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GROUND-WATER RECHARGE

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GROUND-WATER RECHARGE

Introduction

Ground water is an important factor in Soil Conservation Service operations. Large amounts of water are being lost by runoff and evaporation in the same areas where ground-water supplies are being depleted. Added emphasis is needed on the conservation and use of excess runoff where there are possibilities for increased underground storage.

Ground-water recharge is but one phase in the management of a ground-water basin. In some areas, long-term withdrawal exceeds long-term recharge and water is being "mined." Without proper management to obtain a sustained yield, artificial recharge becomes a mere stop-gap measure. It may be possible to manage a ground-water reservoir like a surface reservoir. That is, water is placed in storage in periods of excess and withdrawn in periods of shortage.

The SCS has many opportunities, through its existing policies and programs, to contribute to all phases of ground-water basin management. Only the artificial recharge phase will be discussed in this Technical Release.

Scope

Natural recharge may vary from practically none to nearly all of the runoff from a drainage area. Where water is available, artificial recharge may be used to supplement that naturally recharged. Recharge procedures must be tailor-made to fit a given situation. In this Technical Release, only general procedures and methods will be discussed. More specific and detailed information on the various phases of ground-water recharge will be found in the references.

Service policy and guides concerning ground water studies are found in Engineering Memorandum 51, the Watershed Protection Handbook, Sections 8, 15, 16, and 18 of the National Engineering Handbook, and various guides and memos prepared by the Regional Technical Service Centers and the States. A list of pertinent technical books, reports and research studies is given at the end of this Technical Release.

The technical aspects of drilling, testing, sampling, permeability determinations, ground-water hydrology, hydraulics, and economic evaluation can be found in the references and will be discussed only where they have a special application to ground-water recharge.

Water Rights and Legal Aspects

Water rights laws vary greatly from state to state. In the eastern half of the U. S. most water rights are based on court decisions or on common law in which land ownership is the source of the right. In western U. S. water rights are based mostly on legislative acts in which the source of the right lies in the beneficial use of the water. Prior appropriation and state regulation in the western states are strong factors in the continued beneficial use of water. Many states have extended their water laws to include ground water, springs and wells. These laws may be very rigid in regard to prior appropriation, the quantity and purpose of water use, the development of new wells, and the surface storage of waters.

Local and State water laws as they pertain to ground-water recharge, must be followed. Some of the factors to consider are:

(1) Prior appropriation of surface waters

(2) diversion of water from streams where a sustained flow is needed to remove waste, debris, or pollutants

(3) recharge of polluted, untreated, or otherwise undesirable water

(4) creation of an excessively high water table.

Hydrogeological Aspects

Storage of water within the earth's crust is dependent upon geological processes that have produced voids capable of absorbing, transmitting, storing, and yielding water. Voids are numerous in most earth materials. Some are large enough to transmit water freely, whereas others are so small that surface tension exceeds hydrostatic pressures and the transmission of water is prevented.

Useful ground-water storage capacity is not measured by the porosity of the reservoir but rather by the amount of water that the reservoir will yield by gravity drainage. This is commonly termed specific yield. It is the difference between porosity and field moisture capacity. Potential aquifers below the zone of soil moisture are already at field capacity. Therefore, most of the recharged water either can be recovered or will move to natural discharge areas.

An aquifer is defined as a water-bearing formation. In this Technical Release the term will also be applied to potential water-bearing formations. An aquiclude is a formation which will not furnish an appreciable supply of water to wells or springs. It is used to designate a barrier to the movement of water.

The following conditions indicate possibilities for natural or artificial recharge:

(1) Formations of sand, gravel, or highly fractured rocks either underground or exposed over a large area or in stream channels

(2) the presence of caverns, fractured or faulted zones, or numerous small cavities in rock formations either underground or exposed on the land surface or stream channels

(3) Karst or sinkhole topography

(4) the absence of barriers to the horizontal or vertical movement of ground water

(5) feasible locations for the installation of recharge wells, dams, diversions, or other recharge structures.

The above conditions do not necessarily indicate possibilities for beneficial recharge. The water may emerge in nearby springs or channels, or may recharge an aquifer that is so deep that recovery is impractical. These conditions should be studied carefully to determine whether recharge is feasible.

Wide braided streams, broad alluvial fans, and glaciofluvial deposits may present excellent opportunities for water spreading. These conditions may be especially significant where water from mountain streams can be spread and recharged into aquifers that extend into areas where the water can be recovered for beneficial use.

Geologic reports, ground-water reports, well logs, and descriptions of stratigraphic sections may indicate the possibility of recharge, storage, and recovery of ground water. This preliminary information may justify a detailed ground-water investigation.

Ground-water recharge may also be influenced by such things as the season of the year, intensity and duration of precipitation, topography, vegetative cover, soils, land use, evapotransporation, availability of storage, etc.

The rates and amounts of recharge may be improved by:

(1) Increasing opportunity time by regulating the flow of water over the intake area

(2) desilting and removing materials or debris which might seal the intake area

(3) planting or improving the growth of deep rooted vegetation, except phreatophytes, in intermittent spreading areas

(4) diversions from less to more suitable intake areas.

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

(1) Water (availability, source, turbidity, quality, etc.)

(2) surface soils

(3) depth to aquifer

(4) geologic structure and capacity of the ground-water reservoir

(5) the presence of aquicludes

(6) movement of ground water

(7) location of withdrawal area

(8) pattern of pumping draft.

An investigation to determine the location, extent, permeability and other physical characteristics of the surface and the various underlying strata is needed to select the site best adapted to artificial recharge. The greatest volumes and rates of recharge are possible in thick formations of pervious sands and gravels or porous and cavernous rocks.

The Controlling Stratum

Unless injection wells are used, the stratum that will control the infiltration rate must be identified. This usually is the least permeable stratum between the aquifer and the recharge surface. However, thickness is a factor. Recharge rates will be controlled by the stratum that has the lowest quotient of permeability divided by thickness, considering the head of water applied to be constant (See Wenzel, L. K., 1942, pp. 56-71). Identifying the controlling stratum may entail some drilling, testing and sampling. A few small drill cores may not reveal the true amount of fracturing and jointing in a rock formation.

After the controlling stratum has been identified and its physical properties determined, its depth, attitude, areal extent, and the location and elevation of outcrops must be determined. Not infrequently the controlling stratum is or will be the sediment deposited in a surface reservoir.

If the amount of water that will pass through the controlling stratum is very limited, recharge may be possible only through the use of injection wells. The special problems of injection-well construction and maintenance will be discussed in a later section. If the controlling stratum is near or at the surface it may be possible to disrupt it by mechanical means. Treatment of recharge surfaces to prevent a decrease in infiltration rates with time may be a major item of maintenance in a recharge project.

Effect of the Water Table

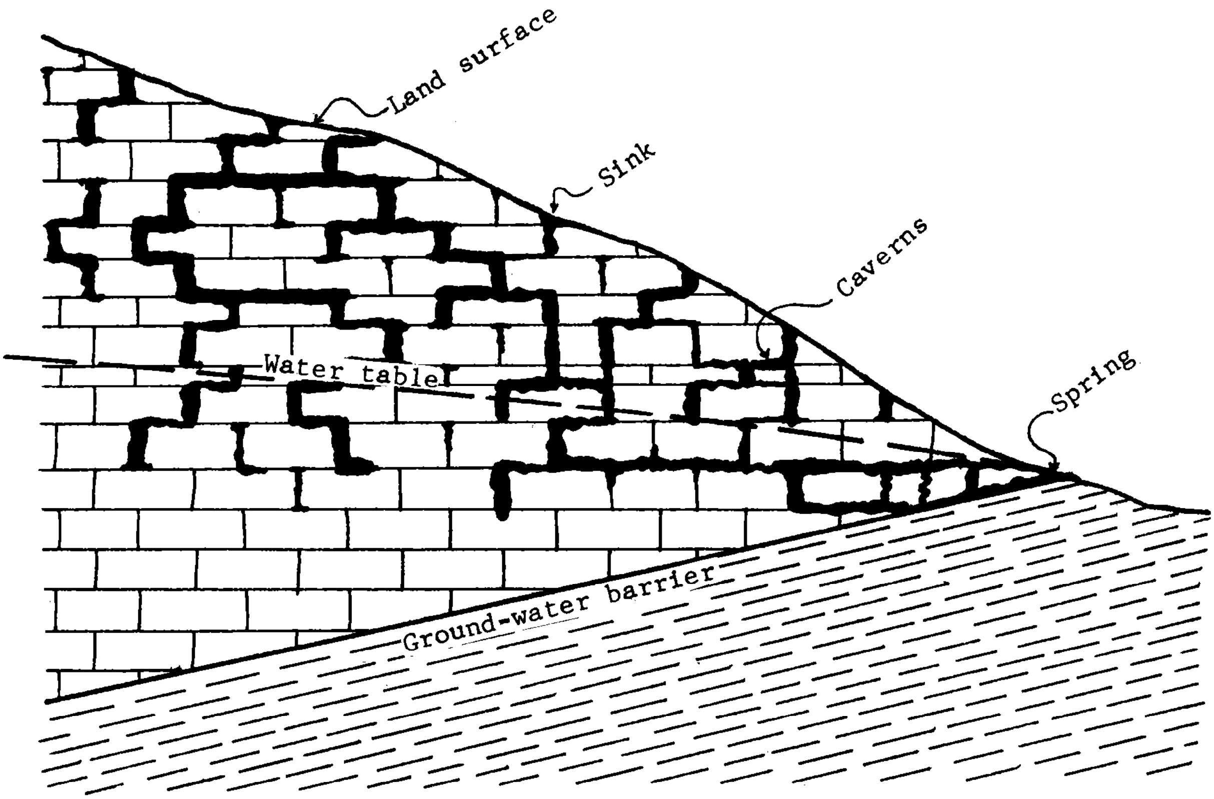
When the water table is near the ground surface, there will be little opportunity for recharge. Some water may go into shallow storage, but when this storage space is filled, any additional infiltration will return to the stream channel or other discharge area.

The effect of a shallow water table may be partially offset if the ground-water gradient is steep. In an aquifer with good permeability this will remove the water rapidly from the recharge area.

Examples

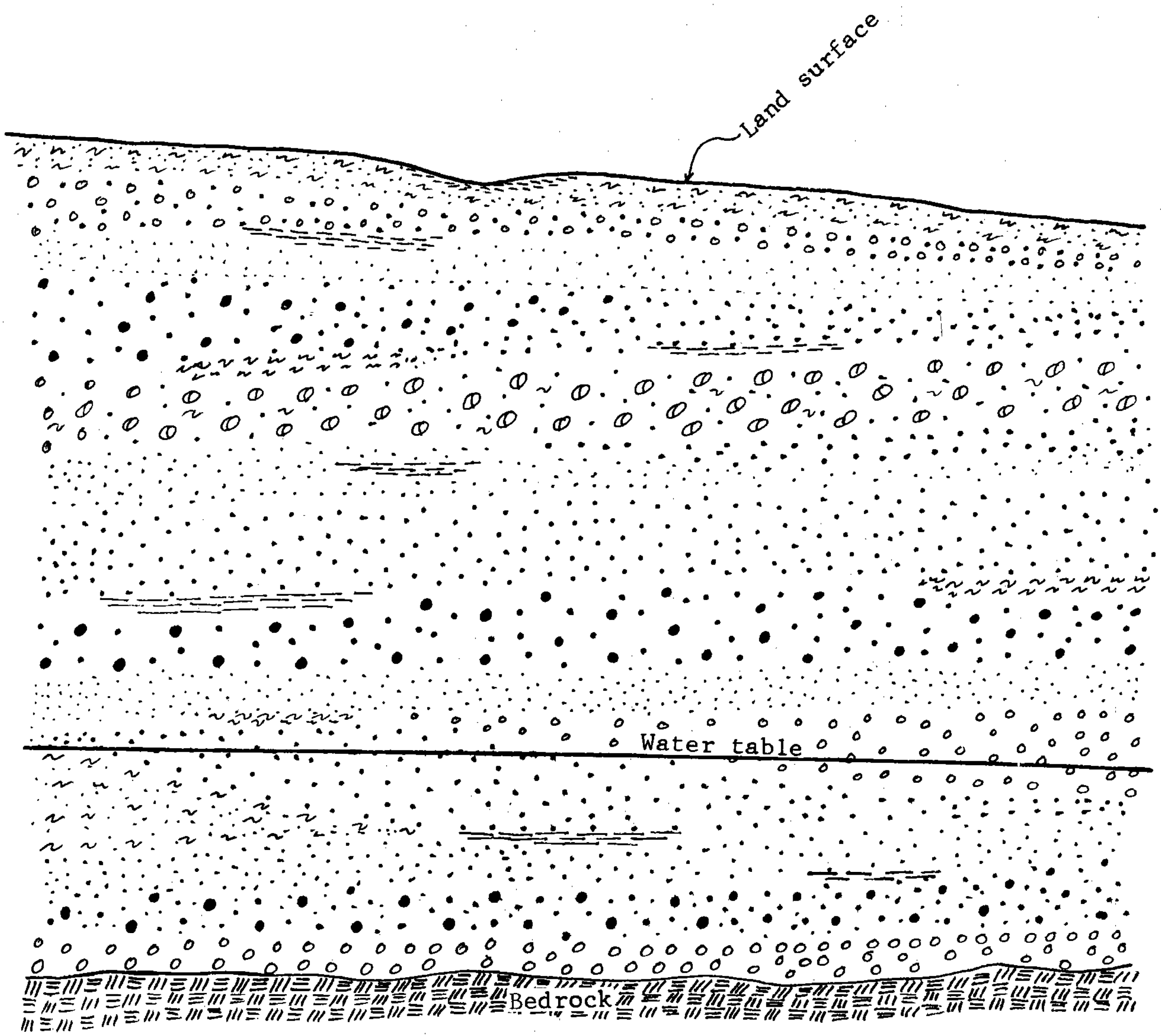
The following are a few illustrative examples of hydrogeological situations that may be conducive to ground-water recharge.

Cavernous Rocks. - A typical situation where recharge to cavernous rocks may be feasible is illustrated below:



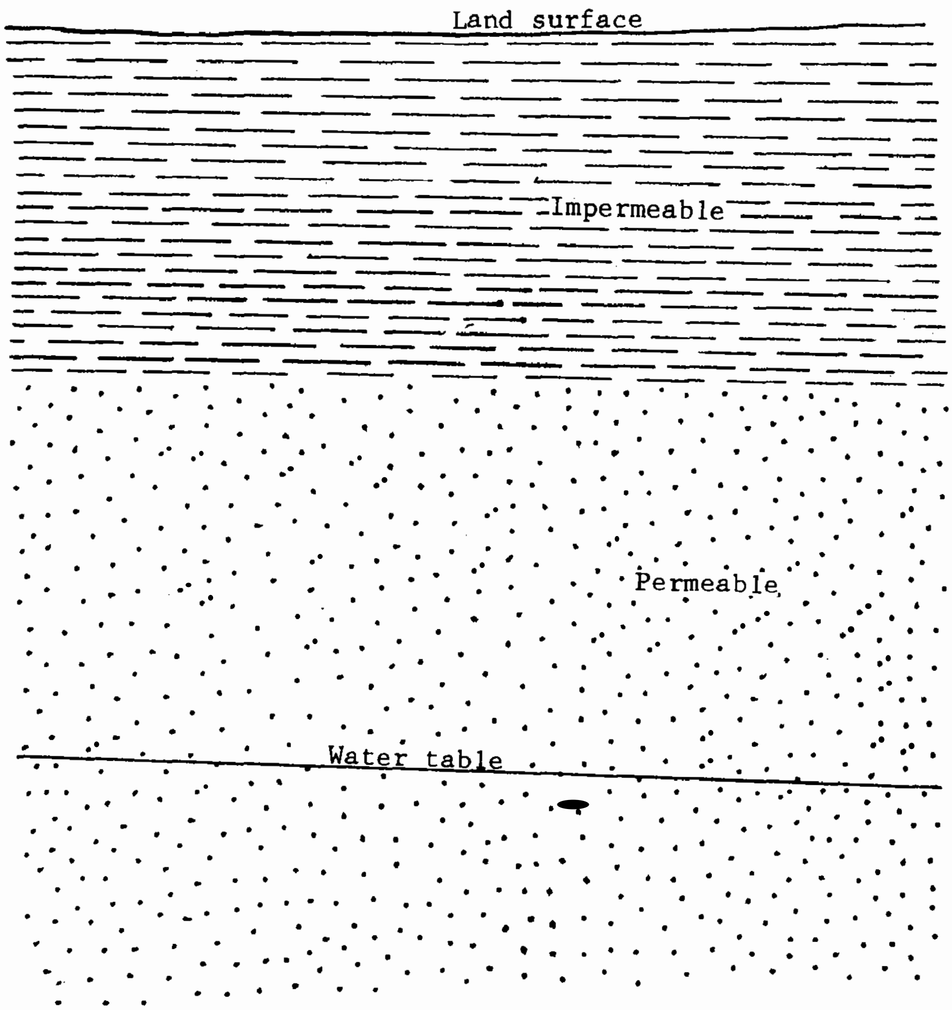
The need for recharge is indicated when springs start to go dry, pumping lifts in wells increase or shallower wells go dry. Water withdrawn under these conditions is being mined. Artificial recharge may be feasible if water is being lost from the recharge area as runoff. Improving natural openings and impounding storm runoff for slower release are the usual methods employed. Benefits may be local or regional.

Unconsolidated Deposits. - Thick alluvium or unindurated continental deposits with a deep water table are illustrated:



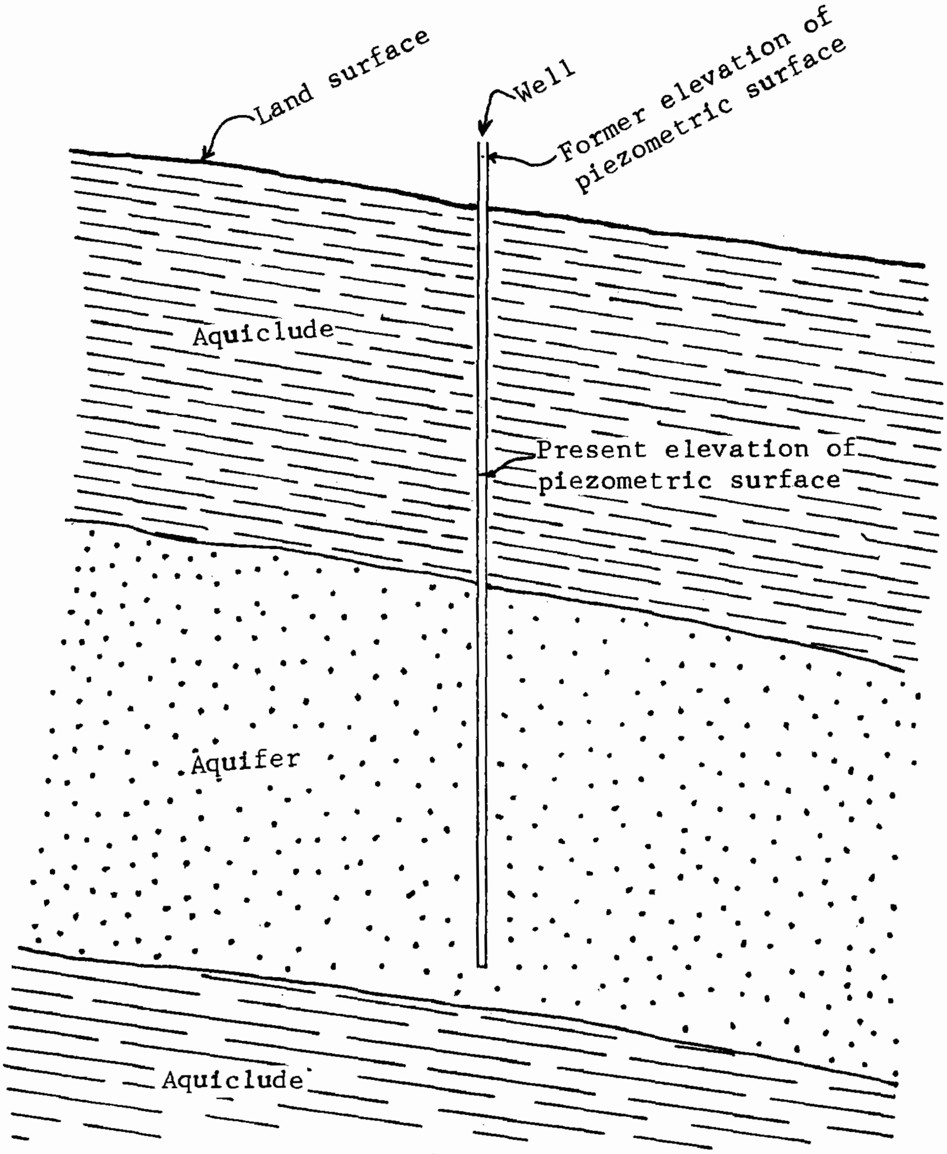
As illustrated, the water table is deep within geologic materials that are unconsolidated and generally permeable. Need for recharge is indicated by long-term increased pumping lifts. If the surface material in this situation is slowly permeable, much of the natural rainfall may run off or become impounded in depressions to evaporate. Recharge is usually possible, if water is available. Treatment and maintenance of recharge structures or water spreading areas will probably be necessary.

Occluded Aquifer. - An example of an occluded aquifer is illustrated below:



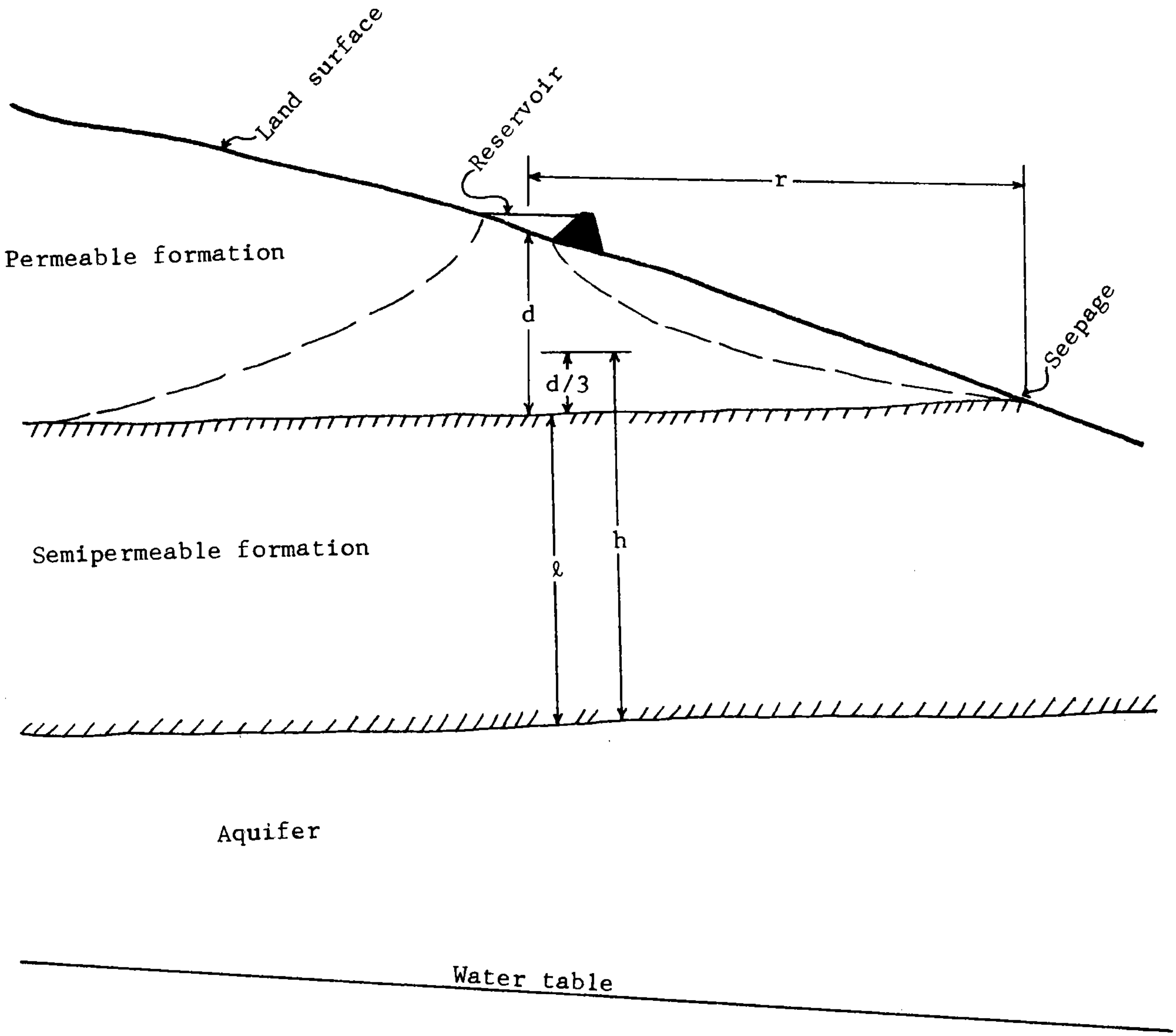
An impermeable or slowly permeable formation overlying an aquifer reduces or prevents natural recharge locally. The need for recharge is indicated by increased pumping lifts. The method of recharge is through injection wells. It may be possible to integrate surface drainage and recharge. Water quality may be a problem.

<u>Artesian Aquifers</u>. Under some conditions artesian aquifers, as illustrated below, may be successfully recharged.



The need for recharge is indicated when wells stop flowing and require pumping with increasingly greater lifts. Recharge is possible only through wells and the rate will be limited by the permeability of the aquifer and the amount of head that can be applied. Unless the aquifer is extremely permeable, recharge at a distant outcrop of the aquifer will not be effective.

Semipermeable Substratum. - The common situation where recharge is controlled by a semipermeable substratum is illustrated below:



As illustrated the rate of recharge is limited by seepage through the semipermeable formation unless recharge wells are used. Recharge will have reached its maximum rate when return flow appears as seepage at the outcrop of this controlling stratum. An approximation of the rate of recharge can be determined as follows:

$Q = kAI$

where Q = maximum rate of recharge if adequate supply of water is available ($ft.^3/day$)

k = permeability of the controlling stratum ($ft.^3/ft.^2/day$)

$A = \pi r^2$ = an approximation of the area of the upper surface of the controlling stratum over which the recharge water will be applied ($ft.^2$)

$\pi = 3.14$

r = the linear distance from the center of the recharge area to the outcrop of the controlling stratum (ft.)

$I = h/\ell$ = effective gradient of the recharge water (dimensionless)

h = approximately equal to the thickness of the controlling stratum, plus 1/3 the depth of the top of the controlling stratum below the surface (ft.)

ℓ = thickness of the controlling stratum (ft.)

All items must be in compatible units.

Measures for Ground Water Recharge

Ground-water recharge may result from land treatment measures or from structural measures planned for recharge or other purposes. Terraces, diversions and stock ponds, the application of irrigation water, canal leakage, and disposal of drainage water may aid recharge. However, recharge will seldom be considered as a purpose of these measures.

Incidental Recharge from Structural Measures

Seepage from reservoirs and from channels in which flow is prolonged by structural measures is the most common source of incidental recharge. Incidental recharge may take place from the sediment pools of reservoirs, especially in the first few years after construction. Borrowing materials during construction may expose strata which are more permeable than the original surface soils. On the other hand, sedimentation in the reservoir may decrease permeability and thereby gradually decrease the rate of recharge.

Seepage from a reservoir does not necessarily recharge an underlying aquifer. It may be intercepted by an impermeable stratum and be returned to the stream channel downstream from the dam. This in itself may be a benefit. The prolongation of streamflow may make water available for beneficial use over a longer period of time.

Where suitable conditions exist, measures might be designed to put large amounts of water underground without appreciable added costs. It may be possible to locate a dam to impound water over caverns, sinkholes, or open fault zones. Sites may be selected where the controlled outflow from structures can enter openings in or near the channel downstream. Diversions or channels may be constructed where they will conduct water into natural openings, pits, quarries, or other recharge areas.

Special Structures for Recharge

Several types of structural measures for ground water recharge may be planned either as multiple purpose structures or solely for recharge.

Water Spreading. - Areas of deep sands, gravels, or cobbles are the most favorable for recharge by water-spreading. The systems used are usually similar to those used for irrigation or wild-flooding. They usually can be classified under one of the following methods:

(1) A series of small basins for impounding water throughout the intake area

(2) a series of shallow, flat-bottomed furrows or ditches, closely spaced, and on a low grade, to spread water throughout the intake area

(3) flooding level areas, or constructing dikes to hold the flooded waters on slightly sloping intake areas.

A combination of two or more of these methods may be used depending upon the topography. The surface should be disturbed as little as possible where flooding is used. The water should be as clean as possible, especially where basins or flooding are used. Infiltration rates may be improved by deep-rooted vegetation or by a surface cover of vegetative debris that is permitted to decompose under alternating wet and dry conditions.

If the water is applied for long continuous periods, experiments have shown that a decrease in rate of intake results largely from micro-organism activity within the soil. Spreading of waters containing large quantities of fine sediment will cause a rapid decrease in infiltration rate and may overshadow any effect of micro-organism activity. Initial infiltration rates may sometimes be recovered by interrupting spreading operations and permitting the soil to dry to or near the wilting point.

Pits and Shafts. - Pits or shafts excavated into deep gravel beds or fractured cavernous or pervious rocks will greatly increase infiltration. Abandoned gravel pits, quarries or mines may be used and are particularly effective if they extend into the aquifer or into cavernous rock formations. Measures may be installed to remove or reduce the amount of debris, clay, silt, and other pollutants where necessary.

Dams and Diversions. - Incidental recharge, whereby large volumes of recharge may be accomplished at no extra cost, has previously been discussed. In addition, small, inexpensive dams may be very effective in impounding streamflow long enough to let it enter large openings in or near the channel. Such structures in favorable locations may recharge much of the runoff. Diversions up to several miles in length may be constructed to direct storm runoff into sinkholes or other large openings. The flood reducing effects of these measures might be significant and should be considered.

Recharge Wells. - Where 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. They also may be installed to increase the volume of recharge in connection with other recharge measures. In some cases, wells that normally are pumped during the growing season are used for recharge during other seasons.

Recharge wells, often referred to as injection wells have been in use in almost every part of the U. S. in connection with irrigation, heat pumps and salt water intrusion control.

One effective system for recharge consists of drilling injection wells into the aquifer downstream from a dam. Water is then conducted from the principal spillway to the wells. The release rate or the number of wells are varied to control the rate and amount of recharge.

In areas of cavernous limestones and sypsum, recharge wells may be placed upstream from a floodwater retarding or other structure. The intake should be well below the crest of the principal spillway elevation, but several feet above the bottom to aid in desilting. Recharge will take place automatically when the water reaches the elevation of the well inlet. The well intake should be provided with an effective trash guard.

Besides the thickness and capacity of the aquifer, the quality of the injected water is extremely important when wells are used. Suspended solids, biological and chemical impurities, dissolved air and gases, turbulence, and temperature of both the aquifer and the injected water will have an effect on the life and efficiency of a well. These are most important in aquifers with moderately permeable granular materials. They may have little effect on the recharge rates of wells in aquifers made up of gravels, cobbles, or cavernous rock, except where the water contains excessive amounts of debris or soil materials.

Wells for draining cropland have been used in many parts of the U. S. This results in ground-water recharge. Wells drilled in the playa lakes in the High Plains of Texas, and in lakes and swamps in the northern Great Plains, have been effective for only about two years due to the rapid rate of plugging the aquifer with sediment. The installation of rock and gravel filters extends their life about two years. The most recent installations place a floating intake in the center of the lake. The water goes through a filtering and desilting process, excess air is removed, and it is then pumped into the aquifer. By reversing the pump 1/2 to 1 hour each day, a large amount of silt and clay is removed so that recharge can be continued. Although this procedure is effective, it is expensive, and does not guarantee against the eventual plugging of the aquifer near the well.

Natural Openings. - In cavernous limestone and gypsum areas natural openings in or near the stream channel may be used in lieu of recharge wells. Recharge water may be conducted to these openings or backed over them in the same way as with recharge wells.

Some natural openings need little or no improvement or protection to retain their effectiveness while others should be improved, protected, and maintained. Openings that need development should be cleaned out and provided with an effective trash guard. Provision should be made for the removal of sediment from the recharge water if necessary. There are many cases where animal burrows or the hollow sound of walking over a spot have led to the discovery of large openings which may be used for recharge. If significant, the amount of induced recharge to large natural openings should be computed in order to determine a reduction in flooding or a reduced size of downstream channel improvement.

Maintenance of Recharge Structures

Some types of recharge structures require frequent attention to maintain their efficiency. This is especially true of injection wells and to some extent of pits or shafts where chemical treatment and the control of sediment bacteria, algae, and air entrainment are involved. Other structures may need only occasional attention to remove debris, divert contaminants or pollutants, and to make mechanical repairs.

Maintenance generally includes:

(1) Removing trash and repairing debris guards

(2) maintaining filtration, flocculation or other water treatment facilities

(3) backflushing recharge wells, with or without the use of detergents, to removed introduced fine sediment from the aquifer

(4) normal structural and mechanical maintenance.

Quality of Water for Recharge

The water used for recharge must be of suitable quality for ultimate recovery and use for its intended purpose. Any water proposed for recharge should be tested by a qualified laboratory.

Silt; Clay; Debris

Silt and clay introduced into a well will lodge in the gravel pack around the well or at the interface between the gravel pack and the aquifer and materially retard the movement of water. It may even penetrate the aquifer material itself and reduce permeability of the material surrounding the well.

Accumulations of organic matter and other debris may reduce the rate of recharge or seal even large openings. The quality of ground water may be affected during the decaying process. However, organic debris entering a limestone aquifer may be beneficial. The decaying process gives off carbon dioxide which increases the ability of the water to dissolve limestone and thereby enlarge the voids in the aquifer.

Chemical Pollutants; Bacteria; Algae

Pollution must be avoided in recharging ground water. Sources of pollution include storm sewers, untreated sewage, waste products, detergents, pesticides, herbicides, toxic and noxious substances, fertilizers, saline water, and heat.

Organic wastes may either contain harmful bacteria or may promote their growth. In a recharge well, bacteria and algae may clog the well screen or the aquifer or both. The decay of organic materials may produce excess nitrates or other toxic by-products. Water from areas where large quantities of pesticides or herbicides have been applied or manufactured should not be used for recharge without careful study.

The danger that public water supplies may become polluted as a result of the movement of bacteria and chemicals with underground waters is a matter of great concern to health authorities. Recent laboratory and field investigations have been made of the travel of pollution from direct recharge into underground formations and of waste-water reclamation in relation to ground-water pollution. These show that a definite hazard exists when polluted water is injected directly into the aquifer by means of wells or is recharged through large openings. A lesser hazard exists with surface spreading methods which permit aeration to reduce pollution. Migration of chemical pollutants was found to be greater than bacterial pollutants.

Dissolved Solids; Precipitates; Ion-exchange

The kind and amount of dissolved solids in water vary considerably from place to place and from one period of time to another. They depend upon the time and amount of precipitation, the chemical changes that take place in the soil and rocks, and availability of soluble substances.

Solubility of oxygen, carbon dioxide, sulphur dioxide, ammonia and other gases in water varies with physical and biological environment and changes with temperature and pressure. Presence of dissolved oxygen affects the habitat of aerobic bacteria which influence the decomposition of organic matter. The solubility of calcium carbonate varies with the carbon dioxide content of the water. The corrosive and electrolytic characteristics of the water will influence the selection of steel or other kinds of metals used for screens, pumps, pipes, and fittings to be used in wells.

Serious incrustations by chemical action may occur in metal-cased wells, particularly where the perforations are above the normal water table and exposed to the air. Perforating only below the lowest elevation of water table is a partial remedy. The amount of incrustation will vary with the chemical quality of water.

Chemical and mineral wastes from mining and industrial areas often are toxic to plants and animals. Waters that contain a high concentration of sodium salts cause infiltration problems. Reactions between chemicals in recharge water and chemicals in the ground water or the mineral makeup of the aquifer may in some cases produce precipitates or an exchange of ions. These conditions could reduce the rate of recharge or the quality of the water.

Temperature; Dissolved Gases

The solubility of air in water is strongly influenced by temperature, as illustrated below:

Temperature		Dissolved air at 1 atmos. pres., volume of air/volume of water
°C	°F	
0	32	.029
10	50	.023
20	68	.019
30	86	.016
40	104	.014

Surface waters (the normal water used for recharge excepting industrial effluents) are normally saturated with air at their given temperature and pressure. This would mean that an injection well pumping 500 gallons per minute of water at 2° or 3° C into an aquifer where the temperature might be raised by 10° C, could potentially release over 500 cubic feet of free air into the aquifer daily. While some of the air might escape, most will take the form of tiny bubbles which fill the aquifer interstices and greatly reduce water intake. This is especially true of fine grained aquifers. To avoid this problem, injected water should have a temperature slightly higher than the temperature of the aquifer. On the other hand, some natural ground waters contain much dissolved gas which might be freed if the injected water is too warm.

Measures for Improving Quality

Debris guards, desilting basins, or both should be installed to remove brush, leaves, junk, sediment or other undesirable material from recharge water. These measures will provide a threefold benefit of avoiding contamination of the underground water, keeping the intake areas open, and preventing clogging the aquifer.

Flocculants may be used to hasten the removal of silt and clay. The use of polyelectrolytic flocculating agents has received much attention recently and the latest information available on their use and cost should be obtained if the need for flocculation is indicated.

Purifying chemicals may be used to treat the water that may be recovered for human use. These treatments usually are too expensive for water which will not be used for human consumption. Aeration may reduce some chemical and bacterial contaminants, but it may permit an increase in the growth of algae. Chlorination of the recharge water, either continuously or in slugs, will reduce the growth of soil- or aquifer-clogging micro-organisms.

Evaluation

Ground-water recharge is included under "Water Management Measures" as defined in the Watershed Protection Handbook. Benefits may be either agricultural (ground water used for irrigation, stockwater, or domestic farm water supply) or non-agricultural (ground water used for municipal or industrial water supply or recreation).

Cost Allocation and Cost Sharing

The Watershed Protection Handbook states the policies on cost allocation and cost-sharing and their application to the benefits from ground-water recharge. The costs of measures installed solely to increase ground water should be allocated to ground-water recharge. If the recovered water will be used for both agricultural and non-agricultural purposes, the portion used for each must be determined. Only structural measures for recharging agricultural water may be cost-shared. If recharge is incidental to the planned structural measures, no cost estimates are needed.

Benefits

Benefits from the recharge of ground-water reservoirs may accrue incidentally from a measure installed for other purposes or may result from measures installed for this purpose. To determine benefits, the amount of water recharged, the unit value of the water, and the cost of procuring water from other sources must be known.

In some cases, benefits from recharge are direct and identifiable and can be specifically evaluated. In other cases the benefits may not be easily identified. Any indirect benefits should be described and evaluated in terms of their incidental or enhancement values. Following are several types of benefits from ground-water recharge:

(1) Storing water in underground reservoirs which may be recovered for beneficial use

(2) raising the water table to increase water supply from shallow wells, to reduce pumping costs in wells, and to maintain water levels

(3) decreasing runoff, thereby directly reducing damages from flooding, erosion, and sedimentation

(4) creating fresh water barriers against the intrusion of salt water along coastal areas, or against the intrusion of undesirable water in inland areas

(5) recharging good quality water to dilute undesirable underground water or to assist in flushing undesirable water from cavernous or very porous aquifers

(6) increasing the flow of springs for agricultural water supplies and for the aesthetic or commercial value of springs for recreation, parks, resorts, and water sports

(7) increasing streamflow to supply water for agricultural purposes, wildlife, recreation, and to assist in removal of pollutants or undesirable debris

(8) maintaining a high water table in marsh areas to insure permanent pools or marshes for the breeding or resting places for waterfowl, fish, and other aquatic animals

(9) replenishing ground-water supplies to prevent or reduce the rate of land subsidence or the weakening of foundations of structures, pipelines, canals, etc., resulting from the excessive withdrawal of water.

Induced Damages

Damages caused by ground water may be identified, but the portion of the damages created by recharge may not always be easily ascertained. Agricultural damages should be determined including interfering with drainage, recharging polluted or poor quality water, and creating high water table conditions that may damage crops or agricultural works of improvement.

Non-agricultural damages should be identified also. These might include the raising of water tables or increasing pore pressures in earth materials. This in turn may cause wet basements, ineffective filter fields and septic tanks, unstable foundations, earth slides, or affect water quality for non-agricultural purposes.

The following conditions may be caused or increased by ground-water recharge and may be either agricultural or non-agricultural:

(1) Mass movements such as slumps, slides, or earth flows commonly cause damage, especially to roads, railroads, buildings, and agricultural works of improvement. Field inspection, interviews with persons responsible for repair and maintenance, review of records, and study of aerial photographs usually will furnish a basis for determining damages. It will be necessary to determine the influence, if any, of ground-water conditions on the development of mass movements.

(2) Ground-water problems may be associated with seasonal high water tables or fluctuating water tables associated with flood events. Locally, the problem may have been analyzed and the source of the ground water determined. Records, newspaper accounts, or affected residents often can relate the occurrence of damaging ground water with past events and developments or with certain recurring events, such as storms of a given intensity or duration. It may be the geologist's responsibility to substantiate or disprove these analyses and determine whether the preliminary investigation appears to warrant a detailed study.

The Value of Recharged Water

Generally the value of recoverable recharged ground water will depend upon its intended use as well as its quality. Recharged water recovered for agricultural use normally would be evaluated the same as a surface supply for that use. Recharge would reduce pumping costs, slow the rate of depletion, and delay the date for a shift from irrigated to dry land farming.

The value of water may range from five dollars to more than $100 per acre-foot depending upon its type of use and the section of the country where it is used. For example, water for irrigating pasture may be low in value, while water for valuable truck or fruit crops may be worth $100 or more per acre-foot. Ground water for irrigating cotton in the High Plains of Texas, with a 200-foot pumping lift, has been valued as high as $63 per acre-foot. A study by the Corps of Engineers of the Edwards underground reservoir of Texas gave an estimated value of $39 per acre-foot.

Engineering News Record, June 4, 1964, reported that the Los Angeles area will pay initially $20 per acre-foot for Colorado River water for pumping into the ground to build up a barrier against salt water intrusion.

Water recovered for cities or industries may be worth more than $100 per acre-foot. W. F. Hughes in "Water for Texas," reported that "..... in 1958, residential and industrial water users in the 10 largest cities of Texas paid an average monthly price of $104 and $72 per acre-foot respectively for treated water." Industrial interests along the Gulf Coast have indicated that a rate of $16.30 per acre-foot of raw water would not necessarily be excessive. However, few agricultural water users can afford to pay this price.

It is quite possible that in areas of water scarcity the demand for water for domestic and industrial use would become so great and the cost of water so high that irrigation would become uneconomic. On the other hand, the need for food might become so great that water for irrigation would have a higher economic value than for industrial use.

Case Histories

York Creek Watershed

In the York Creek Watershed near San Marcos, Texas, two floodwater retarding structures were evaluated for incidental ground-water recharge benefits in the Edwards Underground Water District. A study by the Texas Board of Water Engineers

(1956 and 1962) and the U. S. Geological Survey in this area indicated that natural recharge was taking 70 percent of the runoff. The SCS study estimated that the proper placement of these two floodwater retarding structures would recharge an additional 20 percent of the runoff, or about 840 acre-feet the first year. By adjusting for an average reduction of 10% due to sediment deposition over the 50-year evaluation period, it was estimated that the average annual rate of recharge will be 750 acre-feet. A value of $10 per acre-foot was used, based upon its recovery nearby for home, livestock, and municipal use. This gave an average annual ground-water recharge benefit of $7500 for these two structures.

Lower Running Water Draw Watershed

In the Lower Running Water Draw Watershed in the Texas High Plains, detailed recharge investigations were made by drilling, sampling, and making well permeameter tests. Because of the topography, geology, and low gradient of the water table, it was estimated that all of the incidental recharge from the retarding structures would be recovered within the watershed boundaries. Tests and other studies indicated that the present rate of 1,500 acre-feet annual recharge will be increased to 2,900 acre-feet after the installation of the structures. This additional 1400 acre-feet of ground water was evaluated as supplemental irrigation water for the crops normally grown in that area. The computations were based on the following:

(1) Average crop production without irrigation

(2) increase in production with irrigation

(3) one and one-half acre-feet of water per acre needed for irrigation

(4) the cost of pumping and applying irrigation water.

This gave a value of $12.65 per acre-foot of recharged water, and an average annual benefit of $17,710 to the project for incidental ground-water recharge.

Recharge Under P. L. 46

Guidance should be provided by SCS geologists, engineers, and hydrologists to help district cooperators plan efficient recharge measures and to discourage them from wasting time and money on structures that are not feasible. For example, an irrigation district in southwestern Oklahoma received technical assistance from the SCS in planning ground-water recharge. In this area, underlain by cavernous gypsum, the urgent need for ground water for irrigation has prompted the landowners to install measures for recharging excess runoff. Some impoundments and several field diversions were constructed with SCS technical assistance. The structures were so located that they discharge into natural openings or sinkholes. Some of the openings have been enlarged to recharge larger volumes of water and one irrigation well has been converted into a recharge well. This system has helped alleviate a local water problem at a reasonable cost.

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