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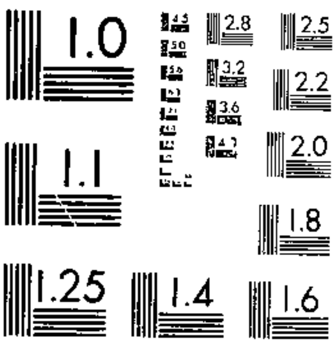

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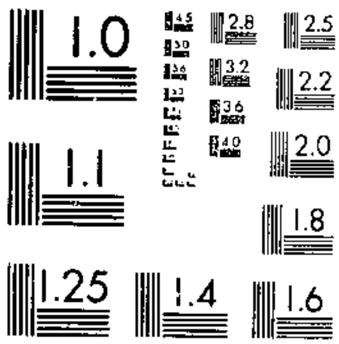

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REPLENISHMENT OF GROUND WATER SUPPLIES BY ARTIFICIAL MEANS

By Dean C. Muckel
Irrigation Engineer

Technical Bulletin No. 1195

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

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REPLENISHMENT OF GROUND WATER SUPPLIES BY ARTIFICIAL MEANS

By DEAN C. MUCKEL, *irrigation engineer, Soil and Water Conservation Research Division, Agricultural Research Service*

During the drought years of the 1930's, increased pumping for irrigation, domestic, and municipal purposes made great demands on ground water supplies. In many areas of the semiarid West, it has become necessary to replenish ground water supplies by artificial means. Artificial recharge is accomplished by diverting water from natural stream channels and spreading it over adjacent permeable soils; by releasing water stored in surface reservoirs to natural channels during periods when the channels would otherwise be dry; or by injecting water into wells, shafts, or pits. Replenishing ground water supplies is now carried on in one form or another at places in the West, and interest is growing rapidly with the decline of ground water tables.

This bulletin contains data on water spreading experiments and information collected on large-scale spreading systems since 1925. In 1937 United States Department of Agriculture Technical Bulletin 578, Spreading Water for Storage Underground, was issued, which contained data and information available at that time. Since then, many more data have become available, particularly through additional experimental work. At the time Technical Bulletin 578 was issued, the spreading operations were confined largely to porous debris cones of alluvial material. High infiltration rates were generally obtained. Since then, the need for conservation of water by spreading has become widespread and it is no longer confined to porous areas. As a result infiltration under prolonged wetting has become more difficult. Methods used to measure infiltration rates, factors influencing them, and experiments to increase such rates are described. This bulletin also includes the results of experimental work designed primarily to promote infiltration on soils of relatively low permeability.

EARLY SYSTEMS

The practice of augmenting the natural processes of replenishment by artificial means is not new. The first recorded case in the United States was in 1889 when the Denver Union Water Co. averted a threatened water famine at its pipeline intake by spreading water over the gravel cone at the mouth of South Platte Canyon in Colorado (*11*).[1] About 1900, the practice was started on the debris cones

[1] Italic numbers in parentheses refer to Literature Cited, p. 50.

of Santiago Creek, San Antonio Creek, and the Santa Ana River in southern California. These early systems were designed primarily to spread water over a larger surface area than had occurred naturally and thereby to increase the amount of water entering the soil to percolate eventually to the water table. Hence, the term "water spreading," which became widely associated with all methods of artificial recharge. When properly used, water spreading describes a method of recharge, and is not an all-inclusive term that is synonymous with artificial recharge.

PURPOSE OF ARTIFICIAL RECHARGE

Most recharging activities are now conducted for the purpose of increasing the amount of ground water available for the common benefit of all users from the reservoirs affected. In southern California, where it is necessary to line many stream channels in order to achieve adequate flood protection, agencies such as the Los Angeles and the San Bernardino county flood control districts have constructed diversion works and spreading basins to maintain ground water recharge; that is, to replace the natural infiltration lost through channel lining.

Spreading grounds and other methods of artificial recharge alone are ineffective as flood control devices. The difficulties and dangers of diverting uncontrolled and debris-laden flood waters, combined with the fact that the capacity of an entire spreading system is usually insufficient to take care of peak flows, preclude water spreading for flood control. Artificial recharge is commonly carried out in conjunction with surface reservoirs in which flood flows can be impounded temporarily. Controlled releases of water from surface reservoirs can then be diverted to spreading areas, shafts, wells, or pits for ground water recharge.

Artificial recharge primarily conserves flood waters and aids in the alleviation of overdrafts or threatened overdrafts in ground water basins. In the West few undeveloped, economical, surface reservoir sites remain, and agencies need to plan for full use of underground storage. Many underground reservoirs have a capacity far greater than the largest surface reservoir; yet few ground water reservoirs are used to store flood water for later distribution. To make full use of underground storage, it may be necessary to lower water levels deliberately by the operation of appropriately spaced wells during dry periods, in order to create storage capacity to be filled during a later period of surplus. Ground water reservoirs, like surface reservoirs, should be depleted during dry periods to provide storage for wet periods. Refilling during periods of surplus may require recharge by artificial means.

LOCATION OF GROUND WATER PROJECTS

Since 1935, several States have undertaken artificial recharge, but in California this method has been carried out most extensively. In southern California, where the work is concentrated, spreading systems are adjacent to nearly every stream.

This bulletin deals primarily with artificial recharge in California, because there are more data and information on the subject in this State than elsewhere. Results of experience and research in California can be applied throughout the West.

In California, 223 ground water basins have been identified. Essentially, these are alluvium-filled valleys that have usable ground water storage (*9*). In many cases adjacent basins are interconnected and the dividing lines are indistinct. Overdrafts exist in many basins. The future economic conservation of the State's water resources will require the full development and planned utilization of ground water reservoirs. Then, a ground water reservoir might be depleted intentionally and recharged in order to make the best use of underground storage capacity.

More than 100 projects, the primary purpose of which is the recharge of ground water, are active throughout the State. In addition, recharge is incidental to waste disposal at numerous locations. Recharge activities are concentrated in Santa Clara Valley and Gilroy-Hollister Basin, south of San Francisco; in the southern part of San Joaquin Valley; and from Santa Maria eastward to Indio, in southern California. In these areas ground water supplies have been most extensively exploited and in many instances severely overdrawn.

AGENCIES OPERATING RECHARGE PROJECTS

Most of the agencies concerned with artificial recharge in California are public districts that include (1) County water districts; (2) water conservation districts; (3) water districts; (4) irrigation districts; (5) water storage districts; (6) county flood control districts; (7) county flood control and water conservation districts; and (8) soil conservation districts.

The work is carried on for the common benefit of all users of water from the ground water reservoirs involved and is supported chiefly by taxation. In addition to the districts, there are two cities that spread water for their own use, two land companies, five water companies, and two private associations engaged in artificial recharge.

Artificial recharge is generally not feasible for an individual or small enterprise, because water loses its identity when diverted and spread or injected into wells, shafts, or pits, and mingles with natural seepage. Wells benefiting from artificial recharge may be many miles from the recharge site and widely distributed over the ground water field.

SOURCES OF WATER

Most water used for artificial recharge in California originates as inflow from the mountains and hills tributary to the ground water basin or as runoff from adjacent valley areas. Water imported from Owens Valley and the Colorado River is being artificially recharged to the coastal plain of ground water reservoirs of Los Angeles County and Orange County. As yet, no reclaimed sewage waste waters are being used, although this source is a possibility in the future.

RECORDS

In many artificial recharge projects records of the amount of water recharged are not kept. This is true of those areas using natural stream channels. Cost figures are lacking in many instances. During the 1930's complete cost figures of much work done on spreading systems by Federal, State, county, and municipal emergency agencies are not obtainable. For those systems recently constructed and operated, records are more complete.

GROUND WATER RESERVOIRS

Description

This discussion will be confined to those ground water reservoirs (called aquifers in some localities) that are geological formations where water is or can be stored by natural or artificial means and from which water can be artificially and economically withdrawn for beneficial use. Such reservoirs are found in stream valleys, interior valleys, and coastal plains. They provide storage for deep percolation from precipitation, streamflow, water not consumed in its use in overlying areas, and water artificially placed in them. Ground water reservoirs serve as regulator conduits to convey water from areas of recharge to those of production and use.

The reservoirs vary from a hundred or more acres to several hundred square miles. The materials contained in them consist of clays, silts, sands, and gravels, frequently intermixed, which vary in porosity, specific yield, and permeability. The more porous materials often occur in stringers and lenses or in extensive strata of varying thicknesses and areal extent. While porosity of the materials is relatively high when compared with that of consolidated rocks, values of specific yield and of permeability that are adequate to allow storage, transmission, and economical production of water occur chiefly in the sands and gravels.

A reservoir formation may be divided or subdivided into basins or subbasins by faults, dikes, masses of less permeable materials, or other features that retard the velocity of water as it moves from one part of the reservoir to another. The water is usually in transit, moving slowly from points of recharge to points of discharge.

General Hydrologic Equation of Ground Water Reservoirs

The general hydrologic equation of a ground water reservoir may be expressed as follows:

Surface inflow plus Precipitation on surface plus Subsurface inflow plus Artificial importation of water and sewage or of sewage	equals	Surface outflow plus Subsurface outflow plus Consumptive use (evapotranspiration losses) plus Artificial exportation of water and sewage or of sewage plus Changes in storage

Artificial recharge by spreading or use of injection wells may increase the inflow side of this equation if the water that is recharged is imported, or artificial recharge may reduce the outflow side of the equation if water or sewage that ordinarily leaves the area is captured and spread within the confines of the ground water reservoir. The ultimate effect in either case is the same; that is, there is an increase in the amount of water going into underground storage.

If the ground water basin has a large capacity, so that the water table can be drawn down without danger of deficiency, and if it will fill during wet periods from natural percolation, there is little benefit to be obtained from artificial recharging other than to keep the water table slightly higher during dry periods. A high water table will cause an increase in surface outflow later. When artificial recharge is practiced, the net increase in water stored is the difference between the amount recharged and that which otherwise would have percolated into the underground basin if the runoff had been allowed to remain in the stream channel. Water imported to an area for recharge purposes is almost entirely a net gain, although some minor losses by evapotranspiration are bound to occur.

METHODS OF RECHARGE

Ponding of water in surface basins is the most common method of artificial recharge now used in California. Furrows and ditches are used but not extensively. Abandoned gravel pits are used. Spreading in natural channels is widely practiced; surface storage is large enough to regulate the erratic runoff to rates of flow that do not exceed the absorption capacity of the downstream natural channels. Infiltration capacity of the channels is sometimes increased by constructing levees and dikes in the channels to form temporary basins. Injection of water into wells, shafts, or pits is used to some extent, but this form of storage is limited to special conditions. This type of recharge puts under ground only comparatively small amounts of water.

Recharge by Spreading

Spreading diverts water to lands not ordinarily wet and thereby increases the amount of water infiltrating into the soil by reason of greater wetted surface. Systems of spreading are similar to various systems of irrigation. They can usually be classified under one of the following methods: (1) Basin; (2) furrow or ditch; and (3) flooding. It is not uncommon to find two or more such methods used in a single spreading system. The topography of the soil surface, general slope of the land, amount of land available for spreading purposes, condition of the water (silty or clear), and streamflow characteristics will govern which method is best suited to a particular site.

The basin method.—In the basin method the water is impounded in a series of small basins formed by dikes or levees. The basins are usually so arranged that the entire area between the dikes can be submerged during spreading. The dikes often follow contour lines. The general slope of the land governs the size and shape of the basins. On flat lands the basins take on a long narrow shape and construction costs increase because of increased height and number of dikes necessary to form the basins. The basin method usually is adapted to slopes of 3 percent or less.

A series of basins is usually arranged, so that the excess water from the higher basin will escape into the next lower basin. The outflow may occur by water overtopping the dikes or passing through the dikes in pipes or other structures installed for that purpose (fig. 1, *A* and *B*). The type of construction is dependent upon the material available. For the overtopping method, the dike must be of nonerodible material.

In southern California the so-called sausage dam (fig. 2, *A* and *B*) is used. This type of dam is porous and is constructed by building walls of rocks of various sizes and binding the rocks together with heavy woven wire. This form of dam is seldom constructed higher than 8 feet and is used only where rock is near at hand. Where rock

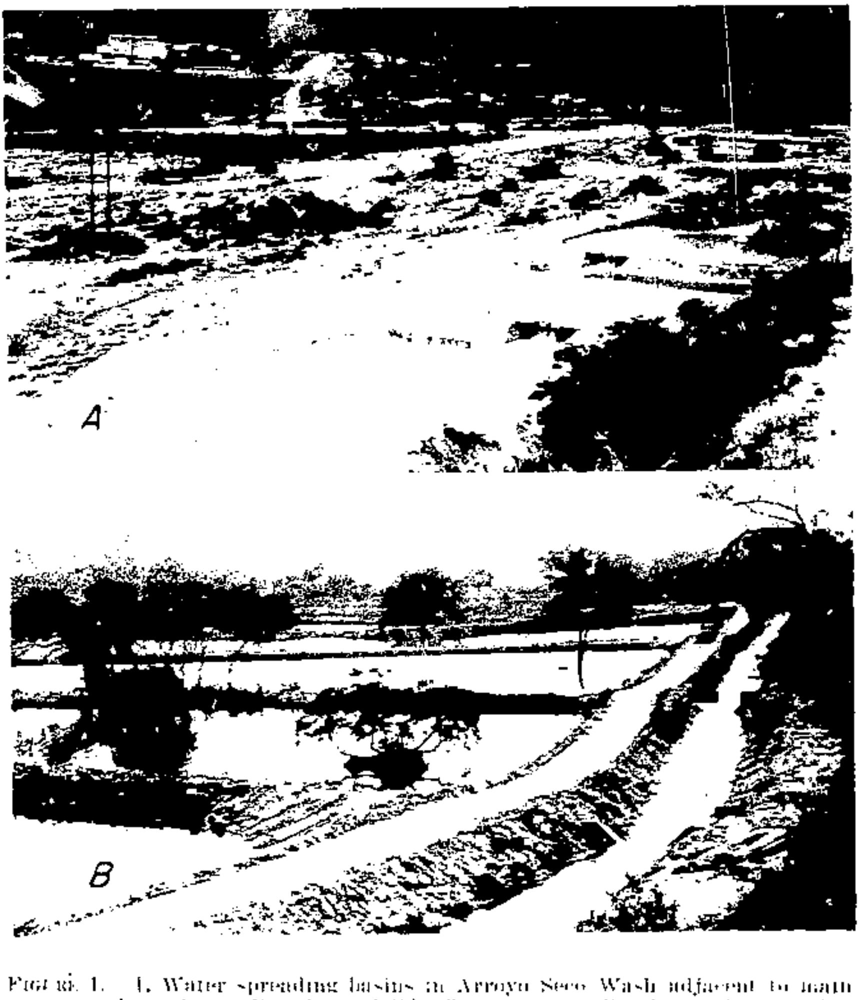

FIGURE 1.—*A*, Water spreading basins in Arroyo Seco Wash adjacent to main stream channel near Pasadena, Calif.; *B*, water spreading basins in operation in Santa Anita Wash. (Photos courtesy of Los Angeles County Flood Control District.)

FIGURE 2.—Dams, or dikes, built of rocks bound together with heavy hog wire to form spreading basin: *A*, Closeup view at San Antonio Creek near Claremont, Calif.; *B*, view showing spreading basins on Cucamonga Creek near Upland, Calif.

is not available and the dikes are constructed of sand and earth, pipes, or other structures are built into the dikes to carry the outflow. The height of the outflow above the ground surface is usually set so that when the basin is full and water is escaping, the water will have backed up to the toe of the dike forming the lower boundary of the next higher basin, thus submerging the entire ground surface.

The basin method may be used where the ground surface is irregular and spotted with numerous shallow gullies and ridges. The basins prevent the water from collecting in the gullies and running off without an opportunity to penetrate into the soil. It has the advantage of furnishing the greatest net wetted area, with only the tops of the dikes exposed and used for service roadways. This is important where high land values limit the area available for spreading.

The claim is often made that the basin method should not be used if the water supply carries silt. It is true that impounded silty water will tend to seal the soil surface more rapidly than flowing water, but basins can be used for desilting purposes. In a series of basins in which one feeds the other, the basins highest in elevation can be arranged to impound the water, causing much of the silt to settle. These basins are cleaned periodically. Thus the lower ones are kept relatively clean and require only infrequent removal of silt.

The Los Angeles County Flood Control District has successfully spread flood waters containing as much as 10,000 p. p. m. of silt. Usually the flows contain 300 to 3,000 p. p. m. To handle such silt-laden flows, diversion is made first to basins designed to operate as desilting basins. At one spreading area the suspended load was reduced from 3,000 p. p. m. in the first basin to 250 p. p. m. in the next basin.

In some instances the basin method has another advantage over other methods. If the water supply comes in flashes and is not in great amounts, the surface storage provided by the basins becomes important. The basins will fill during short runoff periods and impound the water until it has ample time to infiltrate into the soil. For continuous supplies of prolonged duration, the surface storage is of small importance except for regulatory purposes.

An arrangement of spreading basins as used by the Los Angeles County Flood Control District is shown in figure 3. In this case the spreading basins lie on both sides of the paved flood channel of the Rio Hondo River. The Kern County Land Co. and the North Kern Water Storage District, Bakersfield, Calif., also used the basin method, as illustrated in figures 4 and 5.

The furrow or ditch method.—In the furrow method the water is passed through a series of furrows or ditches somewhat resembling an irrigation system. The ditches are shallow, flat-bottomed, and close together so as to make available the greatest possible infiltrating area.

If the water is passed through the ditches at erosive velocities the capacity of the system decreases rapidly. The water erodes into narrow channels meandering about the flat-bottomed ditches, with the result that the wetted area (or infiltrating area) is materially reduced. In some cases low check dams of loose rock are used to retard the flow of water and maintain the maximum wetted area (fig. 6). Where the material is composed of boulders and rocks intermingled with coarse sands, such as are found on many of the debris cones of southern California, erosion is not ordinarily a serious problem under water spreading conditions.

The ditch system usually follows one of three general plans:

(1) Lateral spreading is at right angles to the main diversion canal. Open cuts through the bank of the main feeder canal provide entrance to the laterals. Gates are installed at each entrance to control the amount of water entering each furrow. The ditches range from 3 to 12 feet in width (fig. 7). Their depth is determined by the roughness of the ground surface and in general is not greater than necessary to carry water at a fairly uniform velocity over the ridges and gullies.

(2) Instead of diverting from the main canal to a series of small ditches, the main canal may be divided into two separate ditches:

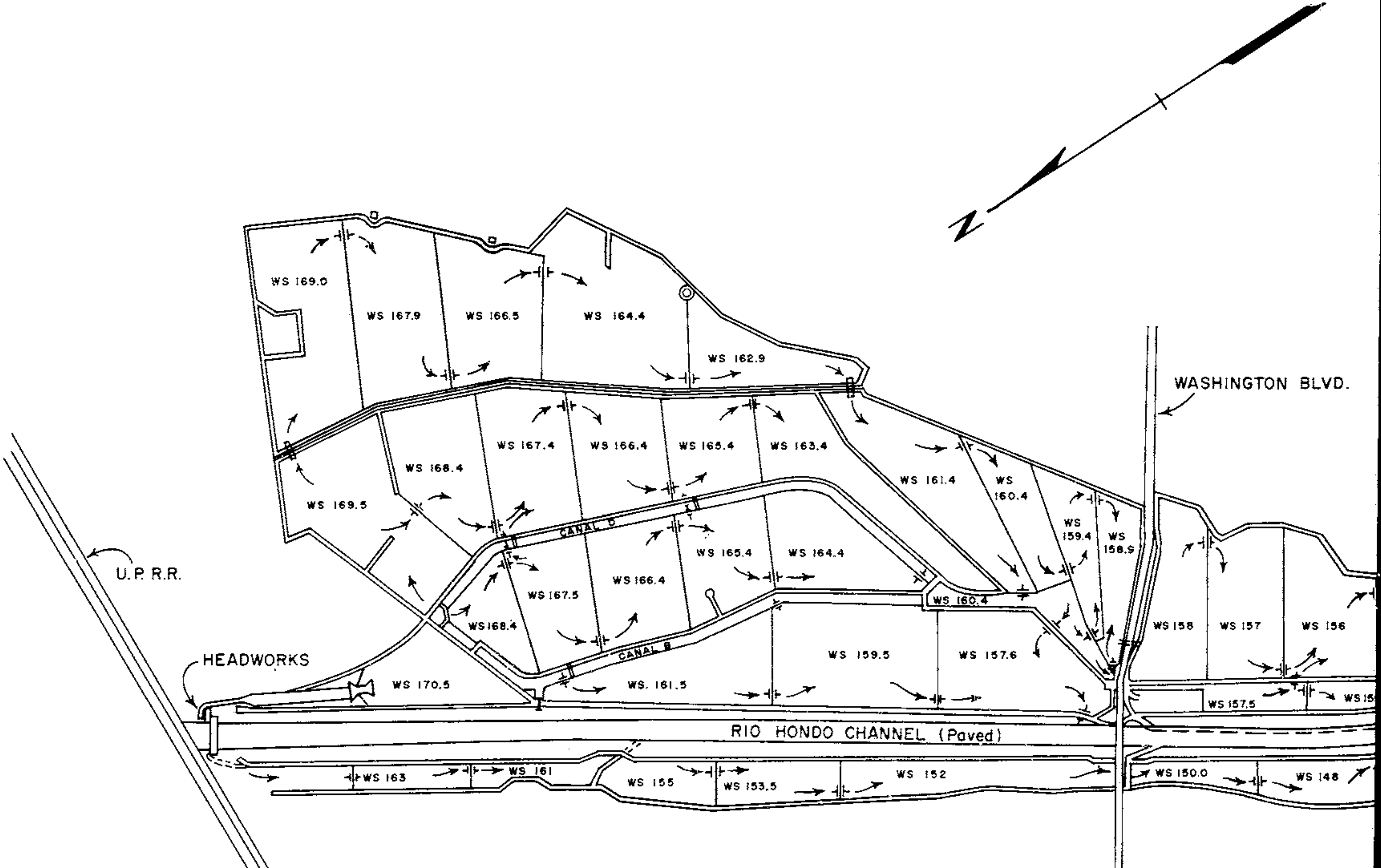

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FIGURE 3.—Arrangement of spreading basins and Rio Hondo flood channel near Montebello, Calif., in the Los Angeles County Flood Control District.

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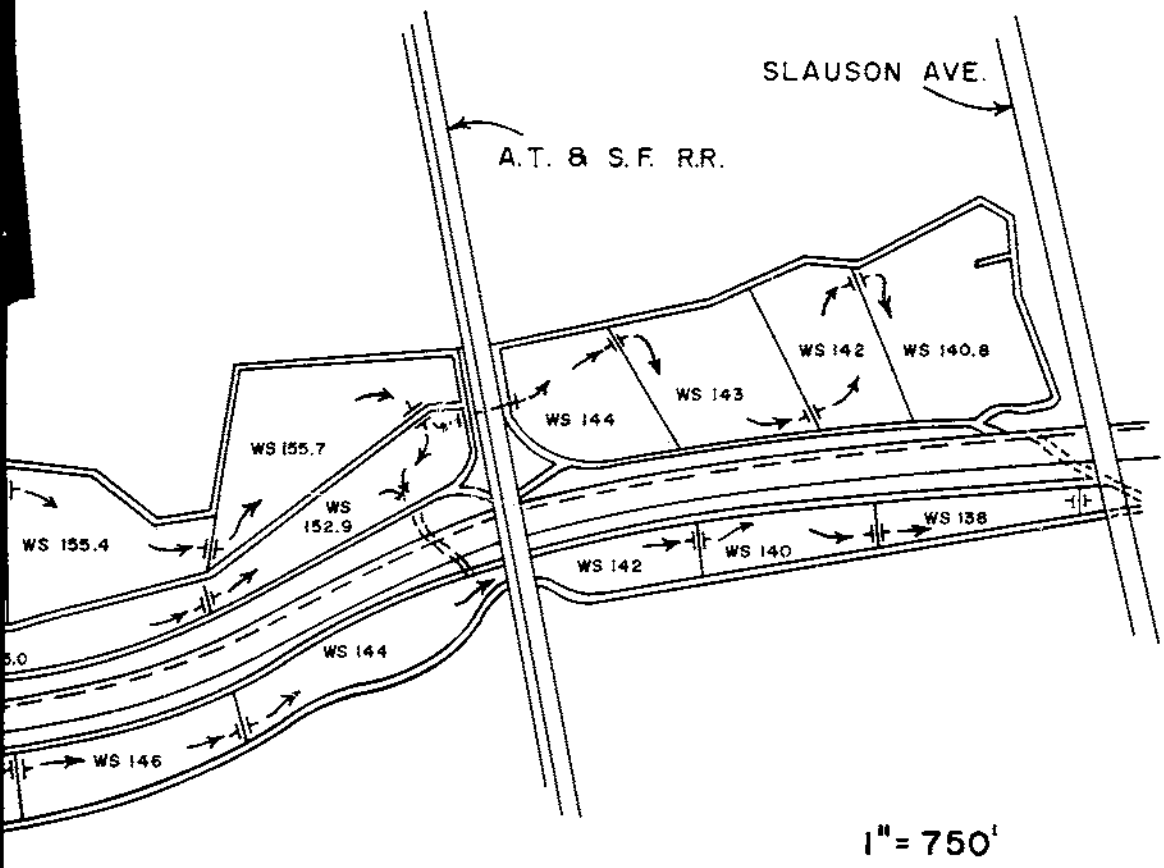
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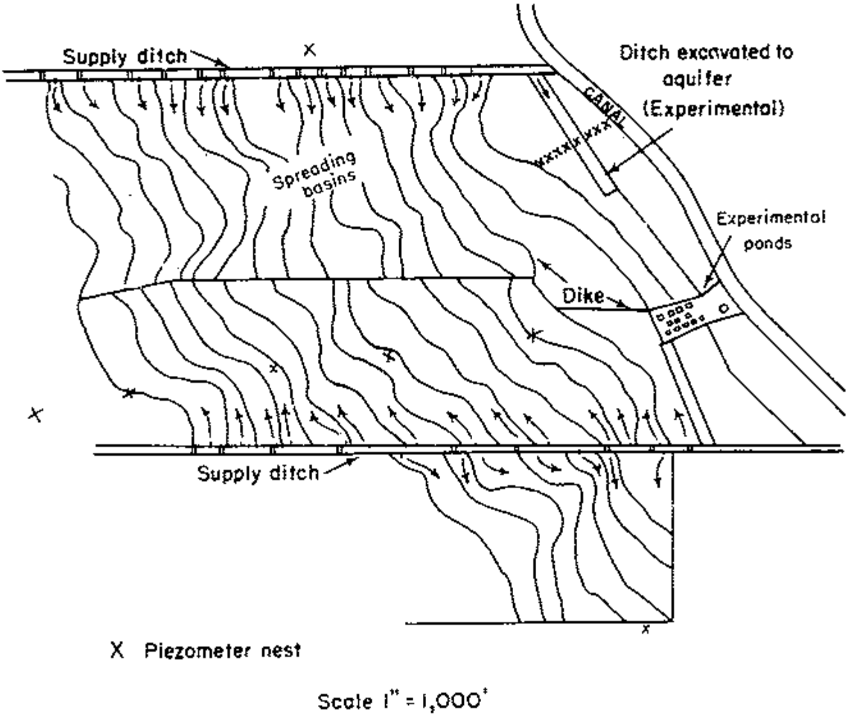

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FIGURE 4.—Arrangement of spreading basins as constructed by North Kern Water Storage District near Bakersfield, Calif.

FIGURE 5.—Spreading basins as used by Kern County Land Co. and North Kern Water Storage District near Bakersfield, Calif. Water is about 1 foot in depth.

FIGURE 6.—Rock dam installed in ditch to prevent erosion into narrow channel. By maintaining a wide ditch, greater percolating area is utilized. San Antonio Creek near Claremont, Calif.

FIGURE 7.—Parallel ditches used for spreading. They are approximately 6 feet wide, 12 to 18 inches deep, with flat bottoms. Note character of material and amount of land in all ditch systems not covered with water. Lytle Creek debris cone near Fontana, Calif.

these two then subdivide into four smaller ditches. This subdivision is continued until the ditches dwindle to mere trickles and finally disappear. At each division point, drop gates are provided to control the water entering each series of ditches (fig. 8).

(3) Water is spread through one ditch that follows approximately the contour of the ground surface. As the ditch comes to the limits of the area provided for spreading, a sharp switchback is made. Thus, the ditch is made to meander back and forth across the land, gradually

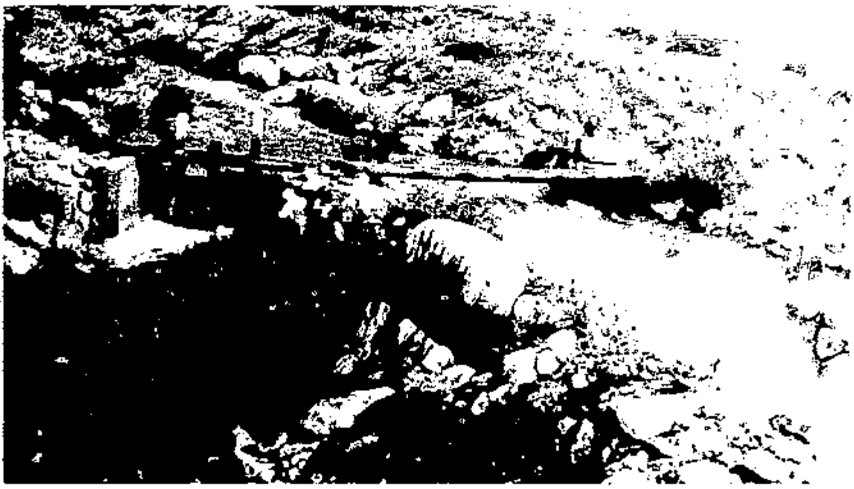

FIGURE 8.—Division of ditch into two ditches. These two ditches are further divided downstream into four ditches, which are further subdivided. San Antonio Creek near Claremont, Calif.

approaching the lower portion of the spreading area. This is commonly called the contour ditch system.

For each series of ditches or furrows of the system, a reception ditch is usually provided, circling the lower portion of the specific spreading area to collect and divert the excess water from the spreading furrows into one main canal. It may then be redistributed in a new series of furrows, or if the limits of the spreading area have been reached, the water may then be diverted back into the main stream channel. If sufficient water is available, this is recommended as good practice for streams carrying considerable silt, since a large portion of the silt may be carried through the spreading system and back into the main stream channel where periodical floods may carry it to the sea.

Generally speaking, no one of these methods has any outstanding advantage over the other. The choice of method is dependent on topography and certain other characteristics of the land.

The furrow or ditch method is used extensively in streambeds, particularly where no permanent works can be installed because of flood hazard. Sandbars or islands above the normal flow line of the stream are furrowed by means of tractor-drawn plows. Water is then diverted into the furrows by temporary dikes or dams (figs. 9 and 10).

The flooding method.—The flooding method consists of passing water over the land surface in a thin sheet. Good results have been obtained in areas of gentle slopes where the topography is not cut by large gullies and ridges. Few such areas exist naturally, however, and often certain preparations must be made to prevent the water from collecting in small streams and running off instead of spreading over the required land surface. Small ditches or embankments may be constructed to divert the water from the shallow gullies to the higher ridges where it may spread in all directions, thereby wetting the slopes of the ridges as it again runs to the lower levels. By the

FIGURE 9.—Furrows made in sandbars or islands to increase wetted area of streambed and promote infiltration. Rio Hondo near El Monte, Calif.

FIGURE 10.—Furrows in sand and gravel beds adjacent to main stream channel, San Gabriel River near El Monte, Calif. (Photo courtesy of Los Angeles County Flood Control District.)

generous use of these ditches or embankments a large portion or all of the area may be wetted.

Water may enter the uppermost point of the spreading area in a main canal and then be released to follow the gullies and controlling structures. Usually, however, the use of one main ditch or perhaps several that meander over the highest ridges or that circle the upper boundary are desirable. From these ditches the water may be diverted at intervals. This method gives better control over the water and, in the event of the failure of a dike or ditch, only a part of the spreading operation will be interrupted while repairs are being made.

Experiments and field observations show that the highest infiltration rates are obtained on areas where the native vegetation and soil covering have been least disturbed. Therefore, for maximum effectiveness of spreading grounds, it is desirable to design the system so as to minimize the disturbance of the natural materials.

It is not possible to spread water by the flooding method on lands where there are irregularities in the ground surface. Then basins or furrows must be used in order to confine the water in a definite area. However, even though a basin or furrow system is the only feasible method for the general area, the flooding method is recommended for all parcels of land in the area adapted to its use. The cost of preparing the land for flood spreading is much less than for any other method and the rates of infiltration are higher.

A disadvantage of the flooding method is that the water is not so easily confined as in other methods. Suitable structures, such as embankments or ditches at the boundaries of the spreading area, are often necessary to prevent damage to adjacent lands by escaping water. As in any other system, the water should be under control at all diversion points and at the entrance to the spreading grounds. The net amount of land actually wetted is usually much less than by the basin method. This may or may not be important, depending on the cost and availability of suitable lands.

It is difficult to design a complete flooding system prior to the application of water. The main ditches, the diversion works, and the control device should first be installed. Then, with the application of water the smaller training walls and ditches can be located and constructed to the best advantage. It is advisable to have at least one man on the grounds during spreading. The ditches and embankments should be patrolled and inspected, and often such simple adjustments as the placing of a few shovelfuls of dirt in the proper place will divert sufficient water to wet several additional acres. In this manner a well developed spreading system may be made highly efficient at very low operating cost.

A method often used to spread water in stream channels is also classified as flooding. Where the stream has a very wide bottom, caused by the meandering of the channel, a low dam or weir may be extended across the bed. The water in passing over the weir spreads out in a thin sheet over the entire streambed and thereby increases the wetted area. Due precaution should be taken not to create a hazard in time of flood by backing up the water or diverting it out of its normal streambed. Practically the only operation cost in this type of spreading is for periodical inspection of the dam or weir.

Recharge by Pits, Shafts, or Wells

Recharge by the use of pits, shafts, or wells is also practiced, although not so extensively as surface spreading. Abandoned gravel pits, old wells, or other existing holes are generally used, although shafts, pits, and inverted wells have been constructed primarily for recharge purposes. In some cases, wells that normally are pumped during the growing season are used for recharge during other seasons.

Usually this method of recharge is confined to specialized conditions. It may be used where impermeable strata or layers occur between the surface and the water table, a condition that renders surface spreading unfeasible. Also recharge by wells may have merit where land values are too high to set aside sufficient area for surface spreading. The advantage of head or water pressure is obtained with this method.

The records on the use of inverted wells for recharge are conflicting. Successes as well as complete failures have been reported. Generally, best results have been obtained by the use of chlorinated water free from silt and by maintaining the well casing constantly full to prevent undue fluctuation and turbulence of the injected water. Chlorination prevents the growth of soil-clogging micro-organisms. The amounts of chlorine required and the best method of application, whether continuous or by periodic slugs, have not been determined.

Silt introduced into a well is detrimental to the intake rate. It lodges in the gravel pack around the well or at the interface between the gravel pack and the aquifer and materially retards the movement of water. Silt may even penetrate the aquifer material itself and reduce permeability of the material surrounding the well. Pumping of recharge wells for 15 to 30 minutes per day to prevent the accumulation of silt in the well has been beneficial in maintaining intake rates in several installations.

Incrustations by chemical action may occur in metal-cased wells. This has been reported as serious, particularly where the perforations are above the normal water table and exposed to the air. Keeping the perforations below the water at all times is a partial remedy. The amount of incrustation will vary with the type of water.

Where water has been injected under pressure into confined aquifers through wells, special construction has been found necessary to prevent the upward movement of water around the outside of the well casing. This has been accomplished by placing a concrete collar around the casing at the upper surface of the confined aquifer (4).

Pits or shafts may or may not extend to the water table. However, they usually are dug to depths that will penetrate the aquifer material. and as a result relatively high initial infiltration rates are obtained. Silting is a problem here as with cased wells except that pits are more easily cleaned.

SELECTION OF RECHARGE SITES

The following factors must be considered in selecting the proper location of sites for artificial recharge:

(1) Geologic structure of the ground water reservoir;
(2) Pattern of pumping draft;
(3) Movement of water underground;
(4) Surface soils;
(5) Water supply (source, turbidity, and quality);
(6) Other considerations.

Geologic Structure of Ground Water Reservoirs

Ground water reservoirs may be divided into two classes: namely, free water reservoirs and artesian reservoirs. The intake area of the place where natural replenishment occurs is generally where artificial recharge practices must be located (fig. 11).

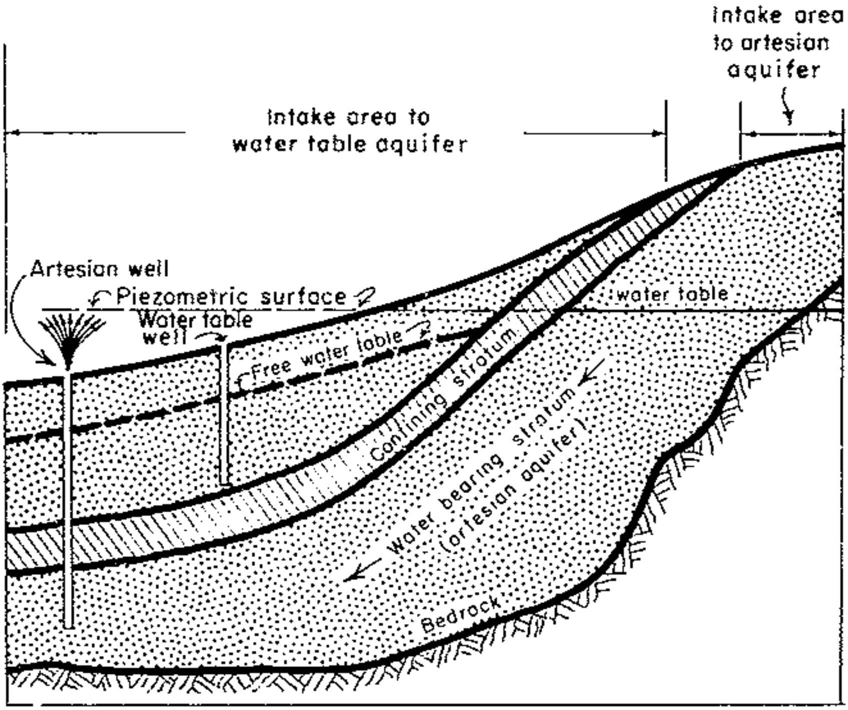

FIGURE 11.—Intake areas to artesian and free water table aquifers.

In locating spreading sites, well logs should be examined to determine if strata or lenses of low permeability occur that would prevent or retard the downward movement of water applied to the overlying land surface. In the case of artesian reservoirs, the natural intake area is usually remote from areas where discharge occurs. The fact that the water is under pressure immediately indicates an overlying stratum of low permeability, and any water spread on the land surface at this point would be of little or no benefit to wells penetrating the confined aquifer. Surface spreading would be beneficial if practiced where the aquifer outcropped at the upper end or extended beyond the limits of the overlying impermeable strata. Injection wells penetrating the confining strata have been tried in certain areas.[2] Here water is forced into the pressure zone by the head developed in the injection well.

Pattern of Draft

The pattern of pumping draft on the reservoir will in many cases dictate the location of spreading sites. Concentrated pumping causes depressions in the water table and artificial recharge may be designed

[2] BANKS, H. O. PROBLEMS INVOLVED IN THE UTILIZATION OF GROUND WATER BASINS AS STORAGE RESERVOIRS. Calif. Div. Water Resources, 24 pp., illus. (Mimeo. copy of paper presented at meeting, Western State Engineers Assoc., Reno, Nev., Aug. 18.) 1953.

to alleviate these depressions or at least to supply additional water. The ground water slope, determined from water-table contour lines, will establish the general area in which artificial recharge should be made.

Ground water flows in the direction of the steepest slope that is normal to the water-level contour lines. In order that the recharge water reaches the pumping wells during the periodic maximum draft, not only the direction of ground water movement but also its velocity is important. The time and the location at which the water enters the soil are also important.

Movement of Ground Water

The rate of movement of ground water is usually very slow compared to that of surface water movement. Under natural conditions hydraulic gradients of more than 10 to 20 feet per mile are seldom encountered. Through soil formations in which wells of good yield may be developed, flow velocities of 5 feet per day are usual. In well assorted gravel, velocities of 30 to 60 feet per day have been observed in the laboratory with hydraulic gradients of 5 to 10 feet per mile. Field tests to determine underflow have shown velocities as high as 400 feet per day. Tolman (*17*) gives the following average velocities for water movement in granular materials:

Type of material:	*Grain size (mm.)*	*Average velocity, 1-percent gradient (feet per day)*
Silt, sand, and loess	0.005 to 0.25	0.065
Sandstone and medium sand	.25 to .5	1.16
Coarse sand and sandy gravel	.50 to 2.0	6.33
Gravel	2.0 to 10.0	30.00

Surface Soils

The geology pattern of pumping draft and rate of movement of water underground will generally outline an area of considerably greater extent than would be required for concentrated artificial recharge purposes. A soil-stratum survey that gives the location, extent, and physical characteristics of the surface and the various underlying soil layers will be required for the purpose of selecting the site most adapted to artificial recharge within that area. Soil surveys made by the Soil Conservation Service or other agencies give surface information that can be of value in selecting a recharge site. These soil surveys are usually limited to the top 6 feet of soil. Before final selection of a site is made, test holes should be drilled or sunk by other means to greater depths to determine if impermeable or relatively impermeable layers exist. A severe condition is illustrated in figure 12. The surface soil here indicates an excellent area for surface spreading, but the underlying material is unsuitable and recharge to the ground water supply would be extremely small.

Where little or no soil data are available or when existing data indicate the need for more detail, borings should be made on a pattern (fig. 13) designed to furnish the needed soil information by the use of a minimum number of holes. Since it is not always possible to determine beforehand the exact spacing of holes needed for complete data, supplemental, intermediate borings may be necessary. For example, a continuous clay stratum that has been found regularly at a

FIGURE 12.—Recent alluvium overwash on an old terrace soil. Infiltration rates of several feet per day might be expected on the surface alluvium, while the underlying soil will transmit water at only a few inches per day. Such conditions are revealed by exploratory borings, and these areas are not suitable for water spreading. Near Mentone, Calif.

depth of 3 to 4 feet in a series of borings may be absent in the next adjacent ones. Intermediate borings will reveal the true extent of the clay stratum. An experienced soil scientist can usually judge from observation of material removed from the holes its relative capacity to transmit water. If material of low permeability is found in several test holes, it is well to draw profile representations as illustrated in

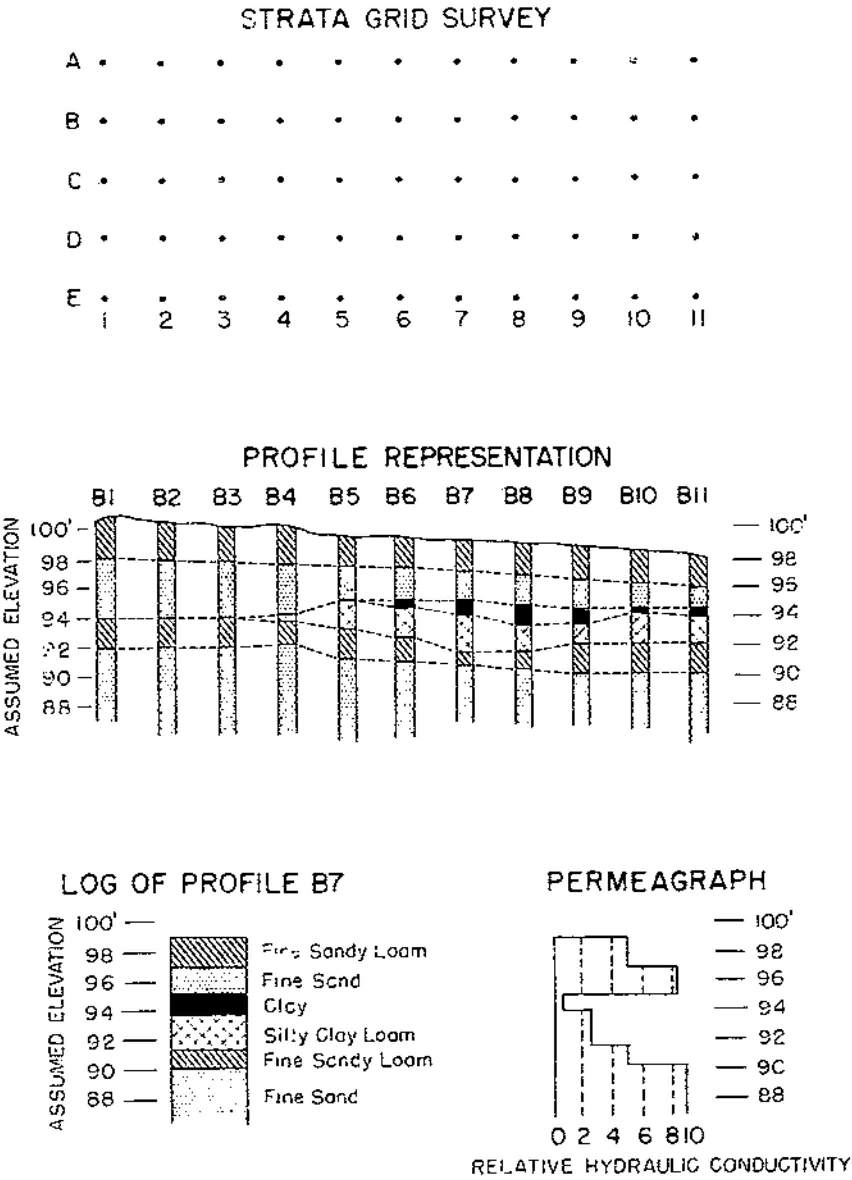

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FIGURE 13.—Stratum-survey diagram, showing stratum-survey grid, profile representation, log, and permeagraph.

figure 13 and determine if possible whether the material of low permeability exists in a continuous stratum or in stringers or lenses.

Under conditions shown in figure 13, surface spreading should be confined to the area on the profile represented by B through B5. The clay lens shown on the section B6 through B11 would cause extremely slow percolation. Similar data should be obtained for other profiles, A1 to A11, C1 to C11, D1 to D11, and E1 to E11, to map completely the area and determine where artificial recharge by surface spreading is feasible. Continuous stratum or strata of relatively impervious material will eliminate surface spreading as a means of artificial recharge, but the possibility of recharge through wells, shafts, or pits that penetrate the impervious strata should be considered.

On those soils that appear to be suitable for spreading, additional tests should be made to determine infiltration rates and hydraulic conductivity, particularly where infiltration may be of questionable magnitude for satisfactory results.

Water Supply

Relation to physical conditions.—The source, availability, location, quantity, and quality of water, as well as the nature of its occurrence, will influence not only the location of recharge sites but the method of recharge to be used. In southern California where many of the early spreading systems were built, the systems were originally intended to capture and salvage uncontrolled water as it entered the valleys from higher elevations. At the mouths of canyons, cone- or fan-shaped accumulations of boulders, cobbles, gravels, and sands occur over which the streams flow only at times of flood. At ordinary stages the flow may be completely absorbed in these debris beds or confined to narrow channels (figs. 14 and 15). This is particularly true of the smaller streams when the canyons from which they debouch are steep. Surface flow appears on the larger streams during and after floods and sometimes throughout the year in the lower sections. Water seeping into these debris cones feeds the underground water supplies of the lower valley lands where irrigated agricultural areas and, consequently, pumping wells are concentrated.

Although these debris cones are in many cases too rough or unsuitable for other uses, they are ideal as spreading areas. They are por-

FIGURE 14.—Character of material carried by flood flows as they leave the mouths of canyons and spread over the debris cones of southern California. The material is permeable and ideal for water spreading purposes. Cold Water Canyon near Corona, Calif.

FIGURE 15.—A gully cut through the debris cone on the Santa Ana River near Mentone, Calif. Spreading grounds are located nearby.

ous: they are properly located with respect to the ground water supply and represent land that is not excessively high in value as compared to adjacent valley lands: they are convenient to the surface water supply. A major problem presents itself in that the debris cones are fairly unstable. Flood flows tend to overflow the existing poorly defined channels and meander over the cones. Also, larger flood flows carry considerable quantities of debris, such as gravels, boulders, and sands, that make diversion of water from the channels a hazardous and often an expensive venture (figs. 16 and 17). In fact,

FIGURE 16.—View of diversion works near upper portion of debris cone. Water is diverted to spreading areas on each side of natural channel. San Antonio Creek near Claremont, Calif.

FIGURE 17.—Same view as in figure 16 but after the major flood of 1938. San Antonio Creek near Claremont, Calif. A dam has since been constructed at approximately this site to control floods. Controlled releases of water from the reservoir will be diverted to spreading grounds.

the cones are still in a state of development by nature and consequently are changing with each flood flow. The major flood of 1938 did considerable damage to many of the water spreading systems located on debris cones and in some cases the damage has not yet been fully repaired. In spite of this handicap, however, spreading grounds built many years ago are still functioning.

After diversion from the main stream channels, various designs have been used to spread the water over the surface. The cones are relatively uneven in topography and numerous old or secondary channels cut their surface. The spreading system used therefore is one that best fits the local conditions. Basins that impound the water and prevent it from collecting in the channels and running off have been constructed in many places. In other places, shallow ditches have been used to direct the water over the porous lands, with the ditch bottoms providing the only percolating area. In some cases, only main ditches are used to direct the water to certain points on the cones where by use of small turnouts the water is permitted to flow out onto the land and infiltrate into the undisturbed gravels and native brushlands.

In recent years development of rural subdivisions in southern California has encroached upon the debris cones, making it even more hazardous to attempt the spreading of uncontrolled flood waters. In the most settled areas and on many of the canyons, flood control projects are in various stages of development. These projects usually are large impounding reservoirs intended for temporary storage. Much of the water from completed projects is now spread or released at such a rate that the natural channels will absorb the water before it reaches the ocean. Under this system more permanent-type spreading areas can be designed and constructed without danger of periodic damage from uncontrolled floods.

Silt.—Silt-laden waters are detrimental to spreading grounds. On the spreading system located at the mouth of the canyon of the Santa Ana River, Calif., the water is spread through a series of basins. The practice here is to divert water into the area only when the silt content is low. Silty water usually occurs during and for a few days immediately following a storm. Whether or not the water is suitable for spreading is left to the judgment of the attendant. At the Piru and Saticoy spreading grounds in Ventura County, Calif., no water is diverted to the spreading basins until the amount of silt is 25 cubic feet or less per acre-foot (575 p. p. m.). Water with a silt content in excess of this is detrimental to the percolating beds of the spreading basins. At the Piru spreading area, the upper basins are arranged to act to some extent as desilting basins. The Los Angeles County Flood Control District, Calif., diverts water to the spreading systems when the silt content drops to 10,000 p. p. m. However, this heavily silt-laden water is passed through desilting basins or traps before it reaches the spreading basins proper.

Imported water.—Water imported to an area is usually under control and the handling of it presents no great problem. For instance, the Kern County Land Co. and the North Kern Water Storage District in California use existing irrigation canals to carry water to spreading grounds located about 20 miles from the river that supplies the water. The canals are completely equipped with gates and turnout structures. They deliver water during the summer for irrigation purposes and convey water for recharge purposes to the vicinity of heavy pumping during the "off-irrigation" season. Location of the spreading sites in this case is governed by the location of the canals and areas needing replenishment. In Orange County, Calif., water imported to the area through pipelines of the Metropolitan Water District is purchased for recharge purposes. Here again, the water is under complete control and problems of flows in excess of the spreading ground capacities do not occur.

Quality of water.—Quality of water to be used for recharge purposes should be considered. Waters that contain a high proportion of sodium salts cause infiltration problems. Waters that contain industrial wastes or that naturally carry quantities of undesirable minerals must be used with caution, so as not to contaminate the ground water.

The danger that public water supplies may become polluted as a result of the movement of bacteria and chemicals with underground waters has long been a matter of concern to authorities responsible for protecting the public health or the quality of ground water resources. Recent laboratory and field investigations on the travel of pollution from direct recharge into underground formations (*4*) and waste water reclamation in relation to ground water pollution (*5*) show a definite hazard exists when polluted water is injected directly into the underground aquifer by means of wells. A lesser hazard exists when surface spreading methods are employed. Sewage effluents were used in the study. Migration of chemical pollutants was found to be greater than bacterial pollutants.

The State of California has a law (*6, sec. 4458*) that specifically prohibits the introduction of sewage into an underground stratum or strata, which states:

No person shall construct, maintain or use any sewer well extending to or into a subterranean water-bearing stratum that is used or intended to be used as, or is suitable for, a source of water supply for domestic purposes.

Although this law applies to "sewage," the policy of the California State Board of Public Health regarding disposal of surface water and the use of wells for recharge is contained in the following resolution adopted May 6, 1939, and readopted with modifications, January 17, 1942:

By reason of the fact that the use of drain wells into water strata for getting rid of road drainage or land drainage may also be the means of carrying dangerous cesspool overflow, or at least dirty water, into water strata which are suitable and valuable for domestic water supply, and may thereby pollute it, and it is found that there are various other ways in which land and road drainage can be eliminated without the use of such drain wells, the State Board of Public Health hereby disapproves of the practice of disposing of road or land drainage into wells, reaching the water strata used or suitable domestic well water, and the board hereby requests the various public officials concerned to lend their support to the fulfillment of this resolution.

The above restrictions do not apply to artificial recharge by surface spreading. However, there is a possibility of nuisance and health hazard from production of mosquitoes in surface spreading ponds.

In the Los Angeles area, investigations have been made (*3*)[3] to determine the feasibility of utilizing sewage water for recharge purposes, particularly with reference to creating a "fresh" water barrier along a certain portion of the coast. Here sewage water is intended to be used primarily for protection of ground water reservoirs from sea water intrusion rather than for reclamation purposes.

Other Considerations

Social and economic factors enter into the selection of a spreading site. The acquisition of sufficient land and rights-of-way as well as water supply is involved. Urban development of land overlying basins could well prove to be a major obstacle to spreading. In the operation of a spreading system nuisances to developed areas arise, such as mosquitoes, rodents, and growth of weeds, which must be eliminated or controlled.

Rights to water for recharge purposes and rights to water that has been spread and made available to wells within a ground water reservoir are at present not clearly defined in most States. As a result, legal controversies may be expected to arise.

INFILTRATION AND PERCOLATION

Definitions

Infiltration and percolation are of prime importance in artificial recharge and continuing high rates are desired in any artificial recharge development.

Agricultural Handbook No. 60 (*18*) defines infiltration and percolation as follows:

INFILTRATION.—The downward entry of water into soil.

INFILTRATION RATE; INFILTRATION CAPACITY.—The maximum rate at which a soil, in a given condition at a given time, can absorb rain. Also, the rate

[3] See also footnote 2, p. 15.

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at which a soil will absorb water ponded on the surface at a shallow depth when the ponded area is infinitely large or when adequate precautions are taken to minimize the effect of divergent flow at the borders. It is the volume of water passing into the soil per unit of area per unit of time. . . .

PERCOLATION.—A qualitative term applying to the downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of one or less.

In surface spreading both infiltration and percolation must occur and whichever has the lesser rate controls the rate of recharge.

Factors Affecting Rates

Infiltration is a complex phenomenon and, because of the many variables involved, no general law for computing rate has been developed. Experience indicates that the infiltration rate of a given soil depends on its physical status and management history. Infiltration is often critically influenced by the change in surface soil conditions brought about by the prolonged application of water. Thus, infiltration rate has been found to change with time; after 1 to 3 weeks of continuous water application, a decline to a fraction of the initial rate may occur. This is a perplexing problem to those practicing artificial recharge. Much experimental work has been done to determine the cause of the decline and to find ways to alleviate it.

Typical infiltration rate curves (not influenced by a high water table) as found on test ponds in Kern County, Calif., are shown in figure 18. The curve representing undisturbed soils indicates that

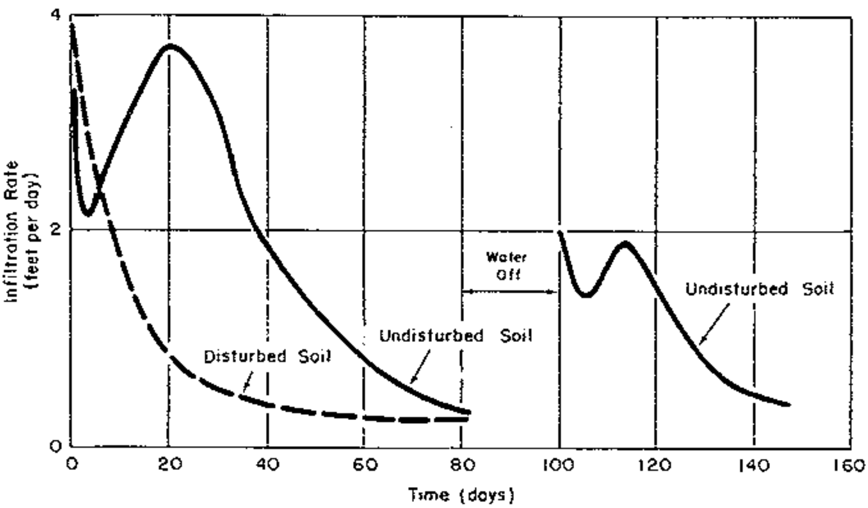

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FIGURE 18.—Typical infiltration rate curves.

after a short shutdown, the curve repeats itself but at lower infiltration values. On the basis of work done in the laboratory with soil cores (7), the S-shaped infiltration rate curve was explained as follows:

a. The initial decrease in permeability or infiltration rate is believed to be caused by dispersion and swelling of the soil particles. This is much more pronounced in some soils than others.

b. The increase in permeability following the initial decrease accompanies the elimination of entrapped air from the soil. This air is slowly dissolved in the water passing through the soil.

c. The gradual decrease in permeability that follows is due primarily to biological activity in the soil.

The explanation of the S-shaped curve was substantiated later by permeability tests with sterile soil and water (*1*). In figure 19, the permeability of sterile soil was maintained at approximately the

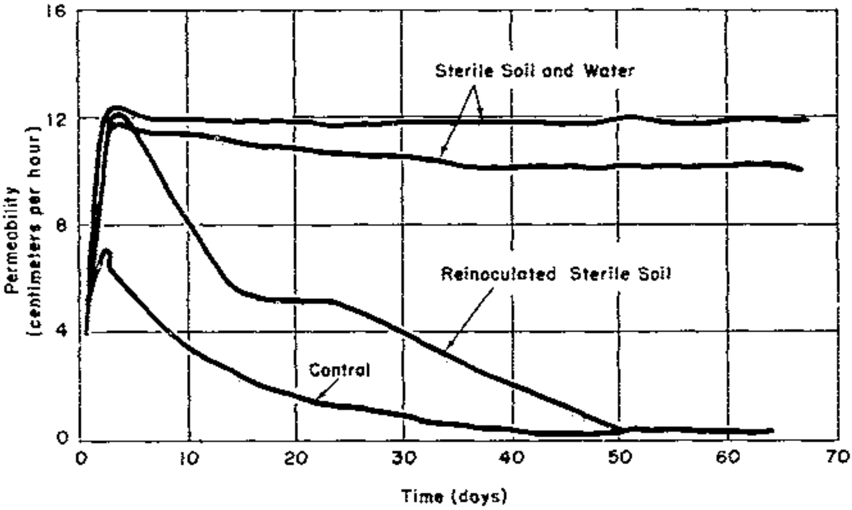

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FIGURE 19.—Permeability-time curves for Exeter sandy loam under prolonged submergence (*1*).

maximum rate, although the control that was operated under ordinary unsterile conditions followed the typical curve of figure 19. The conclusions from this experiment were:

Sterile permeability tests conducted to determine the cause of decreased permeability under prolonged submergence gave no evidence of soil aggregate breakdown due to purely physical causes. The reduced permeability appears to be due entirely to microbial sealing. The soil pores probably become clogged with the products of growth, cells, slimes, or polysaccharides. If any of the observed reduction in permeability was due in part to disintegration of soil aggregates, the dispersion is believed to be due to biological causes, that is, the attack of microorganisms on the organic materials which bind soil into aggregates.

These products of microbial activity not only appear to seal the soil during wetting, but also tend to improve the aggregation of the soil upon drying. This aggregation may in turn cause percolation rates higher than the initial rate. In other words, if energy material is added to a soil so as to promote microbial activity, the percolation rate could be expected to decrease rapidly. But when the soil dries and water is reapplied, the percolation rate could be expected to be higher than the initial run.

Methods of Measuring Rates

Although many measurements have been made of infiltration, as evidenced by the extensive bibliography of Davidson (*8*), no generally accepted procedure seems applicable to all conditions. Most of the infiltration measurements made have dealt with rainfall or irrigation conditions where the water was applied for relatively short intervals and in relatively small amounts. For water spreading purposes, it is usually desirable to determine the infiltration rate over a period of weeks or even months of continuous water application. The time element brings into consideration factors not involved in rainfall and irrigation problems. In water spreading the water must first pass from the surface into the soil and then through the soil and substrata to the ground water, which may be 100 feet or more below the surface. If the rate is controlled at the soil surface, then the soil and underlying materials do not become saturated; but if there are relatively impervious strata in the profile that retard the movement of water below the rate at which it can enter the soil, then water travels through the soil or subsoil above the restricting strata in saturated flow.

Under prolonged spreading operations the capacity of a spreading area decreases, which means either the rate at which the water will pass through the soil or subsoil has decreased. Feasibly then, the rate observed in spreading during a long run might be controlled for a portion of the run at the soil surface (infiltration) and at another portion of the same run by the permeability of the soil or underlying material.

For water spreading purposes the most satisfactory method of measuring infiltration rate is by determining the intake rate of spreading basins, ponds, ditches, or other wetted areas that exist in the spreading system. This method is usually not feasible for exploratory or diagnostic measurements in new areas, because costs are prohibitive in developing large enough test ponds and adequate quantities of water are not available.

The following procedures have been used to estimate infiltration rates that might be obtained under large-scale spreading operations in California.

Soil survey information.—Existing soil surveys made by the Soil Conservation Service or other agencies provide information on profile development, texture, substratum of low permeability if such exists, and other factors that would influence the movement of water through the soils. Much of the soil survey data are obtained by experienced soil technicians who can, with a fair amount of accuracy, predict the infiltration rates within the limits of rapid, moderate, slow, or very slow ranges.

Infiltrometers.—Many investigators and research workers have used infiltrometers in one form or another to determine infiltration rates under rainfall and flood conditions and for irrigation purposes. They have also used them to determine seepage losses from canals (*13, 14*). The American Society of Civil Engineers (*2*) has classified infiltrometers as either "flooding" or "sprinkler" type. The flooding type more nearly approaches conditions encountered in water spreading.

Although infiltrometers of the flooding type have been used rather extensively for irrigation and rainfall studies, only recently has an attempt been made to standardize the size or method of operation

(*10*). This lack of standardization stems from the fact that each investigator has adapted the infiltrometer to the specific conditions with which he is concerned. If the soil contains a plowpan or hardpan, he may need to drive the infiltrometer to a depth reaching or penetrating the hardpan in order to serve his particular purpose. If no shallow, impermeable layer exists, the depth of setting may or may not be of prime importance. Buffer rings have been used by some investigators, while single rings are used by others. The size of infiltrometer used has apparently been selected on the basis of what pipe or material is available and cheapest, although some infiltrometers have been specially fabricated. Diameters of 9 and 12 inches seem to be the most common. If the infiltrometer pipe is manufactured specially for this purpose, the size may be one that will ease computations, such as one covering an even square foot of soil surface. Some experimenters use a series of sizes, which nest together for ease in transporting (*10*), a distinct advantage where settings of several infiltrometers are made. However, nesting is no longer possible if the infiltrometers become damaged in use.

In exploratory work to evaluate unknown areas for water spreading possibilities, many tests were made in Tehachapi Valley, Kern County, Calif., and Ventura County, Calif. Because of the absence of a local water supply, small infiltrometers of 9-inch and 12-inch diameters were found to be the most convenient. Sufficient water could be hauled by truck to replenish periodically 50-gallon drums used for supply tanks. The supply tanks were connected to the infiltrometers by means of hose. Water entering the infiltrometer was controlled by a float valve. The amount of water passing through the infiltrometer was calculated from the losses in the supply tank between observations (fig. 20).

Where a continuous water supply was available, infiltrometers covering 0.001 acre (6.6 feet square) were tried (fig. 21). These consisted of galvanized iron so fabricated that they could be dismantled and moved. Water was held at a constant depth by a float valve and metered into the infiltrometer. Although this type of infiltrometer has the advantage of covering more area than the smaller pipes of 9- and 12-inch diameter, increased cost, the difficulty of moving and setting, and the large quantities of water required usually preclude its use over that of smaller types. At best, infiltrometers provide only a basis for estimating infiltration rates for spreading areas, and a change in size from 9 to 12 inches in diameter to 6.6 feet square does not appear justified in most cases.

Except for determining canal seepage losses, infiltrometers have generally been used to determine rates when there has been a relatively short period of water application. For water spreading purposes the infiltration rate under prolonged wetting is desired. Rates obtained during the initial wetting are not important. Rather, those rates obtained for a week to several months of continuous run are sought. By eliminating the initial rates or those obtained during the early part of a run, several complex problems relating to the use of infiltrometers are avoided. It is well known that dry soil exerts a tension on water moving into it. The magnitude of this tension depends upon the soil moisture content—the drier the soil, the greater is the tension. Therefore, in short-time tests of a few hours or more required for irrigation or rainfall studies, the antecedent moisture

FIGURE 20.—Nine-inch infiltrometers used to determine infiltration rate. Float valves control water at constant level. Fifty-gallon drums used for supply are connected to infiltrometer by rubber hose.

content of the soil has a material influence on the infiltration rate. For water spreading purposes, the concern is with infiltration rates after the initial wetting and during the period when the soil moisture is at all times above field capacity.

Subsurface conditions may have a marked effect on the infiltration rates under prolonged runs, and these conditions must be considered in the use of infiltrometer data for water spreading purposes (*15*). In order to use infiltrometer data properly, an understanding of the conditions under which infiltrometers are used must be clear. The depth of setting, size, whether buffered or unbuffered, and depth of water all may influence the infiltration rates obtained by infiltrometers as compared to infiltration rates from large areas.

The use of infiltrometers is confined primarily to the measurement of infiltration rates as affected by conditions at or near the soil surface. Substrata conditions may distort the picture entirely if strata of less permeable material lie below the soil surface. This is illustrated in figure 22, representing a condition found on Exeter soils near Bakersfield, Calif. The surface 5 feet of soil was relatively

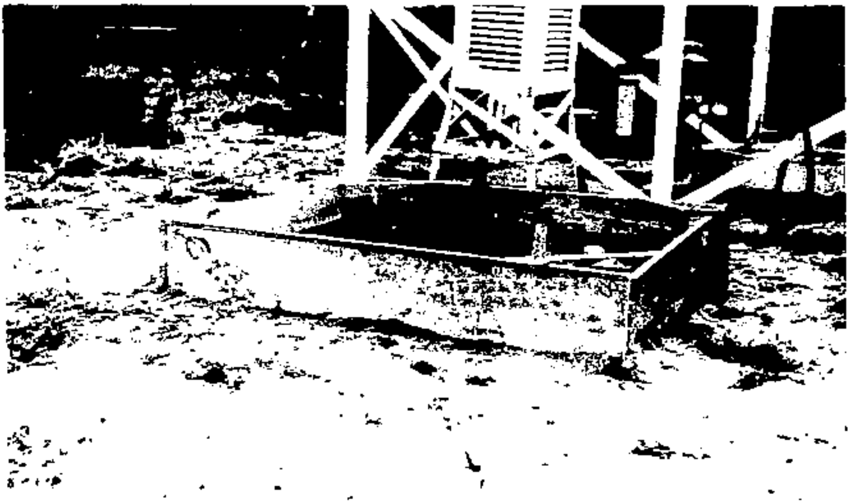

FIGURE 21.—Infiltrometer 6.6 feet square (0.001 acre) used to determine infiltration rates. Water is supplied continuously and metered. Water level is maintained at constant level by float valve. Infiltrometer sides are made of galvanized sheet iron bolted at the corners; depth of setting about 6 inches The infiltrometers can be di mantled and moved.

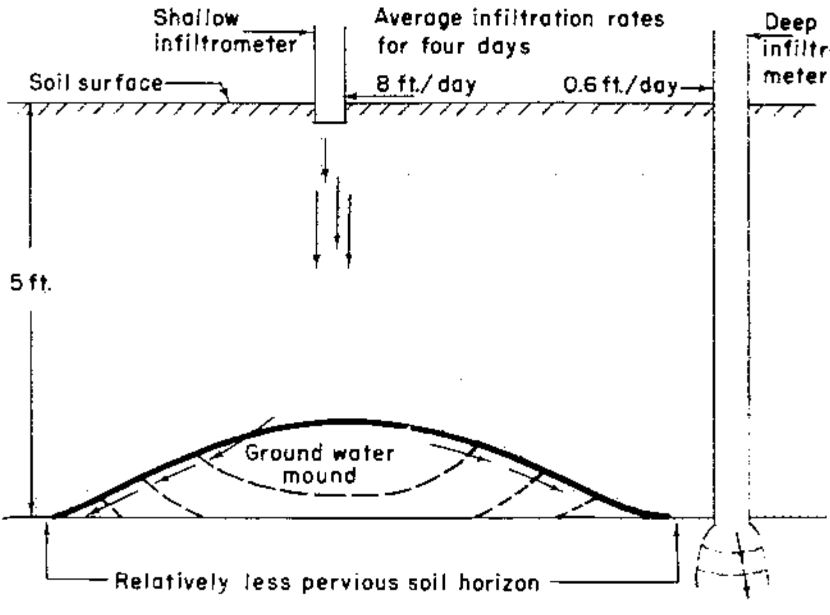

FIGURE 22.—Influence of lateral flow on infiltration rate.

pervious, with an infiltration rate of 8 feet per day being measured with an infiltrometer set 9 inches into the soil. However, soil examination by augering indicated a less pervious stratum at the 5-foot depth. An infiltrometer driven to this stratum indicated an infiltration rate of only 0.6 feet per day, the infiltration rate being controlled by the percolation rate through the substratum. Under the conditions shown, the impervious stratum would not affect the infiltration rate of the shallow infiltrometer. Water would percolate downward until it encountered the stratum at the 5-foot level, where it would move laterally in all directions until the saturated area became sufficient to pass through the less pervious material the quantity of water supplied through the infiltrometer. This can be stated simply by the equation

$$Q = A_1 V_1 = A_2 V_2$$

where Q is equal at the surface and at the 5-foot level, V_1 is 8 feet per day at the surface, and V_2 is 0.6 feet per day at the 5-foot level, with the same effective head. If A_1 at the surface in the infiltrometer is 1 square foot, then A_2, the wetted area on the subsurface stratum, must be 8.0/0.6 or 13.3 square feet.

Buffering of the shallow infiltrometer shown in figure 22 would not necessarily have the desired effect of preventing lateral percolation. If a buffer ring of the usual size, that is, about three diameters of the infiltrometer, is used, then little if any effect can be expected on the infiltration rate for the conditions illustrated. The ground water mound would be somewhat greater both laterally and vertically, but unless the mound rose to the surface, the infiltration rate would not be materially influenced by the buffer ring.

For spreading areas where large areas are covered, lateral movement can take place only at the perimeter. Consequently, the 5-foot zone between the subsurface stratum and the surface would soon become saturated and the infiltration rate would equal the rate of the less permeable stratum plus whatever percolated laterally at the perimeter of the spreading area. The 0.6-foot rate compares closely with that obtained on an adjacent large spreading basin. Under such conditions the distance of impervious stratum below the surface and the size of the spreading area will control to some extent the infiltration rate obtained under large scale spreading.

The foregoing discussion indicates the advisability of exploratory holes in any area to be tested with infiltrometers. For conditions where the impervious stratum is deeper, well logs are helpful, but these seldom indicate the soil condition in the upper zones.

In using infiltrometers at various locations in California to evaluate surface conditions for water spreading, it was found that the infiltration rate usually followed the typical S-shaped curve (fig. 18). Therefore, any tests made should be continued without interruption until the infiltration rate has passed through the initial phases indicated by the curve.

EXPERIMENTS IN SAN JOAQUIN VALLEY, CALIF.

Circumstances Under Which Initiated

Recent cooperative water spreading experiments have been concentrated in the San Joaquin Valley, Calif., particularly in Kern County. Soils in this area, while highly desirable for agricultural purposes, are not ideally adapted to water spreading for replenishment of the ground water supply. The soils range from loams to fine sandy loams, some underlain with hardpan. The need for ground water replenishment is great, however, as evidenced by Simpson (*16*):

Utilization of ground water for irrigation in the Central Valley did not become significant until after 1900. More or less complete direct diversion of surface water supplies during the summer season in south San Joaquin Valley prior to 1910 gave impetus to development of ground water. The combined capacity of wells in the San Joaquin Valley south of Chowchilla was about 7,300 cubic feet per second by 1919 and about 20,600 cubic feet per second by 1929. Overdrafts on ground water occurred in much of the area prior to 1929 and have prevailed since that time. Estimated usable underground storage capacity of approximately 20,000,000 acre-feet has made the long-continued overdraft possible . . .

The combined gross pumpage of ground water from about 35,000 wells in the San Joaquin Valley (south of Merced River) during the seasonal year ending April 1, 1948 is estimated as being close to 6,000,000 acre-feet or about 60% of the total in the state . . .

In the years following 1948, a very rapid increase in well drilling has taken place, as a result of the development of large acreages of new land. The ground water problem resolves itself not only in alleviating overdrafts but also in providing some relief from the high pumping costs caused by higher and higher pumping lifts.

Ground water replenishment by spreading was considered in the San Joaquin Valley, but tests by Haehl [4] as early as 1936 revealed a distinct problem existed in that the infiltration rates of most soils of the valley were relatively low and also that the rates decreased with continued application of water. Late in 1943 a joint investigation was started to study the infiltration problem with the North Kern Water Storage District, the Kern County Land Co., the California State Division of Water Resources, the United States Bureau of Reclamation, the United States Salinity Laboratory, the Arvin-Edison Water Storage District, and the United States Soil Conservation Service,[5] participating.

The expressed purpose of this joint effort was "To determine the cause or causes of the decrease of infiltration rate under prolonged submergence and to determine, if possible, practical methods of establishing and maintaining satisfactory infiltration rates over extended periods of time."

Under this joint effort a series of field experiments was started in 1944. A group of 9 test ponds originally operated by the North Kern Water Storage District was put into operation, and 46 other test ponds were constructed. Fifteen were in isolated locations, representing different soil types and served with different water supplies. The remaining ponds were located in two groups on the predominating soil types of the Kern area. One group containing the original 9 ponds was located near Minter Field, Calif., on soils classified as Exeter fine sandy loam (fig. 23), and the other group was located near Wasco, Calif., on Hesperia fine sandy loam (fig. 24). Both soils are highly valued for agricultural purposes. In addition, there were records made available by the North Kern Water Storage District of test spreading on 17 areas ranging in size from a few acres to more than 50 acres.

[4] Haehl, Harry, consulting engineer. Unpublished folios and data. Kern County Land Co., Bakersfield, Calif.

[5] Now Soil and Water Conservation Research Division, Agricultural Research Service, USDA.

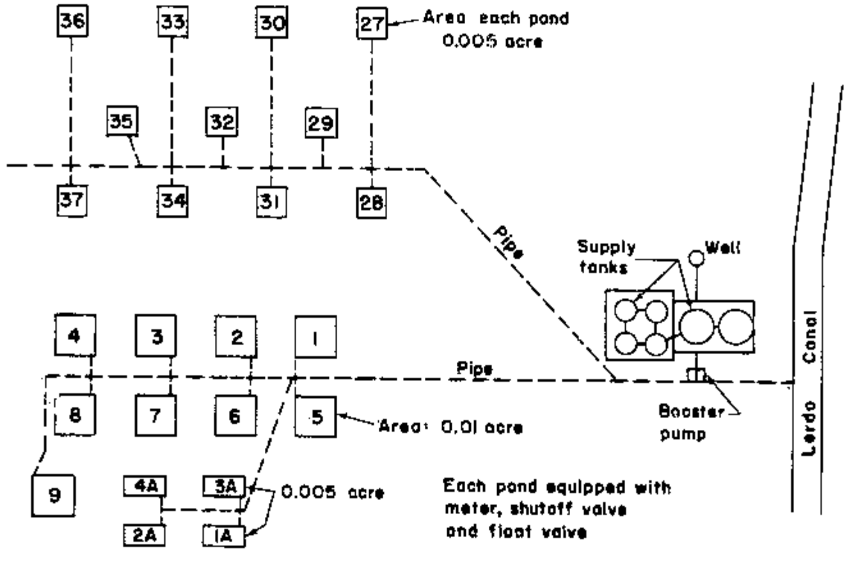

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FIGURE 23.—Layout of test ponds and water supply system at Minter Field, Kern County, Calif.

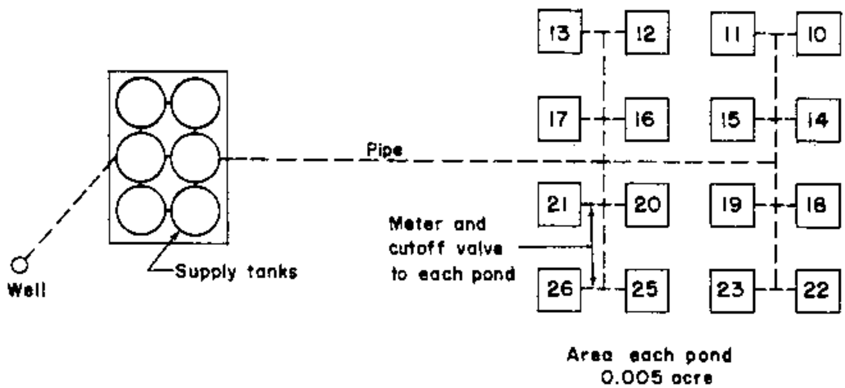

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FIGURE 24.—Layout of test ponds and water supply system near Wasco, Calif.

Test Ponds

Description.—The test ponds mentioned above were either 0.01 or 0.005 acre in size and originally formed by boarding up the sides with 1- by 12-inch lumber. The side walls consisted of three 1 by 12's set 6 inches in the earth and rising 2½ feet above the ground surface. Battens and earth embankments were placed around the outside of the walls. Water was supplied to the ponds by means of underground pipes, each equipped with a domestic-type water meter. The water level in the ponds was controlled by float valves (fig. 25). Galvanized sheet iron was later used instead of 1- by 12-inch lumber.

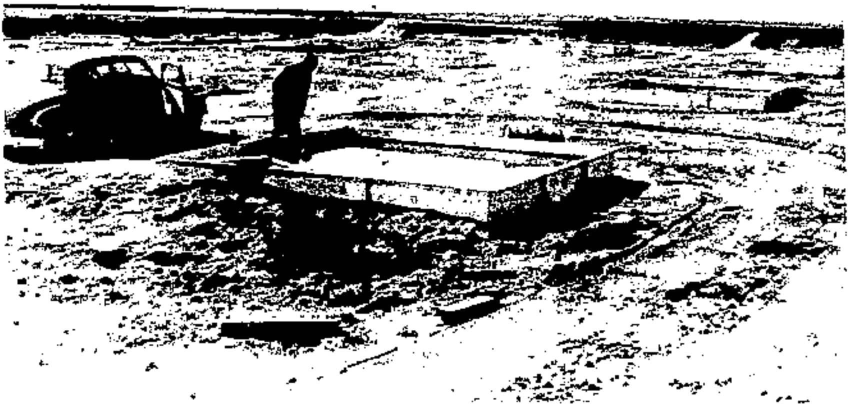

FIGURE 25.—Test ponds installed on Exeter fine sandy loam, Kern County, Calif. Sides are of galvanized sheet iron set about 6 inches into the soil. Water is conveyed to the pond by pipeline equipped with a meter. Water level in the pond is maintained at a constant depth by a float valve.

Daily observations consisted of reading the water meter and staff gage and inspecting the ponds for leaks through the side walls. Daily evaporation was read at a floating tank in one of the ponds. Infiltration rates were computed on a 24-hour basis, corrections being made for changes in surface storage as determined by staff gage readings, evaporation, and rainfall, if any. Usually the readings were taken at the same time each day, but if not, corrections were made for time. The rates were recorded as feet per day and, with all corrections made, indicated the amount of water actually entering the soil in a 24-hour period.

Use of test pond data on large areas.—It was recognized in setting up the experiments that infiltration rates obtained on the small test pond might not be directly applicable to a large area. However, it was reasoned that if a certain treatment given a small pond produced beneficial effects on infiltration rates, the same treatment on a large area should be similarly beneficial, although not necessarily in the same magnitude. This reasoning could be correct only if the infiltration rate was controlled at or near the surface. Tests had produced evidence that the decline in infiltration rate over a long period of time was caused by changes at or near the surface. This being true, then surface treatments might be expected to benefit large areas as well as small ponds.

If a restricting layer underlies an area, data obtained from small ponds may not apply to large areas. Results of infiltration tests made under such a condition are illustrated in figure 26. The topsoil consisted of sandy material with a relatively high infiltration rate. At about a 3-foot depth there was a dense restricting layer. In operating the inner pond only, high rates were obtained—as the water moved downward and struck the restricting layer, it moved laterally, with the result that there was little effect on the infiltration rate. When

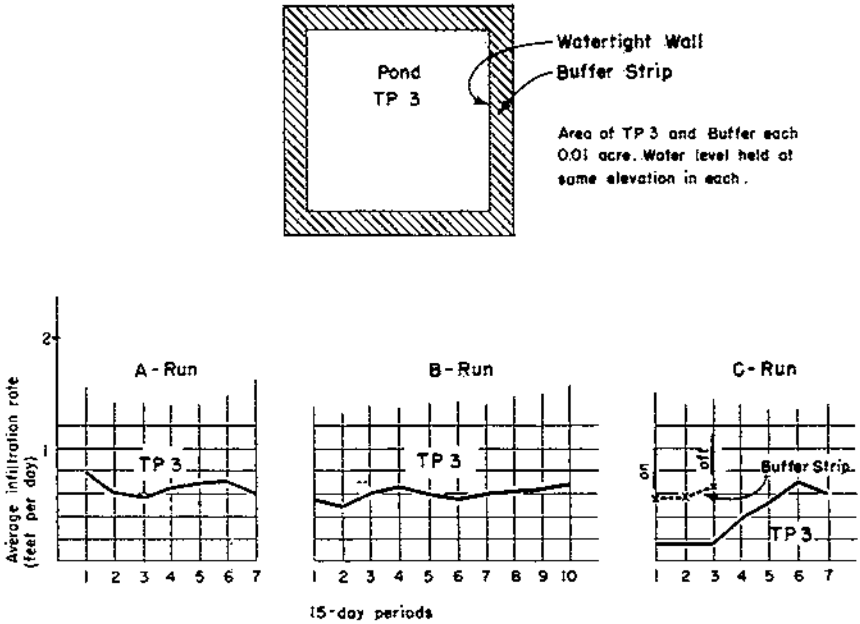

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FIGURE 26.—Effect of buffer strip on test pond TP 3, Tulare County, Calif.

the buffer strip was put into operation the lateral percolation was reduced, causing an almost immediate effect on the infiltration rate. If the restricting layer had been at greater depth, say 20 feet, the buffer strip probably would have had little effect and the whole unit, buffer plus center pond, would have operated as a single pond. However, if several acres of spreading grounds were operated over this area, the infiltration rate would have been reduced because all of the water moving into the soil could not have moved laterally.

The use of surface treatments then can be beneficial only when the control is at or near the surface. There is no benefit derived if the surface infiltration rate is increased over the percolation rate of the material immediately underlying the surface soil.

Treatments to promote infiltration.—The Minter Field and Wasco test ponds were given a variety of treatments. The effects of all treatments were checked against the rate obtained from undisturbed check ponds and also against previous rates obtained on the individual ponds before treatment was given. Some of the experiments were not considered practical on a large scale; rather, they were intended to provide fundamental data that would be useful in developing a practical solution to the infiltration problem.

Treatments are classed under one of five general categories: (1) Chemical, (2) mechanical, (3) operational procedures, (4) addition of organic matter, and (5) vegetative. In some instances there was not a clear distinction as to which classification a treatment might properly be given. For example, the application of gypsum would be chemical and the spading of the surface soil would properly be classed as mechanical, but if gypsum were spaded under, it is not certain from this experiment alone whether the addition of gypsum, the spading, or a combination of the two would affect the infiltration rate. Furthermore, the effect of a treatment might be delayed or be lasting. Then, if it were followed too soon by another treatment, it might be difficult if not impossible to interpret with any degree of certainty the true effect of the second treatment.

Tables 1 to 5, inclusive, contain a list of all treatments and their effects on infiltration rates as compared with untreated control ponds or in some instances with previous records on the same pond obtained prior to treatment. In these interpretations little weight could be given to small differences in infiltration rates before or after a specific treatment: (1) Because the experimental setup did not provide sufficient control or replication for evaluating these small differences; and (2) because it was believed that any treatment must necessarily show substantial beneficial effect on infiltration rate before it could be justified for trial under large-scale spreading operations. Many small fluctuations in the daily infiltration rate curves could not be explained. However, over the long period during which most of the tests were run, these small fluctuations were inconsequential in the interpretation of whether or not a specific treatment benefited the infiltration rate.

CHEMICAL.—The first consideration in connection with chemical effects on the infiltration rates is with the characteristics of the water supply. Ordinarily, in water spreading there is no choice of water. Suitability for spreading should be looked into with regard to the available supply. Considerable information exists as to the effects of certain types of water on infiltration rates in relation to irrigation, and these results in general apply to spreading (*18*).

Sodium is the principal element that affects the movement of water into or through a soil. Its importance lies not so much in the quantity present as in its relation to the elements calcium and magnesium. The sodium percentage calculated by dividing quantity of sodium by the sum of the quantities of calcium, magnesium, sodium, and potassium, all in milliequivalents per liter, is the usual way to express the quality of a water for irrigation with respect to the effect of sodium on the soil.

Water having a high sodium percentage tends to deflocculate the colloidal soil particles, which then hinder the movement of water through soil. No inflexible distinction can be drawn between a good and a poor quality water. Generally, water in which the sodium percentage is above 65 is considered poor quality; between 50 and 65, questionable; and below 50, satisfactory for both irrigation and spreading.

TABLE 1.—*Chemical treatments on test ponds and their effect on infiltration rate, Wasco and Minter fields, Kern County, Calif.*

Treatment	Soil	Effect on infiltration
Gypsum ($CaSO_4$) broadcast in pond while operating (4 tons per acre).	Exeter sandy loam	Beneficial; slight and temporary.
Gypsum ($CaSO_4$) applied to soil surface after removal of top 2 inches of soil and spading 12 inches deep (2 tons per acre) before water spreading.	do	No effect.
Gypsum ($CaSO_4$) broadcast over water surface every 3 to 5 days (1½ tons per acre).	do	Beneficial, but only during periods of application.
Gypsum ($CaSO_4$) spaded under (7 tons per acre) before water spreading.	do	Beneficial; temporary.
Gypsum ($CaSO_4$) broadcast on undisturbed soil surface (10 tons per acre) before water spreading.	do	No effect except during initial application of water; effect lost after 5 days' run.
Calcium chloride ($CaCl_2$) added to water during spreading to maintain hardness of 200 p. p. m.	do	Beneficial during application of calcium chloride only.
Lime (impure) broadcast on water during spreading (5 tons per acre).	do	No effect.
Lime (impure) spaded under 12 inches deep (10 tons per acre) before water spreading.	do	Do.
Copper sulfate ($CuSO_4$) added throughout water spreading run	do	No effect on rate; by visual inspection, algae appeared controlled.

TABLE 2.—*Mechanical treatments on test ponds and their effect on infiltration rate, Wasco and Minter fields, Kern County, Calif.*

Treatment	Soil	Effect on infiltration
Sod removed to a depth of 2 inches, then spaded 12 inches deep	Hesperia sandy loam	Detrimental.
Sod removed to a depth of 2 inches	do	Do.
Sod removed to a depth of 6 inches	Exeter sandy loam	Do.
Spaded	do	Beneficial.
Spaded after a 2-month dry period following water spreading	do	No effect.
Spaded 2 weeks after a long continued water spreading run at low infiltration rate.	do	Beneficial.
Spaded, then irrigated periodically for 1 month, then dried	do	Do.
Spaded 2 weeks after spreading ended, then dried several months	Exeter sandy loam and Hesperia sandy loam.	No effect.
Gypsum applied to soil and spaded under	Hesperia sandy loam	Beneficial.
Spaded, alfalfa planted and given frequent irrigations to establish crop, spreading started during second year after treatment.	do	Detrimental.
Spaded, then rice hulls added	do	No effect.
Lime applied to soil and spaded under	do	Beneficial.
Raked lightly during off period	Exeter sandy loam	No effect.
Scraped to remove top ⅛-inch crust formed during previous spreading.	Hesperia sandy loam	Do.
Raked lightly each day while operating to break air bubbles on ground surface.	do	Do.
Four holes drilled 20 feet with 4-inch auger, then back-filled with gravel and mounded to top with gravel.	Hesperia sandy loam (sand aquifer penetrated by auger holes).	Beneficial.
One hole drilled 20 feet deep with 4-inch auger, then back-filled with gravel and mounded at top with gravel.	Exeter sandy loam (no aquifer material encountered in auger hole).	No effect.
Covered with tar paper roofing so as to operate in darkened condition to prevent algae growth.	Hesperia sandy loam	Do.

TABLE 3.—*Operation procedures on test ponds and their effect on infiltration rate, Wasco and Minter fields, Kern County, Calif.*

Treatment	Soil	Effect on infiltration rate
Changing depth of water during spreading (two soils tested)	Hesperia sandy loam and Exeter sandy loam.	Increase in infiltration rate with increase in depth of water.
Maintaining shallow depth of water (0.2 to 0.3 ft.) on undisturbed soil (two soils tested).	do	No direct effect; shallow water provides opportunity for plant growth in ponds, which benefits infiltration rate.
Interrupting water spreading for a week or less (two soils tested)	do	Temporary effect; infiltration rate reduced after interruption but soon recovered to original rate.
Interrupting water spreading until topsoil dried (two soils tested).	do	Increase over final rates on previous runs usually to initial rate.
Spreading stopped before infiltration rate reached minimum, then soil dried.	Exeter sandy loam	No effect.

TABLE 4. *Organic matter additions at test ponds and their effect on infiltration rate, Wasco and Minter fields, Kern County, Calif.*

Treatment	Soil	Effect on infiltration
Alfalfa hay (10 tons per acre) spaded under and kept moist for 30 days to incubate, then dried.	Exeter sandy loam	Beneficial; peak rate higher than on undisturbed soil and rate decline slower.
Alfalfa hay (10 tons per acre) spaded under and kept moist for 30 days to incubate, then dried.	Hesperia sandy loam	Not beneficial on short run.
Alfalfa hay (5 tons per acre) spaded under and kept moist by frequent irrigations for 30 days, then dried.	do	Slightly beneficial.
Barley crop grown in pond, then spaded under	Exeter sandy loam	No effect.
Barley crop grown in pond, then cut and let lie on ground	do	Do.
Sudan grass grown on pond, then spaded under and kept moist for 30 days by frequent irrigations, then dried.	do	Do.
Paragrass grown in pond, then spaded under and kept moist for 30 days by frequent irrigations, then dried.	do	Beneficial both as to peak rate and sustained rate.
Dallis grass grown in pond, mature tops permitted to lie in pond	do	No effect.
Rice hulls added after spading	Hesperia sandy loam	Do.
Cornstalks (field run) spaded under and kept moist by frequent irrigations for 30 days, then dried.	Exeter sandy loam	Do.
Cornstalks plus ammonium sulfate spaded under and kept moist for 30 days, then dried.	do	High peak rate, but rapid decline to a low rate.
Barnyard manure (8 tons per acre) spread on undisturbed soil	do	No effect.
Cotton gin trash (6-inch layer) spread on undisturbed soil	do	No immediate effect. After long run and subsequent spadings, treatment was highly beneficial both as to peak rates and sustained rates. Beneficial effect still apparent 8 years after application.
Cotton gin trash (4-inch layer) spread on soil and spaded under prior to water spreading.	do	No immediate effect. After drying and spading, treatment was beneficial.

TABLE 5.—*Various kinds of vegetation under water spreading conditions and their effect on infiltration rate at Wasco and Minter fields, Kern County, Calif.*

Treatment [1]	Soil	Plant growth results and effect on infiltration
Rhodes grass (*Chloris gayana*) seed planted after spading under alfalfa hay.	Exeter sandy loam	Seed slow to start. Good stand obtained but did not survive winter. No effect on infiltration rate.
Dallis grass (*Paspalum dilatatum*) seed broadcast after spading	do	Seed failed to germinate. After several repeated attempts a good growth was obtained by planting rows 1 in. deep. Grass showed signs of dying after 21 days of continuous water spreading—water 12 in. deep. No effect on infiltration rate.
Dallis grass (*Paspalum dilatatum*) seed grown in pond as volunteer crop from previous year, old grass permitted to lie on soil surface.	do	Good growth obtained that survived prolonged water spreading at shallow (2-inch) depth. No effect on infiltration rate.
Paragrass (*Panicum purpurascens*) cuttings planted	do	Good growth obtained that survived prolonged water spreading and dry periods lasting several months. Second and succeeding years, luxuriant volunteer stands were obtained. No effect on infiltration rate, first year; rate increased materially, second year.

Buttonwillow (*Baccharis glutinosa*) cuttings planted 24-inch centers).	Hesperia sandy loam	Good growths obtained that survived water spreading at shallow depth and long drought periods. No effect on infiltration rate.
Saltgrass (*Distichlis stricta*) sod laid on original surface	do	Saltgrass crowded out by Bermuda grass. No effect on infiltration rate.
Bermuda grass (*Cynodon dactylon*) sod, 3 to 4 in. thick, laid on original surface after raking to form bond.	do	Grass died where totally submerged. No effect on infiltration rate, first year; beneficial, second year.
Bermuda grass (*Cynodon dactylon*) sod laid on original surface	do	Grass grew luxuriantly with tops above water; much litter from dry grass tops and roots remained in pond during entire run. No effect on infiltration rate, first year; then increasingly beneficial effects for following years until pond was destroyed after 9 years of operation.
Alfalfa grown to maturity by irrigation; then water applied continuously for 10 days at shallow depth; then pond allowed to dry 10 days.	do	Alfalfa failed to survive first (10-day spreading interval); test was run during times when maximum temperatures were in high 90's. No effect on infiltration rate.

[1] Other plants tried that failed to grow on water spreading areas were (1) Bluestem (*Andropogon furcatus*), (2) ryegrass (*Elymus* spp.), (3) Italian ryegrass (*Lolium multiflorum*), (4) birdsfoot trefoil (*Lotus corniculatus*).

Illustrative of the effect of different waters on infiltration are the results obtained during tests in Kern County. Canal water (originating from Kern River) was used in some tests when it was available, and water drawn from a well was used in other tests. Infiltration rates as a result of using well water were found to be about double the rates obtained with canal water on the same ponds on numerous occasions (fig. 27). Both waters are considered satisfactory for irrigation purposes. The analyses are as follows:

Chemical data:	Water: Canal	Water: Well
Conductivity—$K \times 10^6$	239	646
pH	8.0	7.9
Calcium carbonate ..... p. p. m.	49.0	147.5
Carbonate ..... p. p. m.	4.8	0
Bicarbonates ..... p. p. m.	91.5	120.8
Sulfates ..... p. p. m.	7.2	91.4
Chlorides ..... p. p. m.	16.3	29.8
Sodium percentage ..... p. p. m.	56.8	37.6

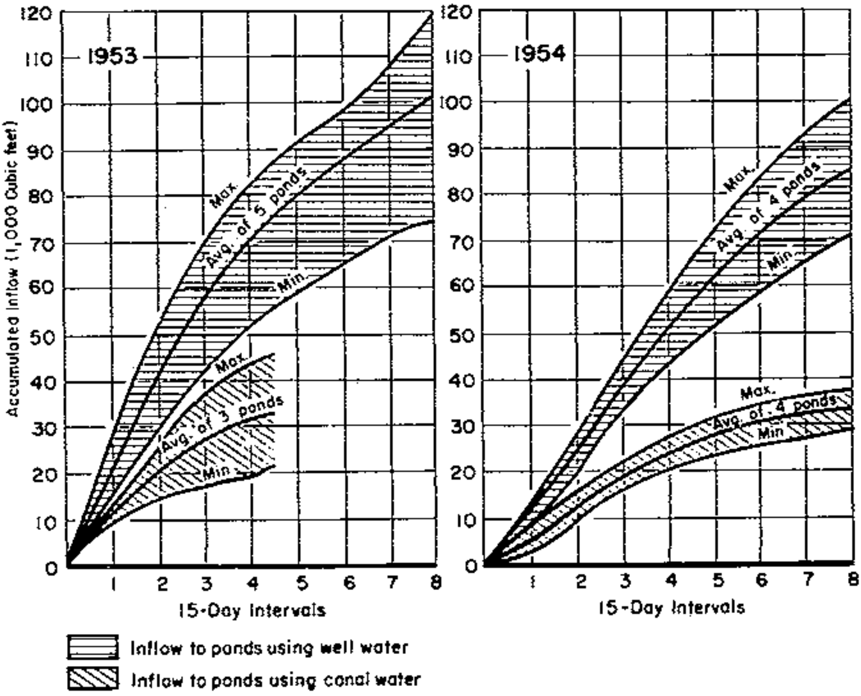

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FIGURE 27.—Accumulated inflow to Minter ponds, using water of different quality. (From Kirkham W. Campbell, Associate Engineer, Kern County Land Co.)

In view of the known effects of water quality on infiltration rates, several experiments were made at the Minter Field and the Wasco group of test ponds to determine the effect and practicability of adding soil or water amendments to lower the sodium percentages. Application of gypsum ($CaSO_4$) and calcium chloride ($CaCl_2$) were both beneficial and increased infiltration, but only temporarily (fig. 28).

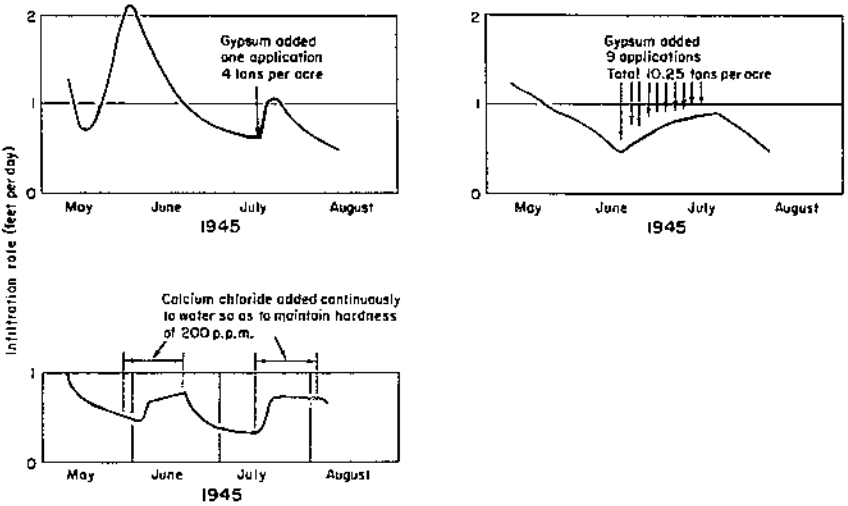

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FIGURE 28.—Effect of gypsum and calcium chloride on infiltration rate on Exeter fine sandy loam near Minter Field, Calif.

The effect of a gypsum application at the rate of 10 tons per acre had a beneficial effect only while the first 16 feet of water (depth) infiltrated. Apparently the gypsum had been leached out with this amount of water. Gypsum was added both by broadcasting on the water and by spading under prior to a spreading run. Other tests to lower sodium percentages were applications of lime to increase the water calcium content and copper sulfate for algae control. Table 1 contains a summary of the chemical treatments and the results obtained. No tests were made to determine whether or not the soil or water was affected by the addition of the chemicals. Results were interpreted from the effect on infiltration rates.

MECHANICAL.—The treatments classified as "mechanical" are those involving spading of the soil, removal of topsoil, raking or scraping the soil surface, driving auger holes that are backfilled with gravel, and covering a pond with tar paper in order to exclude sunlight. The results of the pond treatments are given in table 2.

In general, any mechanical disturbance of a soil that contains fine material will have a detrimental effect on the infiltration rate, as indicated by the operation of the test ponds and from results on large-scale spreading areas. Plowing or disking lands devoted to large-scale spreading in Kern County, Calif., caused detrimental effects in comparisons made with undisturbed soils. Figure 18 illustrates the general result of this practice.

Other mechanical disturbances of the soil that cause compaction have had a marked effect on the infiltration rate. During the process of constructing large spreading areas, the North Kern Water Storage District, Kern County, Calif., leveled the soil surface by heavy machinery at a time when the soil moisture was relatively high because of recent rains. In tests made with soil cores, the leveling operations resulted in an increase of volume weight to a depth of 19 inches (total depth of sampling) with a 13-to-1 reduction in infiltration rate for the top 3 inches of soil. For the soil cores taken from a 16- to 19-inch depth, there was a reduction of about 2 to 1 in the infiltration rate (table 6).

Reduction of the infiltration rate by disturbance is much more pronounced on soils containing fine material than on well-graded sands. In fact, on the river bottom sands of Santa Clara River in southern California, the Santa Clara Water Conservation District found that increased infiltration was obtained by scarifying during spreading operations. Here, the water flows over uniformly graded sands containing little fine material. Mechanical disturbance of the sands was found to be beneficial, even though the disturbance was made during a time when the sands were saturated or nearly so.

TABLE 6.—*Comparison of infiltration rates and volume weights of a fine sandy loam in undisturbed areas and areas disturbed and compacted by leveling operations, Kern County, Calif.*

Depth of sampling	Soil in leveled area [1]			Undisturbed soil		
	Infiltration rate		Volume weight	Infiltration rate		Volume weight
	Initial	After 24 hours		Initial	After 24 hours	
	Cc./hr.	*Cc./hr.*	*Gm./cc.*	*Cc./hr.*	*Cc./hr.*	*Gm./cc.*
0 to 3 inches	30	22	1. 84	940	640	1. 22
3 to 6 inches	130	30	1. 82	550	580	1. 38
9 to 12 inches	150	44	1. 78	200	250	1. 45
16 to 19 inches	192	78	1. 76	236	260	1. 40

[1] Samples taken approximately 1 month after leveling.

Table 7 shows the increased infiltration obtained by scarifying in a 2½-mile section of the river channel extending from Saticoy Bridge to Montalvo Bridge. It was calculated that a total of 1,270 acre-feet infiltrated as a result of scarifying during the first test running from March 7 to April 11, 1933, and a total of 1,500 acre-feet infiltrated during the second test, which ran from December 19, 1933, to February 21, 1934.

OPERATIONAL PROCEDURES.—Under this classification are included trials with different depths of water, different lengths of drying periods between runs, cessation of water application before infiltration rate reaches a minimum, and desilting of the water supply.

It was found that infiltration fluctuated in phases with changes in depth of water, or "head," during a spreading run (fig. 29). However, if a spreading run was started and maintained at a shallow depth (0.2 or 0.3 foot) throughout a run, the infiltration rates tended to be higher and maintain themselves better than when the water was applied at depths of 1 or 2 feet. This may have been caused by differences in sunlight reaching the soil, temperature, or other unmeasured factors. These tests showed that certain plants will thrive with the shallow depths of water, whereas they will not survive under the greater depths.

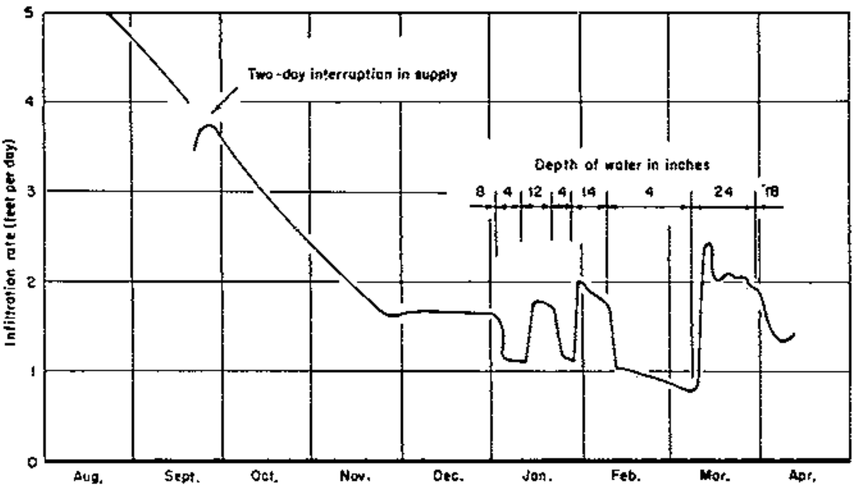

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Figure 29.—Effect of changes in depth of water on infiltration rate in test pond No. 10 near Wasco, Calif., on Hesperia fine sandy loam.

Table 7.—*Effect on infiltration by scarifying in a 2½-mile section of the Santa Clara River Channel, Ventura County, Calif., 1933–34* [1]

Item	Inflow to section	Outflow from section	Infiltration	
			Quantity	Proportion of inflow
	C. f. s.	*C. f. s.*	*C. f. s.*	*Percent*
Average water flow before scarifying, measured Mar. 1, 1933	75.2	66.7	8.5	11.3
(Scarified Mar. 7, 1933)				
Average water flow after scarifying, measured Mar. 8 to Apr. 11, 1933	74.7	50.7	24.0	32.4
Average water flow before scarifying, measured Dec. 19, 1933	39.5	29.5	10.0	25.3
(Scarified Mar. 21, 1933)				
Average water flow after scarifying, Measured Dec. 22, 1933 to Feb. 21, 1934	32.4	14.2	18.2	56.2

[1] Tests and measurements by Santa Clara Water Conservation District.

The effect of interruptions of spreading apparently depend largely on the degree of drying that takes place in the topsoil. Short interruptions of a few days or less cause only a temporary detrimental effect on the infiltration rate. After spreading is resumed for a few days the rates return to what would have been expected had no interruption occurred (fig. 30, *A*). Air entering the soil during the short interruption is believed to be at least partly responsible for the decreased rate immediately following the interruption. Interruptions

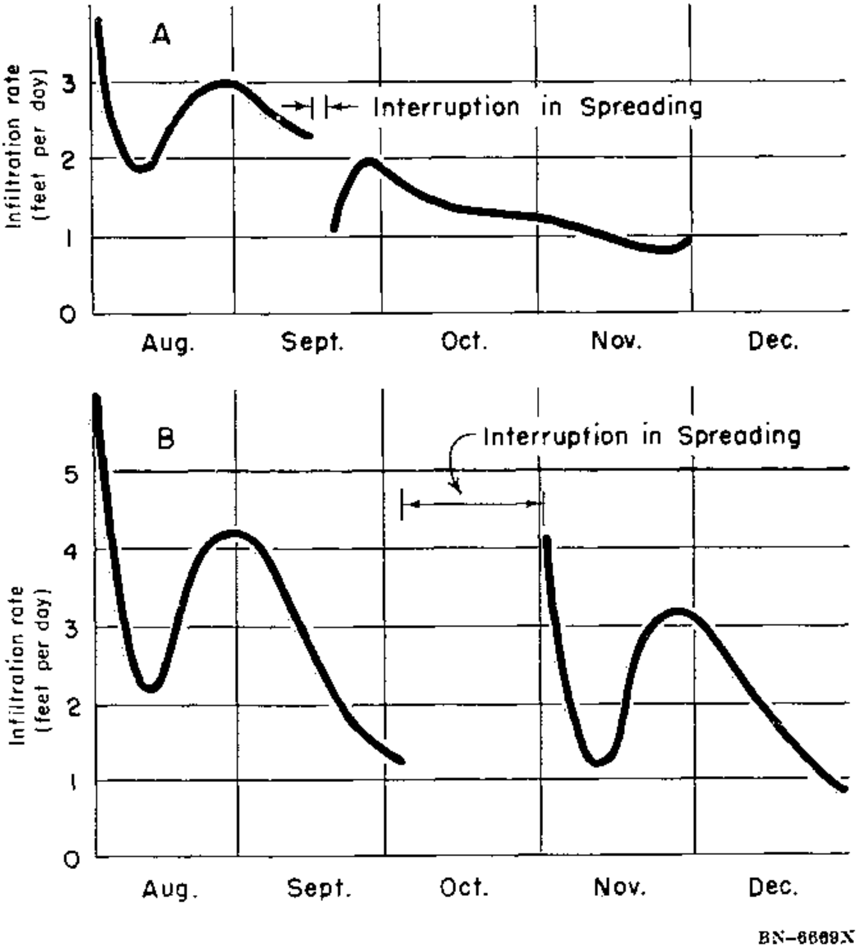

FIGURE 30.—Effect of interruptions in spreading on infiltration rates: *A*, Where free water disappears from surface but soil remains wet; and *B*, where top 6 inches of soil dries to or approaches wilting point.

of such duration that the topsoil dries result in an increase in infiltration rate over that which occurs at the time of the interruption, and in some cases such interruptions result in rate recovery equal to the initial rate. Figure 30, *B*, represents a typical infiltration rate curve obtained many times on the various ponds as a result of prolonged interruption. Soil samples for moisture content were taken during interruptions. In numerous tests the ponds were not reflooded after an interruption until the soil moisture content of the top few inches decreased to about 10 percent by weight. During the summer months, the soil dried rapidly and low soil moisture in the top few inches could be obtained in a short time (2 to 3 weeks). During the winter months, showers and cool, foggy weather usually prevented the topsoil from drying to the desired value. Results of tests classified as "operational" are shown in table 3.

ADDITION OF ORGANIC MATTER.—The addition of organic matter to the soil was tried on several ponds. In some cases the results were remarkable, with the infiltration rates increasing several times the rate obtained on untreated soils. Table 4 is a summary of all experiments using organic matter additions to field test ponds in Kern County, Calif.

Of all the materials applied, cotton gin trash gave the best results. Alfalfa hay at the rates of 10 and 5 tons per acre gave temporarily beneficial results. Barley, Sudan grass, paragrass, and Dallis grass, which were grown to maturity and then spaded under or cut and allowed to lie on the ground, gave indications of being beneficial, although only slightly so. Cornstalks with ammonium sulfate application resulted in high infiltration rates for a short time, but a fairly rapid decline in rate followed the peak. Barnyard manure at 8 tons per acre had no noticeable effect on infiltration.

Cotton gin trash, consisting of boll hulls, leaves, stems, a few seeds, and a small amount of lint, resulted in substantially increased infiltration rates in every trial. The trash was applied in copious amounts, usually as a 6-inch layer. Weight of the trash varied widely, depending on time of ginning, moisture content, composition, and state of decomposition prior to application.

In addition to increasing infiltration rates, the long lasting effect of an application of cotton gin trash is of great importance. High infiltration rates were obtained for several years after a single application of gin trash. On one pond more than 6,000 feet of water have been applied since the trash was introduced, and high infiltration rates still prevail.

Figure 31 illustrates the step by step development of improved infiltration rates following the application of cotton gin trash in a field pond. A decided decrease occurred after the first application of water, but after drying and reapplication of water, there is an increase in infiltration. The several steps identified on figure 31 are described as follows:

Step No. 1—Cotton gin trash applied to the soil and spaded under. Weight of gin trash varies considerably. Application recorded only as "6-inch layer."

Step No. 2.—Water applied to pond and maintained wet for 30 days. This is called the "incubation" period. Decomposition of gin trash takes place accompanied by rapid decrease in infiltration rate.

Step No. 3.—Pond dried until top few inches of soil nears wilting point. Residues of organic matter decomposition improved soil aggregation.

Step No. 4.—Water reapplied. High infiltration rates obtained.

Step No. 5.—Pond redried.

Step No. 6.—Water reapplied. High infiltration rates tending to reach a sustained high rate. Compare with rate obtained on untreated pond.

VEGETATION TRIALS.—Trials with vegetation were made for the purpose of (1) increasing or maintaining infiltration rates and (2) finding a grass or plant that would survive on water spreading areas and provide a cash or forage crop.

For economic reasons, it is sometimes highly desirable to make some use of the land other than for spreading. This is particularly

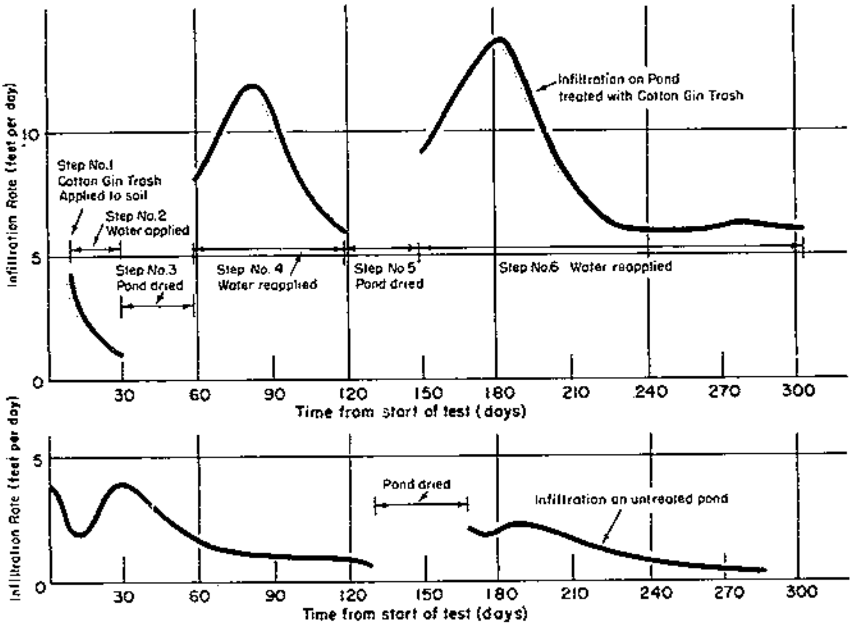

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FIGURE 31.—Effect of cotton gin trash in infiltration, Hesperia fine sandy loam, near Bakersfield, Calif.

true in Kern County (San Joaquin Valley) where spreading is done on highly valued agricultural land. In other areas, where sandy wastelands of no particular value for agricultural or other uses are available for spreading grounds, there may be no valid reason for seeking an outside income crop.

The conditions to which plants are subjected are severe in the San Joaquin Valley. Spreading will normally occur in the late winter and spring months, although in wet years the period might be prolonged considerably. In dry years there may be no water to spread and no water available to irrigate the grasses or plants to sustain them on a spreading area. Normally, there will be drought periods of several months, extending through the summer and fall. The grass or plant desired then is one that will grow under several months of constant wetting, survive the long, hot, dry summers, and provide a hay or forage crop. In order to avoid artificial reseeding, perennial plants or those that reseed or grow voluntarily are desirable.

Several grasses and plants were tried. These were, in general, native to the area and grew under conditions set forth above. Highly pestiferous plants, such as Johnson grass (*Sorghum halepense*) were not considered.

Bermuda grass appears to have the greatest possibilities for the San Joaquin Valley conditions. It grew luxuriantly under prolonged wetting, provided the tops were not submerged (it died under total submergence), and it survived long periods of drought. While it is considered a pest or weed in cultivated crops, it furnished good pasture.

Substantial improvement in infiltration rates was observed on ponds planted with Bermuda grass. The effect was not immediately apparent after planting, but after a dense growth had developed along with a mulch of old grass, consistently high rates of infiltration were observed.

Paragrass also grew luxuriantly under spreading conditions, but as with Bermuda grass the plants died under total submergence. Very dense growth occurred during the summer and each winter the tops froze back to the soil or water surface. Volunteer growth appeared the following spring. Higher than average infiltration rates were obtained on the pond containing paragrass.

Dallis grass, considered a pest in some parts of the valley owing to its tendency to grow in irrigation ditches, Rhodes grass, ryegrasses, saltgrass, Sudan grass, and bluestem grass were all tried, but none appeared to have the possibilities of Bermuda grass.

Buttonwillow shrubs were planted and grown successfully in two ponds, but no effect on the infiltration rate could be noted. As far as is known they have little forage or other value. They were found growing wild on the large spreading areas of southern California.

Alfalfa when wet continuously for a 10-day period and then dried for 10 days failed to benefit the infiltration rate and the alfalfa was severely damaged. A summary of treatments using vegetation on ponds in San Joaquin Valley, Calif., appears as table 5.

In further evidence of the value of vegetation for improving infiltration, experiments at Azusa, Calif., are cited. These were described in detail by Mitchelson and Muckel (*12*) in 1937.

SUMMARY AND CONCLUSIONS

Replenishment of ground water supplies by artificial means has been practiced in the United States since 1900. Early efforts were limited to those areas where the surface soil and underground conditions were well suited to artificial replenishment; that is, water infiltrated readily. Since the drought years of the 1930's, demands on the ground water supply by pumping from wells have become greater and more widespread, and the need for artificial replenishment has extended to areas where the surface and subsurface soils are not ideally suited to water spreading because of low infiltration and percolation rates.

Artificial recharge is accomplished by one of two general methods:

(1) Spreading water over the surface of the land to permit the water to infiltrate into the soil and travel downward until it reaches the water table; and

(2) Diverting water into wells, shafts, or pits from which it infiltrates to the water table.

Surface spreading may be accomplished by use of basins, furrows or ditches, or by flooding. The basin method of surface spreading is the most commonly used, because the water can be controlled the easiest. The surface storage capacity of basins is helpful for regulatory purposes where the supply of water fluctuates. If the water supply contains silt, basins can be arranged so that the uppermost basin of a series can be utilized as a settling pond. For a given gross area assigned to spreading, a greater area is wetted by the use of basins than by any other method of surface spreading.

Pits, shafts, or wells have been tried in many places with varying results. In some cases, the results were successful and in others complete failures. According to the records now available, best results were obtained if chlorinated water of very low silt content is used. Wells or shafts are used only under special conditions where surface spreading is not feasible or where adequate area is not available for surface spreading. Where surface soils or substrata of very low permeability exist between the surface and the water table, wells or shafts penetrating the strata are the only means of recharge.

The problem of decreasing infiltration rate presents itself in all types of surface spreading where the water is applied for long uninterrupted periods. Experiments show this decrease is due largely to micro-organism activity within the soil. Spreading of waters containing large quantities of silt will cause a rapid decrease in infiltration rate and may overshadow any effect of micro-organism activity. Initial infiltration rates can be recovered by interrupting spreading operations and permitting the soil to dry to or near the wilting point. This method will work unless the decrease in infiltration rate has been caused by silt, which must be removed. Best infiltration rates are obtained on a given soil if vegetation is allowed to grow and the soil is not disturbed in any way. Infiltration rates can usually be improved by adding organic matter to the surface soil and permitting it to decompose under moist conditions followed by a drying period.

The use of infiltrometers or small ponds to predict the infiltration rate obtained under large areas is of value only when there is no substratum that retards the downward movement of water. Soil surveys and well logs should be examined carefully when selecting an area for spreading. Material of low permeability should be mapped, and a determination made on whether or not the low permeability material is continuous or in lenses. Better results are obtained by careful selection of a suitable spreading site than by attempting to improve a less desirable site.

Under most conditions water spreading cannot be considered a means of flood control. It is used, however, in combination with flood control structures that impound or otherwise control the water and divert it to spreading systems.

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