapid infiltration and percolation to the ground-water table, (2) surface soil conditions restricting infiltration, (3) shallow, less pervious, soil layers which restrict percolation and infiltration, and (4) deep, less pervious, soil layers restricting percolation to the ground-water table. Soil and water treatments and operational procedures tending to increase permeability or hydraulic gradient are considered. The Darcy law is basic to interpretation of problems and to selection of the method of spreading. It also is the basis for selection of systems of spreading, involving spacing and arrangement of spreading areas, and combinations of methods used to achieve maximum recharge with minimum area. Procedures and experimental data are discussed in terms of Darcy's law. (Author's abs.)

1956b. (and Muckel, D. C.). Replenishing underground water supplies for irrigation purposes: Internat. Soil Sci. Cong., 6th, Paris, Proc. p. 683–689.

Water spreading is one approach to replenishing underground water and storing water. High land values justify treatments that increase soil permeability and that thus reduce the size of spreading areas. Areas devoted to spreading are divided into four general categories based on permeability of surface and subsurface soil. Surface permeability was increased on small ponds by soil treatments with grasses, organic residues, and chemicals. Such treatments are beneficial on large areas where subsurface layers are not limiting. A strip system of surface spreading is suggested where relatively shallow limiting layers occur at sufficient depth to permit appreciable lateral flow. Further reduction in area can be accomplished by treating strips to increase the infiltration rate.

A strip system of long narrow trenches which cut through shallow limiting layers and inject water laterally into aquifer lenses may reduce the area devoted to spreading severalfold. Where restrictive layers are deep, shafts show promise. (Authors' summ.)

1958a. (and Johnson, C. E.). Some methods of alleviating surface clogging in water spreading with emphasis on filters: Am. Geophys. Union Trans., v. 39, no. 2, p. 292–297.

Methods of preventing or alleviating clogging of soil pores when spreading water on soil surfaces or injecting water into aquifers for recharge are discussed. Observation of methods such as suction cleaning or scraping to remove clogging materials and restore the infiltration rate in some installed systems are pointed out. Certain past experimental work on the subject is reviewed.

Of various filter materials used in infiltrometers at Bakersfield, Calif., sand ranging in size from 0.02 to 0.06 inch maintained a higher infiltration rate than pea gravel 0.12 or 0.25 inch in size or the existing aquifer material. Information is given on particle size distribution of both the filter and aquifer materials. Head loss due to filters and within the underlying aquifer are shown. (Authors' abs.)

1958b. The use of filters to maintain high infiltration rates in aquifers for ground water recharge [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 44, p. 207–212.

A method of recharging ground water is the injection of water into aquifer material through pits, trenches, shafts, and wells. Grit sand and aquifer sand filters doubled and more than doubled the total infiltration into aquifer material over a 70-day period at Bakersfield, Calif. Decreases in infiltration rate are associated with increases in suspended load in the water supply. Increases in infiltration rate are attributed to decreases in viscosity and increases in total salts in the water supply. Losses in hydraulic head in the filter material and in the aquifer material are presented. (Author's abs.)

1960. Ground-water recharge—need, progress, and research in California, *in* Irrig. Assoc. Conf., Fresno, Calif., 1960, Proc.: Fresno, Calif., Calif. Irrig. Assoc., p. 63–70.

Water-storage needs of California are reviewed. The availability of large ground-water reservoirs and a shortage of surface-storage capacity indicate a greater dependence, in the future, on ground water.

The results of ground-water recharge research in California are summarized including work on soil factors relating to infiltration rate, soil and water treatments to increase infiltration, filters, operational procedures, and water-spreading systems. A new research program is described which emphasizes the relationships of site characteristics to: (1) recharge potential and the feasibility of recharge by over irrigation of crops, and (2) recharge water characteristics and the resulting quality of ground water. (DCS)

1961. Effect of filtering on model recharge wells: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 87, no. IR–4, pt. 1, p. 55–63.

Maintenance of injection rates is important in the use of shafts and wells for recharge. In an experiment covering 75 days, water rose about four times higher in wells receiving unfiltered water than in those receiving filtered water because of clogging by suspended solids. Filtering through 0.2 foot of material reduced the suspended load from about 20 ppm to 1 ppm. Two filtering arrangements were used where water was ponded and made to flow over the filter material.

Flowing river water passed through the filter at more than twice the rate than when ponded. Fines carried into the filter were returned to the flowing water by raking the filters to a depth of about 0.5 inch and infiltration rates recovered. (From author's synopsis.)

1962. (Johnson, C. E., Bianchi, W. C., and Dyer, K. L.). Activities of the ground-water recharge research project, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Laboratory, 11 p., tables.

Results on the movement of a wetted front traced with neutron moisture meters after flooding of field plots in the San Joaquin Valley are described. Present plans call for comprehensive study of the ground-water mounds associated with flooding practices. Factors influencing the quality of recharged water are also discussed. (DJG)

1963a. Ground-water recharge methods based on site characteristics and on sediment in flood water [with French abs.]: Internat. Comm. Irrig. and Drainage Cong., 5th, Tokyo, Japan, Trans., v. 6, question 18, p. 17–31.

This paper is concerned with types of recharge facilities and comparative rates of recharge, soil and water treatments, and operational procedures

developed to increase the infiltration rate and percolation rate; operations and maintenance of recharge facilities, including methods of alleviating or preventing clogging due to sedimentation and to microbial activity; and the design of recharge facilities. (From author's introd.)

1963b. (and Dyer, K. L.). Some physical and chemical considerations in artificial ground-water recharge, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 12 p., table.

Efficient, economical, artificial recharge requires the logging of the physical and chemical characteristics of the soil and stratigraphy. It requires a knowledge of the relation of these characteristics to infiltration and the subsurface storage and movement of water. Recharge facilities should be made multipurpose whenever possible. Such facilities should be designed in the light of comprehensive plans for the conservation and use of water resources. (Authors' conclusion.)

1964a. Devices for measuring soil water movement in designing recharge facilities: Am. Soc. Agr. Engineers Trans., v. 7, no. 1, p. 67–69.

The paper is concerned primarily with measurements of water movement in soil, but it is also concerned with measurements of soil moisture factors which govern the amount of subsurface storage space available for water and specific yield. Emphasis is placed on measurements in the field and on the use of soil cores in the laboratory. A new permeameter developed to measure various soil-water movements is described. (From author's text.)

1964b. Ground-water recharge hydrology: Ground Water, v. 2, no. 3, p. 16–19.

The hydrology of ground-water recharge depends upon the physical and chemical characteristics of both soil and water. These characteristics must be measured and related to subsurface storage space and water movements to determine the feasibility of a site for recharge and to select appropriate methods and systems of recharge. Then water may be efficiently stored underground to be used independently or conjunctively with releases from surface-storage reservoirs. (Author's abs.)

1964c. (and Dyer, K. L.). Some physical and chemical considerations in artificial ground-water recharge [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 64, p. 347–358, table.

Maintaining or raising ground-water levels by artificial recharge provides a water source for irrigation, industrial, and domestic use and prevention of salt-water intrusion along coastal areas. Programs are being carried out in western United States, especially in California, where ground water furnishes almost half the water used and few economical surface reservoir sites are available in areas of need. A key factor is the infiltration rate—that is, the rate at which water can enter the soil—so that facilities must be based on the physical and chemical characteristics of the soil and substrata. Areas chosen should preferably be those with little change in the salt content of the soil or the water. (From Abs. of North Am. Geology.)

1966a. (and Dyer, K. L.). Some physical and chemical considerations in artificial ground-water recharge, *in* Schiff, Leonard, ed., Bienn. conf.

on ground-water recharge, development, and management, California Univ., Los Angeles, 1965, Proc.: Fresno, Calif., U.S. Dept. Agriculture, 12 p.

A general discussion of some of the physical and chemical aspects of artificial recharge is presented. A key factor, infiltration rate and the problems of soil clogging and its prevention, is discussed. The effect of the chemistry of both soil and percolating water in relation to recharge is examined. The design of recharge facilities based on the physical and chemical characteristics of the soil and substrata is considered. (WK)

1966b. Disposal (conservation) of water by percolation in soil, *in* Doneen, L. D., ed., Symposium on agricultural waste water, Davis, Calif., 1966, Proc.: California Univ. Water Resources Center Rept. 10, p. 203–214.

The author discusses most of the factors that control the movement of water through the soil. In a step by step approach the relationship between soil texture and infiltration rates is described. The process of recharge from surface ponding to the development of a ground-water mound is diagnosed and explained. Treatments to increase permeability are discussed and cases are cited. The design of several types of recharge facilities is also described and quantitative data for many recharge works in the United States are cited. (WK)

1967. (and Muckel, D. C.). Ground-water recharge and storage, *in* Hagan, R. M., Haise, H. R., and Edminster, T. W., eds., Irrigation of agricultural lands: Madison, Wis., Am. Soc. of Agronomy, Agronomy mon. ser. no. 11, p. 92–103.

Considerations in artificial recharge are discussed. Site selection, water movement and its measurement, methods of recharge, and design of facilities are covered. Water-spreading methods and results particularly in regard to infiltration rates are treated comprehensively. Recharge wells and hydraulics of ground-water mounds are dealt with briefly. (DCS)

Schneider, Robert

1964. Cenomanian-Turonian aquifer of central Israel—its development and possible use as a storage reservoir: U.S. Geol. Survey Water-Supply Paper, 1608–F, 20 p.

Israel's master plan for water-resources management includes the underground storage of seasonally available surplus water. Storage is possible almost any place within the highly permeable dolomite and limestone aquifer, but the movement and recovery of injected water could be controlled most easily if local depressions in the piezometric surface were utilized for storage. (DJG)

1967. Geologic and hydrologic factors related to artificial recharge of the carbonate-rock aquifer system of central Israel [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 37–45.

In central Israel, one of the main sources of ground water is a thick, highly permeable dolomite and limestone aquifer system known as the Cenomanian-Turonian aquifer. Its porosity is characterized mainly by solution channels and by cavities produced by faulting and folding. Owing to the scarcity of suitable surface-reservoir sites, excess water is injected into the aquifer through supply wells and specially constructed recharge wells for storage during the nonirrigation season.

In view of the permeable nature of the aquifer, one of the most important considerations in planning artificial recharge is the selection of injection areas that are remote from discharge areas or that are so located that the flow of water toward the discharge area is delayed by detours in its path. There is one large spring discharge site near the center of the area and a much smaller one in the north.

The piezometric surface is very flat but under natural conditions flow is generally westward and northwestward. Intensive pumping from about 1950 to the present has produced several irregularly shaped shallow depressions. There are also several northeast-trending "hills" or "ridges" on the piezometric surface and several of the depressions have lobate protusions extending to the northeast. The ridges appear to coincide with downfaulted blocks or structural basins, regarded as regions of relatively lower permeability than adjacent regions of lower piezometric levels.

As the piezometric depressions remote from the discharge areas are deepened by pumping, they will become increasingly useful as storage areas for injected water. An ideal condition for an injection area is a well-defined piezometric depression with one or more piezometric "ridges" between it and the discharge area. (Author's abs.)

Schwiesow, W. F.
1965. Playa lake use and modification in the High Plains, *in* Studies of playa lakes in the High Plains of Texas: Texas Water Devel. Board Rept. 10, p. 1–8.

Artificial recharge of playa-lake water is discussed as a means of utilizing surface runoff collecting in the playas on the High Plains of Texas. Recharge methods are discussed in general and some specific well-recharge projects reviewed including some operating data and problems encountered such as clogging wells with suspended sediment. (DCS)

Scott, Gayno
1961. Saving runoff water: Crops and Soils, v. 13, no. 9, p. 10–13.

A discussion of ground-water recharge is presented as applied to surface runoff on the High Plains of Texas. Recharge experiments are described including a 500-foot trench with a shutter screen enveloped in gravel located in the bottom of a playa lake. (DCS)

Scott, V. H.
1963. Summary of research activities related to ground water recharge in the Department of Irrigation, Univ. of Calif., Davis, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Research Center, 4 p.

In a study concerning "ground-water flow characteristics of recharge pits as influenced by pit geometry" using a Hele-Shaw viscous-fluid model, results show that the location of the free water surface was unaffected by side slope and depth of impermeable layer, that the amount of flow from the side of the pit as compared to the bottom was greatly affected by the side slope, and that the percentage of flow through the sides of the recharge pit was not significantly affected by the depth of the impermeable layer or by the depth to the water table.

Results of another study, "dynamic project planning and developing ground-water supplies," stress the integration of flood control and recharge facilities. (DJG)

1966. Ground-water research, University of California, Davis, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, development, and management, California Univ., Los Angeles, 1965, Proc.: Fresno, Calif., U.S. Dept. Agriculture, 3 p.

This paper reports briefly some of the research activities being conducted by staff of the Department of Water Science and Engineering, University of California at Davis. The research in artificial recharge concerns quality of recharge water, recharge through a multiple well system along a coastal aquifer, and the potential for recharge by a trench or wells. (WK)

1967. (and Aron, G.). Aquifer recharge efficiency of wells and trenches: Ground Water, v. 5, no. 3, p. 6–12.

Artificial recharge through wells and trenches was investigated. These methods were explored according to construction and operating cost and hydraulic efficiency as influenced by such factors as the depth to the aquifer; the thickness, depth of saturation, permeability, and specific yield of the aquifer; interference of closely spaced wells; and duration of continuous operations of the wells or trenches. Furthermore, effects of bacterial growth and chemical composition of the recharge water on the hydraulic performance of wells or trenches are discussed. (From authors' abs.)

Seares, F. D.

1966. Disposal of flood and agriculture waste waters by spreading, *in* Doneen, L. D., ed., Symposium on agricultural waste water, Davis, Calif., 1966, Proc.: California Univ. Water Resources Center Rept. 10, p. 215–222, table.

A multipurpose spreading operation which emphasizes the disposal of suitably treated agricultural waste waters, and which also incorporates the spreading of local storm water and imported water for additional ground-water replenishment, provides a promising method of handling this pending problem. If these waters are of a quality similar to those from domestic sources receiving standard rate secondary treatment, their spreading may be found to enhance the infiltrating characteristics of the basins. However, experience thus far indicates that a rotational operation of the spreading basins to allow significant drying periods must be incorporated. If waste water is to be the primary source for significant periods of time, the intermittent spreading cycle may have to be as short as one day, with the distribution facilities designed accordingly. Costs of spreading, including amortizations of facilities, should not exceed \$20 per acre-foot at the very maximum and could be as low as \$5 per acre-foot if year-round sources of water are utilized. (From author's conclusion.)

Shamir, U. Y.

1967. (and Harleman, D. R. F.). Numerical solutions for dispersion in porous mediums: Water Resources Research, v. 3, no. 2, p. 557–581.

A numerical method is presented for the solution of problems of dispersion in steady three-dimensional potential flow field in porous mediums, in which the miscible fluids have the same density and viscosity. The method is devel-

oped and tested for two-dimensional problems, and the extension to three dimensions is presented. Emphasis is put on the efficiency of the numerical scheme and on its generality. It is shown to be independent of the geometry of the flow field. The computer program for carrying out the computations as described is tested with simple problems, for which exact or approximate analytical solutions exist. It is also used to obtain solutions to a few problems for which no other solution is known. (Authors' abs.)

Shestakov, V. M.

1967. (and Kravchenko, I. P.). A contribution to the technique for evaluation of natural and workable resources of near-canal fresh-water lenses [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 83–90.

The fresh-water lenses which are formed near large canals, as a rule, are hydraulically connected with the canal and located immediately over an aquiclude. For such conditions, the technique of evaluating the workable resources, when a linear water intake is located along canals, is developed. Alongside the use of the analytical calculation methods, the application of the modeling methods is described. For the "hanging" (perched) lenses, the approximate methods of calculations and the methods of modeling using solid and net-like electrical models are presented. Also, the technical problems of hydrogeological investigations required for determining the initial hydrogeological parameters are discussed. (Authors' abs.)

Sieckman, D. L.

1957. Water-spreading activities of the U.S. Bureau of Reclamation at Fresno, Calif., *in* Conf. on water spreading for ground-water recharge, Proc.: California Univ. Water Resources Center Contr. 7, p. 50–51.

A brief description of the progress of ground-water replenishment in the Millerton Lake service area, California, from 1951–55 is presented. (WK)

Sisson, W. H.

1955. Recharge operations at Kalamazoo: Am. Water Works Assoc. Jour., v. 47, no. 9, p. 914–922.

Artificial recharge of waste water from a plant through constructed and natural ponds was reported. Percolation rates, ground-water levels, and temperatures were determined. Polluted water from industrial wastes entered the aquifer, and disposal wells in brine strata were subsequently utilized while only clean waste water was placed in the ponds. (DCS)

Skinner, M. M.

1963. Artificial ground-water recharge in the Prospect Valley area, Colorado: Colorado State Univ., Agr. Expt. Sta. Gen. Ser. 792, 89 p., tables.

A general description of the Prospect Valley area is presented, including the physiography, geology, and hydrology with special emphasis on surface- and ground-water for irrigation. The procedure and results of a quantitive ground-water recharge investigation at Olds Reservoir are discussed, and an equation is evaluated for describing the dissipation of a ground-water mound beneath a spreading basin. A ground-water inventory for Prospect Valley is itemized for the period 1942–62, and the "current, permissive, sustained ground-water yield" is discussed. Based on historical water-supply deliveries, some water-resources management aspects are proposed involving conjunctive use of surface- and ground-water supplies. (Author's abs.)

Skinner, R. A.

1966. Economics and acceptability of ground-water recharge, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, development, and management, California Univ., Los Angeles, 1965, Proc.: Fresno, Calif., U.S. Dept. Agriculture, 7 p.

This paper is a summary of salient points of the economics and acceptability of ground-water recharge and contains the author's opinion regarding recharge in long-range planning of water resources in California. (WK)

Smith, H. F.

1967. Artificial recharge and its potential in Illinois [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 136–142.

A definite relationship has been shown between the grain size of filter blankets and the percentage of sediment that penetrated the aquifer through a recharge pit. High rates of recharge have been achieved under certain conditions where the filter grain size was optimum, the pit was the correct shape, and the permeability was high. Recharge data are summarized in a table.

Criteria established for evaluating the recharge potential of aquifers include: thickness of aquifers, areal extent of aquifer, and minimum economical withdrawal rate; as well as limits of turbidity, temperature, and mineral and bacteriological quality of recharge water.

These recharge criteria were applied to areas of Illinois where aquifers were known to exist. Estimates were made of the potential artificial recharge into surface sands and gravels of the State, particularly in northeastern Illinois where population is dense and where withdrawals exceed natural and induced recharge. (Author's abs.)

Smith, S. C.

1964. (and Bittinger, M. W.). Managing artificial recharge through public districts: Jour. Soil and Water Conserv., v. 19, no. 1, p. 7–11.

Artificial-recharge operations generally require group action, commonly resulting in the formation of public districts which are public corporations empowered by the State to accomplish certain objectives for this purpose. Various characteristics of districts involved in the planning, financing, construction, and operation of artificial-recharge facilities are examined in this paper. (From authors' summ.)

Smith, W. O.

1967. Infiltration in sands and its relation to ground-water recharge: Water Resources Research, v. 3, no. 2, p. 539–555.

Several experiments on the mechanics of infiltration with sands and glass beads involve one or the other of the following: a bulk mass of liquid originating at the surface of the medium in a stream ranging from a thin thread to a sizable flow, a sheet of liquid laid entirely across the surface of the medium, and, finally, drops of liquid similar to raindrops falling on the surface. All result in virtually the same picture, that of a drop of liquid falling in a capillary tube.

The equations of capillarity are reviewed according to thermodynamics and are given in both differential and integral form. It is concluded that infiltration is a downward movement of water in bulk form under ordinary hydraulic laws, subject only to the reduced or otherwise altered pressures caused by capillarity within the bulk mass of liquid. Film flow appears to be confined to local flow to contact points, which situation is compatible with the condition that the free energy of capillary surfaces in a sand must be at a minimum. The results when applied to the infiltration process agree with field data. (From author's abs.)

Sniegocki, R. T.

1956a. (and Geurin, J. W.). Artificial-recharge experiments in the Grand Prairie region, Arkansas: Arkansas Water and Sewage Conf., 25th ann., Proc., v. 39, no. 9, p. 22–25.

The paper contains an outline of the testing procedures used and control points from which data were collected. The results of the first recharge test are discussed. (DCS)

1956b. Progress report on studies of artificial recharge in the Grand Prairie region, Arkansas: U.S. Geol. Survey open-file rept., 207 p.

The collection and interpretation of geologic and hydrologic data collected prior to recharge tests are discussed. Two artificial-recharge tests were made. The equipment, procedures, and data collected are included. (DCS)

1957. Artificial recharge experiments in the Grand Prairie region of Arkansas, *in* Ann. conf. on water for Texas, 3d, College Station, Tex., 1957, Proc.: Texas A&M Coll. System, Water Research and Inf. Center, p. 75–76.

After an initial test of recharging ground water through wells to determine the feasibility of well recharge under the most favorable conditions, surface water treated in various ways was then used in 10 other recharge tests in the Grand Prairie region where the main emphasis of the study was to investigate fundamental principles of well recharge under varying conditions. Well-clogging problems resulting from entrained air and precipitation of iron are discussed. (DJG)

1958. Tests show how recharge wells work: Johnson Natl. Drillers Jour., v. 30, no. 5, p. 6–7.

This report is a paper that was presented at the third annual conference "Water for Texas" at College Station, Tex., in September 1957.
See Sniegocki, R. T., 1957.

1959. Plugging by air entrapment in artificial recharge tests: Water Well Jour., v. 13, no. 6, p. 17–18, 43–44.

During experiments to determine whether untreated surface water could be used successfully to recharge the alluvial deposits of the Grand Prairie region of Arkansas, air entrainment resulting from the equipment arrangement was the most serious cause of plugging. Special redevelopment procedures, involving the use of sodium hexametaphosphate and vigorous surging and pumping, were necessary to restore the specific capacity of the well. (DJG)

1960. Ground-water recharge and conservation—effects of viscosity and temperature: Am. Water Works Assoc. Jour., v. 52, no. 12, p. 1487–1490.

Several recharge tests through wells were described. Two tests were made in which effects of water viscosity variation due to different water temperatures were observed. One test was made with water at an average temperature of 66°F, and the other, at 43°F. Native ground-water temperature was 65°F. Recharge specific capacity was 9.4 gpm per foot higher for the warmer water; computed temperature corrections applied to permeability would predict a difference of 8.7 gpm per foot. It was indicated that differences in recharge specific capacity and ground-water mound buildup during the two tests were caused by changes in the water viscosity. The problems arising from a ground-water temperature reduction were discussed. (DCS)

1962. (and Reed, J. E.). Principles of siphons with respect to the artificial recharge studies, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 15 p.

See Sniegocki, R. T., 1963b.

1963a. (Bayley, F. H., 3d., and Engler, Kyle). Equipment and controls used in studies of artificial recharge in the Grand Prairie region, Arkansas: U.S. Geol. Survey Water-Supply Paper 1615–C, 39 p.

The purpose of this report is to present information about the equipment, controls, and control procedures used during a series of recharge tests using waters of different quality and two differently constructed injection wells. (From authors' introd.)

1963b. (and Reed, J. E.). Principles of siphons with respect to the artificial recharge studies in the Grand Prairie region, Arkansas: U.S. Geol. Survey Water-Supply Paper 1615–D, 19 p.

In artificial-recharge experiments in the Grand Prairie region, siphoning has caused both favorable and adverse effects. This report discusses these effects and methods of utilizing or minimizing them. For any recharge rate, negative pressure exists in the injection line when water is siphoned into the recharge well. The length of the injection line in which the vapor-pressure limit prevails is principally controlled by the depth to water in the recharge well. Filtering through a closed system into the recharge well allows the negative head to increase normal filter-head loss and destroys filter effectiveness. A valve at the discharge end of the injection line provides a means of eliminating negative pressure in the line. (Authors' abs.)

1963c. Geochemical aspects of artificial recharge in the Grand Prairie region, Arkansas: U.S. Geol. Survey Water-Supply Paper 1615–E, 41 p., tables.

Chemical changes in the injected water and native ground water during artificial recharge through a well have an important bearing on the success or failure of recharge-well operation. In this study, the principal chemical changes observed that may cause clogging of the recharge well and aquifer were a change in calcium carbonate saturation of the injected and native water whereby the calcium carbonate precipitated, a precipitation of iron when reducing and oxidizing waters are mixed, an iron exchange and clay dispersion, and changes in water stability caused by water treatment. (From author's abs.)

1963d. Problems in artificial recharge through wells in the Grand Prairie region, Arkansas: U.S. Geol. Survey Water-Supply Paper 1615–F, 25 p.

Most of the problems of recharge through wells involve clogging of the well and aquifer. In this study, the principal causes of clogging were air entrainment, suspended particles in the recharge water, and micro-organisms. Other problems in operating a recharge well included the effects of injecting water with a high viscosity and the interpretations of water-level changes in the aquifer during recharge tests. The results of this investigation indicate that wells should be recharged with treated water. Water-treatment cost and contemplated use of the reclaimed water are the principal factors involved in determining the economic feasibility of artificial recharge (From author's abs.)

1964. Hydrogeology of a part of the Grand Prairie region, Arkansas, U.S. Geol. Survey Water-Supply Paper 1615-B, 72 p., tables.

The first phase of the study of artificial recharge through wells in the Grand Prairie consisted of the collection and interpretation of detailed geologic and hydrologic information in the vicinity of the proposed recharge test site. This report describes that investigation. (From author's abs.)

1965. (Bayley, F. H., 3d., Engler, Kyle, and Stephens, J. W.). Testing procedures and results of studies of artificial recharge in the Grand Prairie region, Arkansas, U.S. Geol. Survey Water-Supply Paper 1615-G, 56 p., table.

The purpose of this report is to present a summary of testing procedures, the pertinent data collected, the results of 23 recharge tests, and an estimation of the cost of recharging by methods used in the Grand Prairie study started in 1953. (From authors' introd.)

Soil Conservation Service

1967. Ground-water recharge: U.S. Dept. Agriculture, Soil Conserv. Service, Eng. Div., Tech. Release 36, 22 p.

This report presents a general review of the field of artificial ground-water recharge including criteria for artificial recharge methods and site selection, effect of water quality on recharge, evaluation of benefits and damages from artificial recharge, value of recharged water, and a few case histories. (DJG)

Sternau, R.

1966. Underground water storage study, recharge and mixing investigations at well Yarkon 4: Tel Aviv, Tahal—Water Planning for Israel, Ltd., Tech. Rept. 14, Pub. 478, 60 p. tables, pls.

The report describes a recharge-discharge test of a well in a karstic limestone carried out at high recharge rates, exceeding 1500 cu m per hr. Low recovery of the recharged water was obtained, presumably because of high natural flow rates in the aquifer. Chloride and radioactive cobalt-60 were used as tracers. (DCS)

1967. Artificial recharge of water through wells—Experience and techniques [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 91-100.

During recent years recharge operations were carried out in Israel in more than 100 wells. The amount of injected water totaled over 100 million cu m. In the wells of the limestone-dolomite aquifer, the recharge rates reached 2,000 cu m per hr and more during prolonged uninterrupted periods. The performance of the recharge wells was very satisfactory.

Experience shows that it is most unsuitable to recharge a well with free-falling water. In places where a locally confined limestone well was recharged by free-falling water, air was sucked into the well during the process. When the inflow of water was stopped, air was released and burst out powerfully from the well casing, the air gathering water on its way.

Much care had to be taken of wells where the limestone aquifer was directly overlain by layers of loose sand. Where the injected water rose up into the loose sand and then dropped upon stoppage of injection, subsidence of the ground occurred and caused complete loss of one well.

The two above-mentioned phenomena are discussed. Recommendations are made for adequate injection procedures and well construction.

Various types of installation were used in the recharge operations. These are described and discussed. The installations differ in cost and in injection rates. The choice of type of installation depends on the required hydrological benefits and on the type of operation (depending on whether a pause between injection and pumping is desired.)

The various techniques are compared and a proposal is made for a standardized cheap installation to be used in wells for both pumping and recharging. (Author's abs.)

Stevens, P. R.

1960. Ground-water problems in the vicinity of Moscow, Latah County, Idaho: U.S. Geol. Survey Water-Supply Paper 1460–G, p. 325–357, tables.

Consideration is given to augmenting the municipal ground-water supply with surface water of which 12,000 acre-feet is potentially available. Treated surplus water from this source could be used to replenish the artesian aquifer in the Moscow basin. Injection through wells is considered the most feasible way of recharge. (DJG)

Sunada, D. K.

1963a. Investigations on flow through porous media at the University of California, Berkeley, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 11 p.

Results are described of a porous-media model investigation of the hydraulics of flow near recharge wells, and glass bead-oil model studies of: (1) nonsteady flow from a large storage capacity well into unsaturated confined formations, and (2) the effect of boundary conditions such as size and shape of the surface recharge source and initial ground-water depths on the recharge rate from a surface cavity. (DJG)

1963b. (and Todd, D. K.) Radial flow behavior of artificial recharge from surface cavities: Berkeley, California Univ., Hydraulic Lab., 57 p.

This investigation presents a model study of several radial flow problems related to surface-water recharge operations. Boundary conditions of geometry and size of the recharge area and initial ground-water depths were studied. Conical and cylindrical recharge sources of various dimensions were used as the recharge area. Several ground-water depths were selected to evaluate the growth of ground-water mounds beneath a circular spreading area. In addition to the above boundary conditions, the effect of a silt layer around the recharge area was evaluated for the conical and cylindrical shapes.

A wedge-shaped porous-media model of lucite was employed for the flow tests. Glass spheres as the porous medium and mineral oil as the fluid made the medium translucent, so that the flow conditions were readily observable.

The time and space distribution of the flow from cavities of various shapes and sizes are presented graphically for ease in interpretation. It was found that for the same depth and radius, a cylindrical cavity was more efficient than a conical cavity in recharging water. An empirical steady-state flow equation which relates the flow from a cavity to its size and shape was obtained from the model data.

Model results indicate that theoretical contributions on the growth of a ground-water mound beneath a circular spreading area are difficult to apply to actual problems due to air entrapment beneath the recharge source. However, qualitative descriptions of the limitations of theoretical approaches are presented. (Authors' abs.)

Suter, Max

1954. High-rate artificial ground-water recharge at Peoria, Illinois, U.S.A.: Internat. Assoc. Sci. Hydrology Pub. 37, p. 219–224.

The pilot plant recharge operation consists of a pit 40 by 62.5 feet with sloping sides dug to a depth 10 feet below river pool stage and fed by gravity with screened and chlorinated river water. Some findings are: (1) most flow occurs through the sides of the pit, as flow through the bottom is slowed down by backwater effect, (2) hydraulic studies with a model and comparison of various existing pits show that the rate of inflow is higher in small pits than in large ones, other factors being equal, (3) rate of inflow depends more on the facility to get water away from the pit in the strata than through the bottom layer into the strata, (4) clogging of the filter bed is of minor importance, (5) effects of infiltration on chemical, temperature and bacteriological conditions are described. (From author's summ.)

1956a. High-rate recharge of ground-water by infiltration: Am. Water Works Assoc. Jour., v. 48, no. 4, p. 355–360.

The development, design, and operation of the recharge pit at Peoria, Ill., were discussed. High rates of recharge were obtained. Comparison of recharge from previous years showed the use of pea gravel instead of sand on the pit bottom had the greatest effect on increasing the rate of flow from the pit. (DCS)

1956b. The Peoria recharge pit—its development and results: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 82, no. IR–3, p. 1102–1117.

Research on artificial recharge was done in Peoria, Ill., by the State Water Survey to find methods for overcoming the losses in ground-water storage due to overpumpage. A method was found to obtain the high rate of inflow of from 23 to 27 mgd per acre. Many types of hydrologic, chemical, and bacterial observations were made. Some of the relations found cannot yet be explained. (Author's synopsis.)

1959. Artificial ground-water recharge at Peoria, Illinois: Ill. State Acad. Sci. Trans., v. 52, no. 3, 4, p. 96–99.

Owing to economic considerations, artificial-recharge operations designed for a high rate of recharge over a small area consisted of pits rather than wells. The progress made on artificial ground-water recharge by use of these pits is discussed. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1960. (and Harmeson, R. H.). Artificial ground-water recharge at Peoria, Illinois: Illinois Water Survey Bull. no. 48, 48 p.

This report summarizes research and demonstration of the pit method of artificial recharge at Peoria and its contribution to solution of the problem of declining ground-water levels.

Described in this report are the types of recharge pits and operating techniques developed by the Illinois State Water Survey and those which were built by local industries. Summaries of operating records over an 8-year period show capacity and cost information. (From authors' abs.)

Task Group 2440–R on Artificial Ground-Water Recharge

1956. Artificial ground-water recharge: Am. Water Works Assoc. Jour., v. 48, no. 5, p. 493–498.

A summary of developments in ground-water recharge subsequent to the 1952 report is contained in the article. Answers from States to questions concerning legislation, underground disposal, present recharge practices, and future possibilities were reported. (DCS)

1958. Developments in artificial ground-water recharge: Am. Water Works Assoc. Jour., v. 50, no. 7, p. 865–871.

Recharge projects and development by States are summarized from returns of a questionnaire sent in 1957. Answers from States to questions pertaining to various aspects of artificial ground-water recharge were reported. Data giving recharge rates were included in the report. (DCS)

1960. Developments in artificial ground-water recharge in the United States: Am. Water Works Assoc. Jour., v. 52, no. 2, p. 1220–1224.

Results of a biennial questionnaire circulated in 1959 are reported. Information concerning national and State legislation, recharge activities in several States, and past studies was presented. (DCS)

1960b. Purposes of artificial recharge: Am. Water Works Assoc. Jour., v. 52, no. 10, p. 1315–1318.

The purposes for which artificial recharge is practiced were enumerated. Illustrations of each purpose were made by presenting an example of an operating or experimental installation along with a brief discussion. (DCS)

1963a. Design and operation of recharge basins: Am. Water Works Assoc. Jour., v. 55, no. 6, p. 697–704.

A general discussion of recharge basins including purposes, geologic considerations, design details, construction, and operation is made. Specific examples of use and operation are presented. (DCS)

1963b. Artificial ground-water recharge: Am. Water Works Assoc. Jour., v. 55, no. 6, p. 705–709.

Results of a biennial questionnaire are reported. Recharge in various States is discussed and data are presented concerning different aspects of

artificial recharge such as types reported by State, acreages used, and infiltration rates. (DCS)

1965. Experience with injection wells for artificial ground-water recharge: Am. Water Works Assoc. Jour., v. 57, no. 5, p. 629–639.

A comprehensive review of recharge-well construction and operation is presented. (DCS)

1967. Artificial ground-water recharge: Am. Water Works Assoc. Jour., v. 59, no. 1, p. 103–113.

Results of the Task Group's biennial questionnaire are reported. Reports of special interest were received from Illinois, Nevada, New Jersey, and Ohio. Replies to the questionnaire concerning various aspects of ground-water recharge are discussed. Data are presented on infiltration rates of the Peoria recharge pits, irrigation-water recharge to ground water, and irrigation-water recharge from wells and surface water. (DCS)

Taylor, G. H.

1961. Recharging ground-water reservoirs: U.S. Geol. Survey open-file rept., 31 p.

A simplified version of artificial ground-water recharge for the layman is presented in the form of questions and answers. (WK)

Taylor, L. E.

1964. The problem of ground-water recharge—with special reference to the London Basin: Inst. Water Engineers Jour. v. 18, no. 3, p. 247–254.

Selected artificial-recharge operations in Germany, Sweden, and the United States are reviewed as well as various recharge possibilities in overpumped areas in the London Basin. (DJG)

Thomas, R. O.

1955. General aspects of planned ground-water utilization: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 81, Paper 706, 11 p., tables.

This paper briefly reviews the legal status of ground water in California, discusses the present development of ground-water supplies with particular reference to current problems caused by haphazard development, recommends a suitable organization for full beneficial control and use of available water supplies through coordinated use of surface- and ground-water storage capacity, discusses briefly the probable outstanding problems of such coordination operations, and concludes with an illustrative operational example of the benefits attributable to the planned utilization of underground storage. (Author's synopsis.)

1961. Legal aspects of ground-water utilization: Am. Soc. Civil Engineers Trans., v. 126, pt. 3, Paper 3238, p. 633–654.

The historical basis of water-rights doctrines, their application to rights to the use of ground water, general considerations affecting the regulation of rights, and various aspects of ground water utilization, including problems of recharge and water demand, are presented. A presentation is made of some of the possible legal-problem areas that may arise in planning and administering future ground water operations. (Author's synopsis.)

Thomasson, H. G., Jr.

1960. (Olmsted, F. H., and LeRoux, E. F.). Geology, water resources, and usable ground-water storage capacity of part of Solano County, California: U.S. Geol. Survey Water-Supply Paper 1464, 693 p., tables.

A part of this study deals with the artificial recharge necessary to the utilization of the artificial reservoir capacity of 400,000 acre-feet in the Putah area. This recharge can be accomplished in one or more ways. The most important possibility appears to be in the application of imported water to the lands for the irrigation of crops. The channels of Putah Creek and of the small stream to the south offer natural recharge facilities that might permit the conservation of 100,000–150,000 acre-feet in a period of 5–10 wet years. Spreading ponds on the more permeable soils might be needed to distribute the recharge properly. The use of wells or shafts, however, appears to be the least practicable because of the difficulty in getting large rates of flow into and away from them in most of the area. (From authors' abs.)

Tiemer, Klaus

1967. Sur le probleme de l'emmagasinement souterrain des eaux superficielles par infiltration artificielle dans des zones de rebattement [The problem of underground storage of surface water by artificial recharge in cones of depression] [in French with English abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 229–236.

Commonly, the underground storage of surface water influences the groundwater regime in an extensive area. The influences are to be estimated in advance, particularly if the intensity of the artificial infiltration varies in time. For these purposes, a suitable mathematical model is developed. The possibilities of the practical application are discussed. (Author's abs.)

Tixeront, J.

1967. (and Daniel, J. M.). Alimentation et suralimentation des nappes souterraines—observation d'un cas de suralimentation par pompage L'oued, BISKRA, Algérie[Recharge and induced recharge of ground water—Observation of a case of induced recharge by pumping, Wadi BISKRA, Algeria] [in French with English abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 173–181.

Artificial recharge of aquifers is considered under different points of view. An analysis in depth of natural-recharge conditions is outlined as essential to operate an artificial-recharge plant.

Water quality, particularly with respect to suspended load, is presented as the main factor of this analysis. Drying of mud crust after floods and blowing by wind during summer could explain the continuous recharge of arid-zone aquifers, in spite of decreasing surface permeability of alluvial deposits during the floods under effect of mud load.

The study at Wadi BISKRA, Algeria, gives an example of such a process and shows the regularization of discontinuous recharge into a continuous discharge through an underground reservoir. Moreover this example shows that recharge can be induced by modifying the initial natural state by pumping.

Starting from observed variations of ground-water level under the effects of floods and computing the daily natural rate of recharge into the reservoir, it has been possible to calculate the optimal value of useable discharge of

the ground-water reservoir by means of an analog model. (From authors' abs.)

Todd, D. K.

1959a. Annotated bibliography on artificial recharge of ground water through 1954: U.S. Geol. Survey Water-Supply Paper 1477, 115 p.

Domestic as well as available foreign references on artificial ground-water recharge are listed and annotated. (DJG)

1959b. Ground-water hydrology: New York, John Wiley & Sons, Inc., 336 p.

A comprehensive account of the fundamentals and recent methods and problems encountered in the field of ground-water hydrology is given. The subject of artificial recharge of ground water is covered where a description of the several methods is summarized. Data on artificial recharge in many parts of the United States and Sweden are cited and tabulated. (WK)

1960. Salt water intrusion of coastal aquifers in the United States [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 52, p. 452–461.

The paper describes the occurrence of salt-water intrusion, originating from connate or oceanic sources, in coastal aquifers of the United States. The present status of intrusion in 23 coastal States is reviewed. Mention is made of areas, causes, effects, remedial measures (including artificial recharge), and future possibilities of intrusion. Advances in knowledge of intrusion and current research are reported. An understanding of the hydrodynamics of the phenomenon is developing. Particularly significant is progress in analysis of the formation and maintenance of the interfacial transition zone. (Author's summ.).

1961. The distribution of ground water beneath artificial recharge areas: Internat. Assoc. Sci. Hydrology Pub. 56, p. 254–262.

The time and space distribution of ground water below artificial recharge areas is analyzed for idealized conditions. Assuming constant recharge into a homogeneous horizontal formation, good approximations to the unsteady ground-water distributions can be obtained. Effects of finite and infinite boundary conditions are considered for their longitudinal influence on flows. The importance of geometric variables such as size of recharge basin, depth to ground water, and thickness of the formation is reviewed. Practical problems of recharge into layered and nonhomogeneous formations are discussed. Mdoel techniques for studying flows from recharge areas where analytical approaches cannot be applied are described and results from experiments in progress are presented for illustration. (Author's abs.)

1962. (and Marmion, K. R.). Artificial recharge research in the Hydraulic Laboratory, University of California, Berkeley, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif., 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 2 p.

Research underway included: (1) solving Philip's theoretical equation for infiltration of water into porous media for specific boundary conditions, (2) model study of subsurface flow below recharge areas, (3) a model and analytical study of the effects of nonhomogeneous flow, and (4) flow of fluids from

recharge wells connected with large underground cavities in permeable formations. (DJG)

1964. Ground water, *in* Chow, V. T., ed., Handbook of applied hydrology: New York, McGraw-Hill Book Co., Inc., sect. 13, p. 1–55.

Practices, methods, and problems of artificial recharge are summarized. Data for California agencies conducting recharging, types and numbers of recharge projects, and quantities of water recharged during the 1957–58 season are cited and tabulated. Spreading-basin and well-recharge rates for numerous areas in the United States are also cited. (WK)

1965a. Economics of ground water recharge: Am. Soc. Civil Engineers Proc., Hydraulics Div. Jour., v. 91, no. HY–4, p. 249–270, tables.

The author summarizes benefits and alternatives to artificial recharge, reviews cost components of artificial recharge projects, and summarizes costs of selected recharge projects. On the basis of economic data available, the writer concludes that the variables governing costs and benefits of artificial recharge preclude development of any concise summary; however, the data presented can be of assistance to engineers concerned with planning and designing such projects. (WK)

1965b. Nuclear craters for ground water recharge: Am. Water Works Assoc. Jour., v. 57, no. 4, p. 429–436.

Technical and economic considerations of constructing nuclear craters for basin storage and artificial ground-water recharge were made. Properties of nuclear craters were discussed. Cost data were given and an economic comparison between a crater project and a conventional reservoir and basin project was made. Safety considerations were also presented. (DCS)

Toups, J. M.

1963. Spreading for ground water recharge in the Orange County Water District, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 3 p.

Spreading of 240,000 acre-feet per year will be sufficient to fill the Orange County Water District basin with between 300,000 and 500,000 acre-feet of remaining storage. Tentative plans call for using reclaimed sewage and imported water to create mounds at strategic places for protection against salt-water intrusion in the basin.

Operations at the Santa Ana River spreading grounds and at the new Carbon Creek spreading ground, including the 64-acre Crill Pit where current spreading rates exceed 3 vertical feet per day, are discussed. (DJG)

Trauger, G. W.

1962. (and Trauger, F. D.). Description of an early experiment in ground-water recharge through wells at Lindsay, California [abs.]: Jour. Geophys. Research, v. 67, no. 9, p. 3534.

In the winter of 1931–32, the Lindsay-Strathmore Irrigation District used its facilities to recharge privately owned wells with surface water brought by canal and flume from the Kaweah River. The water injected into the wells was free of suspended sediments, low in dissolved solids, screened, and chlorinated. A total of 1,914 acre-feet of water was injected into 75 wells in a period of 3.5 months. The temperature of the water pumped during the subsequent irrigation season indicated that most of the recharge water was recovered. No case of well failure or damage was reported. (Abs. in Jour. Geophys. Research)

Trueb, Ernst

1962. Hydrological interpretations of temperature measurements in ground-water currents, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 3d, Berkeley, Calif. 1961, Proc.: Fresno, Calif., Soil and Water Conserv. Research Div., Southwest Br., Ground-Water Recharge Lab., 8 p.

Approximate equations dealing with temperature gradient permit the development of information about ground-water flow in Switzerland. Sufficient measurements at numerous depths in the profile provide information on the porosity of the gravel and its temperature characteristics. For the interpretation of the results of pumping experiments, continued temperature measurements are a helpful approach to the understanding of the influence of infiltration. (From author's summ.)

Uppal, H. L.

1966. (and Khanna, P. L.). Artificial charging of brackish ground water: Irrig. and Power [India], v. 23, no. 2, p. 151–162.

In the first part of this paper the authors review the advantages, necessity, and methods of ground-water recharge. Artificial charging is a useful measure of enriching the underground water with good water, in areas of excessive salinity, and of raising the water level.

Following the general review the authors state that this measure is being tried in Rewari Tehsil where it is proving quite useful.

The object in introducing the measure of artificial charging is not to improve the entire ground water of the areas, as its quantity is unlimited as compared to the stream water which can be sent underground, but to superimpose it with fresh water. The results so far achieved show a favorable trend inasmuch as the water table has risen in the sowing season, and withdrawal from wells has thus been facilitated. The quality of water has also improved to some extent. (From abs. in Water and Water Eng.)

Vachaud, Georges

1967. Étude de la valeur du coefficient d'emmagasinement des nappes à surface libre, considerant l'écoulement dans la zone non satureé [On the storage coefficient of unconfined aquifers, considering the flow in the unsaturated zone] [in French with English summ.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 69–82.

It is generally assumed that the flow of water, per unit volume of soil, after a change of the water-table level in an unconfined aquifer, is given by the specific yield or effective porosity.

During drainage or recharge of the aquifer, the moisture profiles above the water table will tend towards a limit, given by the corresponding branch of the capillary pressure-moisture content curves, and the storage coefficient reaches a constant value after a certain period of time *t*, depending upon the permeability of the material. Furthermore, that limit is a function of the drawdown, and the storage coefficient is equal to the specific yield only in the case of a very large drawdown.

Taking into account the initial depth of the water table and considering equilibrium conditions of drainage, the storage coefficient is dependent on: (1) the initial depth *H* of the water table, and (2) the drawdown *Z*. For a given drawdown *Z*, the value of the storage coefficient does increase when *H* increases and reaches a constant limit—equal to the specific yield—for a critical depth corresponding to the suction for which the residual moisture content is attained. For values of *H* larger than this critical depth, the storage coefficient is constant and independent of *Z*.

Using the capillary pressure-moisture content curves, we have computed, for different types of soil, the values of the storage coefficient as a function of *Z* and *H*. The results obtained give the amount of the error made in considering the initial assumption. It is very easy to apply that method to recharge problems. The next step will be to consider the time-dependent value of the storage coefficient given *H* and *Z*. (From author's summ.)

Valliant, J. C.

1960. Ground-water recharge and soil management: High Plains Research Found. Rept. 2, 3 p., Halfway, Tex.

Research on an experimental recharge well is described. The effect of silt, the movement of water underground, and the effect of chemicals on the water are being studied. Data are given on the amount of recharge and pumpage in 1959 and economic considerations are discussed. (DCS)

1961a. Artificial ground-water recharge: High Plains Research Found. Rept. 18, 8 p., Halfway, Tex.

The paper presents a general discussion of the need for artificial recharge in the High Plains of Texas. An experimental recharge well and its operation are described. Use of flocculating agents and mechanical filters to remove suspended materials is discussed. (DCS)

1961b. How to install and operate a recharge well: High Plains Research Found. Rept. 23, 3 p., Halfway Tex.

Construction and operation of a recharge well for utilization in recharging playa-lake water are described. (DCS)

1962. Artificial recharge of surface water to the Ogallala Formation in the High Plains of Texas: High Plains Research Found. Bull. 1, 17 p., Halfway, Tex.

Recharge studies and operations conducted from June 1959 to June 1962 showed that artificial recharge of ground water through properly installed and maintained wells is a practical means of replenishing the underground water source in the High Plains of Texas. A total of 325 acre-feet of untreated playa-lake water was recharged through two research wells. Installation and operating procedures to obtain a properly functional recharge well are discussed. Rate of recharge is the main controlling factor in recharge of raw lake water. No reduction in pumping capacity or recharge rate (850 gpm) has resulted due to pumping and surging practices. (From Abs. of Recent Pub. Material on Soil and Water Conserv.)

1963. Artificial recharge of surface water to the Ogallala Formation in the High Plains of Texas, *in* West Texas water conf., 1st, Lubbock Tex., 1963, Proc.: Lubbock, Texas Technol. Coll., West Texas Water Inst., p. 60–64.

Artificial recharge through dual purpose wells, mechanical filter systems, and chemical flocculants under study were discussed. A total of 325 acre-feet of water recharged in a 3-year period constituted 32 percent of the pumpage on the research farm for the same period. Some privately owned recharge wells utilized to recharge untreated playa-lake water had been in operation for 10 years. It was concluded that recharge through properly installed and maintained wells is practical. (DCS)

1963b. Artificial recharge of surface water to the Ogallala Formation in the High Plains of Texas, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 7 p.

Well-maintenance practices, including proper development, and filtration and chemical-treatment practices for the removal of suspended sediments from playa-lake water which is injected through multipurpose wells in studies by the High Plains Research Foundation are described. (DJG)

1964. Artificial recharge of surface water to the Ogallala Formation in the High Plains of Texas: Ground Water, v. 2, no. 2, p. 42–45.

In 1957, the High Plains Research Foundation, Halfway, Tex., initiated a full-scale program to investigate all factors affecting the recharge of surface water to the ground-water formation. Some of the factors being investigated and studied are: rate of recharge, effects of solids contained in the lake water being recharged, maintenance practices, and evaluation of different filtering materials. This program was started because of concern about the declining water table and the potential of the lakes as a means of recharging the formation.

Artificial ground-water recharge in the High Plains is accomplished by injecting water collected in playa lakes into a well constructed for this purpose. Either by gravity or pumping, water is placed back into the underground formation through the well casing in reverse of the pumping process. These wells can be used for irrigating crops as regular irrigation wells. (Author's abs.)

1965. Research with multiple-purpose (recharge) wells and artificial recharge of run-off water in the Texas High Plains, *in* West Texas water conf., 3d, Lubbock, Tex., 1965.: Lubbock, Texas Technol. Coll., West Texas Water Inst., p. 94–96.

Experimental recharge of playa-lake water through irrigation at the High Plains Research Foundation is reviewed. Recharge and irrigation pumpage for the period 1959 through 1964 were 499 and 1778 acre-feet respectively. Mechanical filters for suspended-sediment removal proved unsuccessful; however, chemicals and grass filtration were being investigated. Pollution research and storage aspects of recharge were discussed. (DCS)

1966. Managed recharge can work for you: Irrig. Age, v. 1, no. 4, p. 38–39.

Ground-water recharge is discussed and examples of multiple-purpose wells used for recharge and irrigation in the High Plains of Texas are cited. Utilization of grasses to assist in removing suspended solids from surface runoff water in playa lakes is also discussed. (DCS)

1967. Ground-water recharge research—High Plains Research Foundation, *in* West Texas water conf., 5th, Lubbock, Tex., 1967, Proc.: Lubbock, Tex., Texas Technol. Coll., West Texas Water Inst., p. 75–78.

Declining water level in the Ogallala Formation and the supply of surface runoff into playa lakes are discussed. An example of recharge well installation and of its operation resulting in clogging the well is described. Other examples of recharge well installations and their use to drain playa lakes were cited. (DCS)

Van Haaren, F. W. J.

1965. Infiltratie van water van de Lek in de duinen [Infiltration of river water in a dune area] [in Dutch with English summ.]: Water [Netherlands], March 1965, p. 61–68.

Water from the River Lek, a branch of the Rhine, is being infiltrated in a dune area in the North Sea coast near Haarlem, Holland. The infiltration system, built and owned by the Municipal Water Works of Amsterdam, comprises infiltration basins, capturing canals, and drainage systems. These are described in some detail and technical information on water velocities in the system, retention time, and capacity, is given. Before infiltration, the river water, the quality of which is rather variable (graphs are given), is prefiltered and chlorinated. Improvement of chemical, radiological, and bacteriological quality during infiltration is described. Experience gained here during 7 years of successful artificial-recharge operation of a dune-water catchment area has shown that underground storage is a valuable method from the point of view of quantity as well as quality. (From abs. in Water and Water Eng.)

Venhuizen, K. D.

1967. The storage capacity in the dunewater catchment area of Amsterdam and its effect on the water quality [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 109–123.

The dunewater catchment area of Amsterdam is situated south of Zandvoort and covers approximately 3,650 hectares.

The extraction of water was started in 1853 by means of open canals, later on also by means of wells.

By 1915, the amount of the extraction equaled the total effective rainfall. After that, more water was extracted than percolated in the dune area. Since 1957 part of this area is being infiltrated with prefiltered water from the Rhine River, transported by a pipeline with a total length of 53 km. The infiltration water is captured by means of horizontal drains, which carry it to the open canals. At present the infiltration area is about 430 hectares and the maximum capacity amounts to 70 million cu m per year. In another part of the dunes, storage canals have been built with a total storage capacity of 10 million cu m. The infiltration area combined with the storage capacity and well system fixes the probable aggregate capacity at 82 million cu m per year. By mixing the types of water by a preconceived method, it is possible to influence the quality of the final product. (Author's summ.)

Vibert, A.

1965. Un aspect essentiel de la realimentation artificielle des gisements aquifers naturels [An essential aspect of ground-water recharge]: L'Eau [France], v. 52, p. 227–232.

Artificial recharge, having become increasingly necessary in many parts of the world, has led to many problems of ground-water contamination and of reduction of permeability. The recharging waters should usually receive preliminary treatment.

Other problems of quality degradation of ground water are due to inflows from salt water or from polluted rivers, such as the Seine at Croissy. Water-table elevations must be kept high enough to prevent these incursions. A mound of recharge water of acceptable quality is often the best solution. (Abs. in Texas Water Devel. Board Rept. 8,)

Viparelli, M.

1961. Les courants d'air et d'eau dans les puits verticaux [Air and water currents in vertical shafts] [in English and French] La Houille Blanche [France], v. 16, no. 6, p. 857–869.

When the shaft inlet and outlet pressures are equal, the water falls freely along the walls. At low discharges, a central air core forms, surrounded by an annular flow of water; at high discharges, the air core breaks up into large bubbles or air pockets. At both discharges, the air velocity tends more and more towards the water velocity as the length of the shaft increases.

When the pressure at the outlet exceeds that at the inlet, a hydraulic jump generally forms in the lowest part of the shaft. If the jump is complete, the air entrainment rate depends on both the free-falling distance of the water alone and the flow down stream. If the jump is incomplete, the air flow depends on the water velocities before they are damped out by the very agitated conditions in the jump. Air-to-water discharge ratios for some of the cases described are given in terms of pressure difference between the shaft inlet and outlet and of the free-falling distance of the water. (From author's abs.)

Walker, T. R.

1961. Ground-water contamination in the Rocky Mountain Arsenal area, Denver, Colorado: Geol. Soc. Am. Bull., v. 72, no. 3, p. 489–494.

Improper waste-disposal practices by spreading in surface waste basins have been responsible for contamination of the underlying ground-water aquifer by unintentional artificial recharge. Contaminated ground water within the affected area is toxic to agricultural crops and unpotable for humans. Corrective measures have been taken to halt further contamination but the area of toxicity is expanding owing to migration of the body of ground water already contaminated. (WK)

Walton, W. C.

1964. Estimating the infiltration rate of a stream-bed by aquifer-test analysis: Internat. Assoc. Sci. Hydrology Pub. 63, p. 409–420, tables.

The nonequilibrium formula, the image-well theory, and aquifer-test data for observation wells near a stream and within the streambed area of infiltration are used to determine the hydraulic properties of an aquifer, the amount of water being diverted from a stream, the streambed area of infiltration, the average head loss due to vertical percolation of water through the streambed, and the infiltration rate per foot of head loss.

Potential recharge by the induced infiltration of surface water is evaluated from the computed infiltration rate and streamflow records, the variability of the viscosity of water with temperature changes being taken into consideration.

Methods used in quantitatively appraising the infiltration rate of a reach of the streambed of the Mad River near Springfield, Ohio, are described. Infiltration rates range from 39,800 to 1,000,000 gpd per acre of streambed per foot of head loss. (From author's abs.)

1966. (and Ackroyd, E. A.). Effects of induced streambed infiltration on water levels in wells during aquifer tests: Minnesota Water Resources Research Center Bull. 2, p. 43, tables.

Electric analog computers, in which the streambed is simulated as an area of recharge in accordance with natural conditions instead of as a recharging image well, were used to appraise the accuracy of estimated effects of induced infiltration on water levels based on the image well theory. Electric analog computers for two aquifer test sites for which field data are available were constructed. The selected aquifer test involves two aquifer-stream situations: (1) where the cone of depression spreads beneath and beyond the entire streambed, and (2) where the cone of depression spreads only part way beneath the streambed.

It is concluded that, during induced infiltration aquifer tests, the image-well theory closely describes drawdowns on the land sides of streams with a high degree of accuracy whether the cone of depression spreads beneath and beyond or only part way beneath the streambed. Drawdowns beneath and beyond the streambed and the streambed areas of infiltration based on the image-well theory are not those which are observed in the field. However, the streambed infiltration rates per foot of head loss, based on hypothetical drawdowns beneath streambeds and streambed areas of infiltration computed with the image-well theory, seem to be empirically correct. (From authors' abs.)

1967. (Hills, D. L., and Grundeen, G. M.). Recharge from induced streambed infiltration under varying ground water-level and stream-stage conditions: Minnesota Univ. Water Resources Research Center Bull. 6, 43 p.

An aquifer-stream system was studied using electric analog computers and analytical methods to gain information regarding the magnitude of induced recharge. Factors which must be considered to obtain valid estimates of recharge were dealt with. (DCS)

Warner, D. L.

1965. Deep-well injection of liquid waste. A review of existing knowledge and an evaluation of research needs: Public Health Service Pub. 999-WP-21, 55 p.

A review of the knowledge pertinent to the use of deep wells for the subsurface injection of liquid waste has been carried out to evaluate the technical and economic feasibility and desirability of this method and to outline existing research needs. This review has shown that the deep-well injection of liquid waste is technically feasible to many areas of the country and, if properly planned and implemented, is not likely to be harmful to natural resources. While most of the technical knowledge and experience necessary to carry out the deep-well injection of liquid waste is presently available, further investigation is necessary to solve specific problems that remain as barriers to the safe, efficient, and economic use of this method. (Author's abs.)

1966. Deep well waste injection-reaction with aquifer water: Am. Soc. Civil Engineers Proc., Sanitary Eng. Div. Jour., v. 92, SA–4, p. 45–69.

A theoretical and laboratory study was made of the mixing between interstitial and injected waters in porous media and the effect of this mixing on permeability when the liquids involved react to form a precipitate.

The mixing that occurred during the displacement of various solutions from a column of unconsolidated sand was a result of hydrodynamic dispersion. Once the dispersive character of the porous medium was determined, the amount of mixing and the amount of chemical reaction between the displacing and displaced solutions could be quantitatively predicted adequately.

The precipitates formed during the displacement of barium chloride by ammonium sulfate and during the displacement of calcium chloride by sodium sulfate were not found to cause measurable permeability reduction. The ferric hydroxide precipitate formed during the displacement of ferric chloride by ammonium hydroxide reduced the permeability of the sand column by about 30 percent.

A zone of nonreactive solution injected between two reactive solutions prevented any reaction. The minimum size of the zone necessary to prevent reaction in the laboratory experiment was determined from dispersion theory. (From author's summ. and conclusions.)

1967a. (and Doty, L. F.). Chemical reaction between recharge water and aquifer water [with French abs.]: Internat. Assoc. Sci. Hydrology Pub. 72, p. 278–288.

Chemical reaction between recharge water and aquifer water may influence water quality and aquifer permeability and may cause fouling in discharge wells. However, evidence suggests that the danger of permeability reduction may not be very great.

Precipitates of calcium and magnesium carbonate and iron compounds are most likely reaction products.

The amount and distribution of reactive chemicals remaining in solution can be related to the dispersive characteristics of a porous medium. Reactions of various rates are considered.

It may be desirable to prevent reaction. It is suggested that, in some cases, this can be accomplished by emplacing a buffer zone of nonreactive water between the recharge water and aquifer water. (Authors' abs.)

1967. Deep wells for industrial waste injection in the United States, summary of data: Federal Water Pollution Control Adm., Water Pollution Control Research Ser. Pub. WP–20–10, 45 p.

This publication contains a summary of data for deep wells used for industrial waste injection and some of their characteristics including: operation, location, well depth, depth of injection horizons, geologic formation used for injection, chemical and physical character of waste, injection rate, injection pressure, and sources of information. The data cover 110 wells from 16 States. (DJG)

Warnick, F. M.

1955. (and Greenhalgh, W. H.). Ground water and drainage problems of the Weber Basin project Utah: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 81, Paper 619, 7p.

Recharge experiments have shown that the Weber River recharge area has a high infiltration rate and indicate that artificial recharge is feasible. The amount of water dissipated in a recharge pit, having a maximum surface area of 3.25 acres during the 7-week test period, totaled 2,172 acre-feet. This amounts to an average continuous intake of about 7 cfs per acre for the entire period of the experiment. The intake fluctuated between 5 and 9 cfs per acre, generally increasing from a lower to higher rate as the experiment proceeded. The recharge affected the water levels in an observation well one-fourth of a mile west of the recharge pit. The overall rise in water level amounted to 34.3 feet, reaching a high point on March 26, 1953, and being 141.3 feet below ground surface at that time. (WK)

Watt, A. K.

1958. Ground-water problems and recharging operations: The Municipal Utilities Magazine [Canada], July, p. 46–55, 76–79.

The recharge of wells which can be increased indirectly or directly is briefly discussed. One form of indirect recharge is the placing of wells close to a stream or lake into which the aquifer normally discharges. By lowering the water levels in the region of the pumped wells sufficiently, a reversal in hydraulics gradient will be set up, inducing recharge into the aquifer. Direct methods of recharge can be divided into two categories: (1) recharge by some form of surface application, and (2) recharge through wells. (From abs. in Water and Water Eng.)

Wegenstein, M.

1954. La recharge de nappes souterraines au moyen de puits centraux et galeries d'alimentation horizontales [Recharge of aquifers by means of horizontal collector wells] [in French with English summ.]: Internat. Assoc. Sci. Hydrology Pub. 37, p. 232–237.

A new and very efficient method of recharge has been realized by adopting horizontal type collector wells introducing the surface water into the ground-water stream.

In artificial recharge, the surface water is to be cleaned of its coarser suspended particles. The remaining mineral pollution, however, still causes a slow but steadily increasing clogging. It therefore has to be removed from time to time. In comparison with common vertical wells where this cleaning proves to be very intricate and rather uncertain as to its effects, the horizontal type collector offers great advantages. During the period of infiltration, all valves mounted on the 10 to 20 horizontal screen pipes remain open, resulting in a minimum inlet velocity for the surface water entering the water-bearing stratum. During the cleaning procedure, however, when the direction of flow is reversed, one valve only is open at a time, while the others are closed. Since the whole discharge has to pass through the gallery pertaining to the one open valve, the scouring velocity is far greater than the infiltration velocity. Thus, all impurities which have entered the ground during the period of infiltration are washed out. (From author's summ.)

Welsch, W. F.

1956. Conservation of ground water: Water and Sewage Works, v. 103, no. 10, p. 468–473.

A description of the recharge basins and diffusion wells used to conserve ground-water supplies on Long Island, N.Y., is given. (DJG)

1959a. Replenishment of ground water by artificial recharge of storm water runoff Nassau County, New York, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 44–47.

Recharge basins used in Nassau County are described. The combined capacity of a settling basin and infiltration basin is sufficient to impound the estimated runoff from the tributary watershed area caused by a 5-inch rainfall in 2 days which statistically occurs every 5 years. At present, approximately 123 acre-feet per day is recharged; future development may ultimately increase this to 215 acre-feet per day. (DJG)

1959b. Storm water recharge on a wholesale basis: Water Works Eng., v. 112, no. 10, p. 906–907, 935.

The successful replenishment of sand and gravel aquifers on Long Island, N.Y., through storm-water recharge basins is discussed. Approximately 40 mgd and 10 mgd are estimated to be annually recharged in Nassau and Suffolk Counties respectively. (DJG)

1960. Ground-water recharge and conservation—Conservation in Nassau County: Am. Water Works Assoc. Jour., v. 52, no. 12, p. 1494–1498.

A discussion of ground-water recharge through basins and wells on Long Island, N.Y., was presented. Salt-water encroachment resulted from overdrafts on ground-water reservoirs. Aquifers are being recharged by storm runoff and uncontaminated waste water to halt encroachment and conserve ground-water supplies. (DCS)

Whetstone, G. A.

1955a. Replenishment of ground-water reservoir practices being studied: Cross Section, v. 1, no. 7, p. 1, 3.

A survey is made of a number of examples, methods, and problems of artificial recharge in California; Brooklyn, N.Y.; Louisville, Ky.; and El Paso, Tex. Methods reviewed include spreading, ditches or furrows, pits and wells. (WK)

1955b. Replenishment of ground-water reservoir practices being studied: Cross Section, v. 1, no. 8, p. 1.

Several promising methods of artificial recharge are suggested as applicable to the High Plains of Texas, such as "sausage" dams for water spreading, various types of surface treatment to increase infiltration, collection and return of clean process water, and the use of wells and pits. (WK)

1956. Artificial recharge through tunnels [abs.]: Am. Water Well Assoc. Jour., v. 48, no. 11, p. 1444.

At Famagusta, Cyprus, ground-water recharge through wells was increased by connecting the wells, just above the water table, with a horizontal tunnel. It is suggested such a method merits consideration at other locations. (DCS)

1957. Replenishment of ground-water reservoirs: Water Power, v. 9, no. 8, p. 297–300.

This article contains a general discussion of artificial recharge, its advantages, some criteria for selecting sites, methods of recharging, and recharge

in power schemes. Several examples are cited and references are included. (WK)

White, A. H., Jr.
1958. Artificial recharge wells in Texas High Plains will aid in prolonging area economy: Cross Section, v. 4, no. 11, p. 3–4.

Recharging underlying formations through wells in the High Plains of Texas by surface runoff which collects in lakes appears to be one major solution to the problems confronting the area in prolonging its present agricultural, industrial, and municipal economy. (WK)

1959. Underground water district promotes water conservation programs: Cross Section, v. 6, no. 5, p. 2–3.

Functions of the Texas High Plains Underground Water Conservation District, including its artificial-recharge practices and research studies, are described. (DJG)

Whitfield, M. P.
1963. Ground-water recharge operations of the Alameda County Water District, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge and ground-water basin management, 4th, Berkeley, Calif., 1963, Proc.: Fresno, Calif., Ground-Water Recharge Center, 4 p.

District activities in the Alameda Creek alluvial fan ground-water basin include increasing use of off-stream spreading areas, storage of flood flows in the proposed Del Valle Reservoir, and use of available gravel pits for recharge operations. (DJG)

Wichman, S. H.
1967. (and Ahlers, G. K.). Recharging conserves nuclear reactor cooling water: Water and Wastes Eng., v. 4, no. 3, p. 79–81.

After untreated well water is used to cool a closed loop of highly purified water which in turn cools a nuclear reactor, it is then piped into one of two basins for recharge in Upton, Long Island, N.Y. A sustained percolation rate of 4 inches per minute is attributed to: (1) sandy soil of the recharge basin, (2) location of the recharge basin on high ground, and (3) alternate daily use of the two recharge basins. No measurable increase has been found in the ground-water temperature, although recharge of this warm water has occurred over the years. (DJG)

Widmer, Kemble
1966. Study of ground-water recharge in Santa Clara Valley, California, and its application to New Jersey: Am. Water Works Assoc. Jour., v. 58, no. 7, p. 893–904.

Application of ground-water recharge could make a substantial contribution towards increasing the available total water supply in many parts of the State of New Jersey. The paper discusses the water-supply situation and some problems in New Jersey. The development and operation of the Santa Clara Valley Water Conservation District, San Jose, Calif., is presented outlining its recharge activities and the results in restoring ground-water levels. Data are given of infiltration rates in the recharge areas. Conditions in New Jersey are compared to those in the Santa Clara Valley. Salt-water encroachment and recharge through wells are discussed. (DCS)

Wiener, Aaron

1962. (and Wolman, Abel). Formulation of national water resources policy in Israel: Am. Water Works Assoc. Jour., v. 54, no. 3, p. 257–263.

The author discusses the master plan of water-resources development in Israel in which treated sewage and intermittent runoff will be artificially recharged. Included in the plans is a coastal collector that will consist of a system of shallow wells and drains near the Mediterranean coast which will control the outflow of fresh water to the sea. The otherwise unavoidable loss of fresh water protecting the aquifer from salt-water intrusion will be reduced from the usual 20–25 percent of the average annual natural replenishment to 6–8 percent. This plan will provide large-scale underground storage without risk of increasing fresh-water leakage into the sea. (WK)

1963. Water development procedures in arid and semi-arid Tel Aviv: Tel Aviv, Tahal—Water Planning for Israel, Ltd., Pub. 269, 14 p.

Brief mention is given to the greater Tel Aviv sewage-reclamation recharge project on which construction will begin by the end of 1963 after a successful 2-year pilot study. (DJG)

1967. The role of advanced techniques of ground-water management in Israel's national water supply system: Internat. Assoc. Sci. Hydrology Bull., v. 12, no. 2, p. 32–38.

A general review of arguments for and against ground-water utilization was presented. Israel's situation and the various aspects of ground-water management were discussed. An underground storage study was completed; however, implementation of the underground storage management policy based both on indirect storage and on direct injection underground started immediately after the first basic results of the study concerning qualitative management measures, the question of travel of injected water bodies, and dispersion and mixing phenomena had become available. (DCS)

Willets, D. B.

1957. (and McCullough, C. A.). Salt balance in ground-water reservoir operation: Am. Soc. Civil Engineers Proc., Irrig. and Drainage Div. Jour., v. 83, Paper 1359, no. IR–2, 10 p.

Planning by the California Department of Water Resources for development of water in California to meet ultimate water requirements of the State revealed the necessity of planned operation of the State's ground-water reservoirs for seasonal and cyclic storage of water. A problem that must be solved in such operations is maintenance of suitable mineral quality of the ground water. This paper discusses the sources and disposal of salt in ground-water reservoirs, presents an illustration of relationships and requirements for water to maintain salt balance in a hypothetical ground-water reservoir, and discusses the deficiencies in present knowledge and in data-collection programs for evaluation of salt-balance problems. (Authors' synopsis.)

Williams, R. E.

1967. (and Farvolden, R. N.). The influence of joints on the movement of ground water through glacial till: Jour. Hydrology, v. 5, no. 2, p. 163–170.

Hydrographs of piezometers installed at various depths in glacial till in northeastern Illinois indicate variations in the rate and magnitude of responses of potential to precipitation. Zones of oxidation along these joints suggest that water moves farther in joints before losing its oxygen than does water moving through intergranular pore spaces. A relatively high permeability for the joints is thus indicated. It appears, therefore, that the paths of high permeability in which some piezometers are installed are joints. Theoretical reasoning predicts the observed variation of potential in the vicinity of joints in a compressible layer. An analysis based on one-dimensional consolidation is given. The influence of joints in glacial till on waste disposal, on groundwater recharge, and on the behavior of water levels in the vicinity of a pumped well in an aquifer confined by glacial till is discussed. (Tulsa Univ., Inf. Services Dept.)

Wilson, L. G.
1967. Sediment removal from flood water by grass filtration: Trans. Am. Soc. Agr. Engineers, v. 10, no. 1, p. 35–37.

This paper summarizes work conducted by the Institute of Water Utilization at the University of Arizona on the effectiveness of grass filters for sediment reduction and on the factors involved in the successful use of this method. It is pointed out that development of efficient and economical methods of sediment removal is one of the principal problems facing workers in artificial-recharge research. It was concluded that grass filtration appears to be an effective and economical first-stage procedure for reducing sediment in floodwater. Interrelated factors affecting sediment removal are length of check, initial turbidity, application rate, slope, grass height and degree of ramification, and degree of submergence. Bermuda grasses were the most effective for sediment removal. (DCS)

Winn, R. W.
1960. Clarification of lake water prior to artificial recharge by wells: Lubbock, Texas Technol. Coll., Dept. Geology, M.S. thesis, 56 p.

Various methods of applying flocculating agents to playa-lake water and their effectiveness in reducing suspended-sediment content of the water were studied. Artificial recharge operations using treated lake water were performed. Twenty-six to 76 percent of the suspended solids in the lake water were removed with the smaller percentage being attributed to remixing by wind action. Measurements of the amount of material entering the well and amounts recovered by pumping were made. (DCS)

Winn, R. W.
1961. (and Reeves, C. C., Jr.). Replenishment in the High Plains: Water Well Jour., v. 15, no. 2, p. 6–7, 34–35, 37.

The use of playa-lake water to recharge the Ogallala Formation is discussed. Up to 75 percent of the lake's suspended sediment was removed by airplane spraying of an anionic water-soluble flocculant, Separan AP–30. The rate as well as the method of application affect the amount of suspended sediment removed. (DJG)

Wright, K. R.
1960. Use of models to study ground-water problems: Am. Soc. Civil Engineers Trans., v. 125, paper 3017, p. 133–140.

Two types of models, electric analog plotter and hydraulic, were found satisfactory for the investigation of a problem concerning ponding of paper-mill wastes on the surface and allowing subsequent infiltration into the ground water. The field location of the waste disposal was near Wausau, Wis., in the Wisconsin River valley. (DCS)

Wyatt, Wayne
1958. Procedure outlined for installation of a recharge well: Cross Section, v. 5, no. 1, p. 1, 4.

A detailed description of the installation procedure of a recharge well in Hockley County, Tex., is presented. (WK)

Zajíček, Václav
1967. Hydrological documentation for the exploitation of reservoirs in permeable solid rocks for the purpose of artificial infiltration: Internat. Assoc. Sci. Hydrology Pub. 72, p. 124–131b.

In older water-management plans, sites for future impounding reservoirs were determined on the basis of geomorphological conditions in areas of Cretaceous rocks. Geological investigations carried out in the final stage showed that there were porous permeable sandstone rocks belonging to the basal layer of the Cretaceous beds; since the filtration losses were assumed to be considerable, the chosen dam profiles were abandoned.

At present there is a new approach to such valley sites. In the representative area, a dense network of hydrogeological probes has been developed covering an area of several square kilometers. This network permits following the permeable layer up to the place where the layer is naturally drained in the form of large springs due to defects in the artesian upper confining layer. A large town is interested in utilization of this permeable layer for water-supply purposes. Other hydrological surveys supply data on the direction and velocity of flow, on the filtration and storage capacity of the rocks, and also on their amelioration ability with regard to water quality. This proves the feasibility of the construction of the impounding reservoir and other similar reservoirs in the infiltration zone of the Cretaceous rocks, since the filtration losses resulting from the large-space infiltration appear as a positive item in the budget of artesian aquifers. A combination of surface and underground storage has a favorable effect also from the point of view of evaporation. (From author's abs.)

Zaoui, J.
1965. Le Probléme de l'alimentation artificielle des nappes—puits d'injection zone d'épandage, intervention des modeles mathematiques [The artificial recharge of aquifers—recharge wells, water-spreading areas, the use of mathematical models] [in French]: La Houille Blanche [France], v. 20, no. 3, p. 247–250.

A brief history is given in this article of recharging methods, and various methods using wells, tunnels, dams, ditches, basins, and so forth are examined. The effect of natural factors and technical measures applied in practice are discussed.

Other points reviewed include the expression of the phenomenon in equation form and the integration of these equations, and finally, the possibilities of constructing mathematical models as a means of predicting the behavior of a water table under artificial recharging conditions. (From abs. in Water and Water Eng.)

Zielbauer, E. J.

1966. Sea water intrusion and the barrier projects, *in* Engineering geology in southern California: Glendale, Calif., Assoc. Eng. Geologists, Los Angeles Sec. Spec. Pub., p. 264–269.

Hydrogeologic investigations of sea-water intrusion have been made in the coastal margins of Los Angeles, Orange, and Ventura Counties. The first successfully operated sea-water barrier formed by well injection was constructed along Santa Monica Bay to protect and recharge the west coast ground-water basin, and a pumping project for ultimate barrier use was recently initiated on an experimental basis in the Hueneme area. Two other barriers are planned at Dominguez Gap and Alamitos. Detailed geologic and hydrologic studies were conducted along each barrier alinement. Aquifers are Pliocene-Holocene, and only in the Alamitos project are structural features such as the Seal Beach fault and an elongated dome important. (From Abs. of North Am. Geology.)

Zodtner, Harlan

1959. The use of nuclear explosions as an aid in artificial recharge, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, 2d, Berkeley, Calif., 1959, Proc.: Fort Collins, Colo., Western Soil and Water Management Research Br., p. 93–95.

From the results of the experiments it appears possible to influence the movement and storage of water as follows: (1) increase porosity by shattering rock or other "tight" material and thus provide ground-water storage, (2) provide an area through which water can move by shattering materials of relatively low permeability, (3) increase the rate of flow through an area by shattering a soil layer and thus increasing its hydraulic conductivity, (4) increase the rate of flow by increasing the hydraulic head in the chimney of disrupted material, and (5) minimize salt-water intrusion by reducing permeability near the shot point. (DJG)

1966. Ground water resources using nuclear techniques, *in* Schiff, Leonard, ed., Bienn. conf. on ground-water recharge, development, and management, California Univ., Los Angeles, 1965, Proc.: Fresno, Calif., U.S. Dept. Agriculture, 4 p.

The author examines ground-water recharge applications in relation to nuclear craters. He suggests that a nuclear crater located in permeable alluvial material and supplied with water which is permitted to infiltrate into the ground would serve as an excellent structure for artificial recharge of ground water. It could be compared to a combination of the conventional basin-and-pit projects, having the large contact area of a basin and the depth and storage characteristic of a pit. In terms of size and nature of water that can be handled, a nuclear crater would exceed any present conventional individual project. (WK)

Anonymous

1955. Small wells near river bed provide emergency supply: Public Works Mag., v. 86, no. 8, p. 100–101.

Irregular sand or gravel aquifers along stream courses offer an emergency water supply. By regulating the flow of an upstream reservoir and pumping from four small closely spaced wells, the city of Perry, Okla., was able to induce stream water into the aquifer with a resulting yield of 90,000 gpd.

Probably the yield cannot be sustained owing to the nature of the deposit. (DJG)

1956. Wells will do double duty: Johnson Natl. Drillers Jour., v. 28, no. 1, p. 8–9.

Using the "heat pump" principal on a big scale, ground water from two aquifers will be called upon to work both summer and winter for air conditioning and for heating a large suburban shopping center south of Minneapolis, Minn. Much of the water used for air conditioning in the summer will be put back underground through wells and this same water will be reused for heating in winter. (DJG)

1957a. Artificial recharge in the Texas High Plains: Cross Section, v. 3, no. 10, p. 3.

A large part of the natural recharge in the High Plains of Texas is from depression ponds. However, much of this water is evaporated; thus, any recharge of this water by multipurpose wells will be of public benefit. (WK)

1957b. District attempts to establish ground water recharge as "Great Plains" practice: Cross Section, v. 3, no. 11, p. 1–2.

This article presents the reasons for the efforts being made by the Board of Directors of the High Plains Water District to encourage the adoption of ground-water recharge as one of the practices to be set up under the Great Plains bill, a soil- and water-conservation measure. (DJG)

1957c. Declining underground water levels spur interest in wet weather lake water: Cross Section, v. 4, no. 1, p. 1–4.

Various methods used by farmers on the High Plains of Texas for recharging playa-lake water are pictured and briefly described. (DJG)

1957d. L.A. looks further into well recharge: Eng. News Rec., v. 158, no. 18, p. 24.

The brief article describes the aims of a study that would protect the ground-water quality in the Los Angeles area. The study is to determine the feasibility of constructing recharge wells to extend the salt-water barrier from the present length of 1 mile to that of 11 miles. A pipeline would import untreated Colorado River water for barriers as well as for spreading-ground use. (WK)

1957e. Multi-purpose recharge well program is discussed with Soil Conservation Service: Cross Section, v. 4, no. 1, p. 1.

Cost-benefit data are generally discussed as related to the economic justification for the inclusion of a multipurpose recharge-well program to be established by the Soil Conservation Service as a water conservation practice under the Great Plains Act (Public Law 1021). (DJG)

1957f. Progress report—ground-water recharge project: Stuttgart, Ark., Ground-Water Recharge Proj. Comm., Stuttgart Chamber of Commerce, 8 p.

Recharge experiments in the Grand Prairie region of Arkansas are reviewed. Equipment used is described, recharge tests are discussed, and causes of a well plugging are enumerated. (DCS)

1957g. Rainfall runoff salvaged by Texas Technological College: Cross Section, v. 4, no. 5, p. 3.

A portion of runoff diverted into a large playa lake from road ditches will be used to recharge the underlying Ogallala aquifer at Lubbock, Tex. (DJG)

1957h. Recharge operations can conserve water resources: Johnson Natl. Drillers Jour., v. 29, no. 2, p. 8–9.

A general discussion is given of the Peoria, Ill., recharge pits and the Long Island, N.Y. recharge basins and wells. (DJG)

1958a. Rivers or lakes can recharge aquifers: Johnson Natl. Drillers Jour., v. 30, no. 5, p. 1–4, 11, 14.

Considerations in the development of induced recharge facilities are discussed. Results of a test using a series of vertical wells to induce infiltration of Lake Superior water into shallow sand and gravel aquifers at Superior, Wis., is described. Advantages of vertical wells or infiltration galleries and radial collector wells for induced infiltration are generally discussed. (DJG)

1958b. Texas Highway Department will drain area right-of-way with recharge wells: Cross Section, v. 5, no. 5, p. 1.

A study involving the drainage of playa lakes using recharge wells was approved for the Texas Highway Department. (DJG)

1959a. Chemical offers new approach to solving problem of sediments suspended in lake water: Cross Section, v. 5, no. 11, p. 2–3.

Attempts are being made at a farm near Dimmitt, Castro County, Tex., to remove suspended sediment from playa-lake water intended for recharge. A solution of Separan AP–30, a flocculating chemical, will be added as the lake water passes into a gravity flow line leading to an earthen pit settling basin. Then the water will be drained by gravity into a recharge well. Effectiveness and costs will be determined. (DJG)

1959b. Texas Technological College constructs a drainage-filtering recharge system in a playa lake: Cross Section, v. 5, no. 9, p. 2–4.

A system of lateral lines buried beneath a playa lakebed is being investigated in an attempt to develop a method of filtering the lake water prior to recharge. The laterals are connected to a main which feeds the water into a recharge well by gravity flow. Various designs of pipe material and backfill are being tested. (DJG)

1961a. Gravel filters used in laboratory to extract suspended solids from water: Cross Section, v. 7, no. 12, p. 1.

During a model gravel-filter efficiency study at Texas Technological College, 85 percent of suspended silt and clay was removed from the water when the flow rate through the filter ranged from 0.25 to 0.50 gpm per square foot. (DJG)

1961b. District installs new experimental recharge well, filter system: Cross Section, v. 8, no. 1, p. 2.

The efficiency of a filter system consisting of 500 feet of 16-inch shutter-screen type of casing laid horizontally in a ditch cut in a playa lakebed and backfilled with pea-sized gravel is being determined in Floyd County, Tex.

After a rain, water will move through the system by gravity to a recharge well. (DJG)

1964. Water is stored in underground bank: West Texas Today, v. 45, no. 11, p. 22–23, 48–49.

The operation of the Colorado River Municipal Water District which is storing water in the Ogallala Formation in Martin County, Tex., is described. (Abs. in Texas Water Devel. Board Rept. 8)

1965a. Unique water conservation project at DuPont Industries, Deepwater, New Jersey: Water Well Jour. v. 19, no. 7, p. 50–51.

Treated surplus water from a canal adjacent to the Chambers Works Power Division's treatment plant is being injected into upper Raritan strata to make good quality water available, when needed. The recharged water is intended to displace water of undesirable quality already in the formation. Water is being injected into the aquifer through one well at approximately 300 gpm, and plans call for storing of 60 million gallons before the beginning of the drought season. (DJG)

1965b. Water conservation with a recharge well: Johnson Natl. Drillers Jour., v. 37, no. 2, p. 1–2.

Injection of properly treated runoff water at Deepwater, N.J., under relatively high pressure, would be practical on a large scale, using injection wells constructed to provide high efficiency. Storing of water in the Raritan Formation, with greater recharge than withdrawal, would also block encroachment of salt water. (DJG)

1966. Going to the well: Chem. Week, v. 98, no. 7, p. 59–60.

In the northeastern United States, ground-water levels that normally rise during winter in this area of the Nation are remaining unusually low, and there are predictions of a fifth consecutive year of low rainfall. These factors could make this the most difficult year for plants to get water supplies. However, at Du Pont's huge 6,000-employee Chambers Works (Deepwater, N.J.), a newly tried well-injection technique is helping management breathe a little easier, even though its 820-million-gallon fresh-water reservoir, a dammed, 10-mile stretch of the Salem Canal, is only slightly more than half full. In principle, the well-injection is simple. Surface water, that is suitable for process use and that collects in ponds and so forth at this time of the year, is pumped down a well after it has been treated; it is used as needed, instead of being allowed to evaporate or run to the sea. In addition, the injection project might help hold back invasion of sea water—a constant and growing threat in many areas. In all, Du Pont plans a total of five injection wells—each capable of holding roughly 100 million gallons of water and delivering 700 gpm. Test drilling obtained data needed to design the injection wells. The injected water pushes impure water in ground formations away from the well and mixes to only a small extent at the interface. (Tulsa Univ., Inf. Services Dept.)

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