Basic Principles of Groundwater Recharging

PDH Credits:

1 PDH

Course No.:

GDR101

Publication Source:

US Corp of Engineers (Unified Facilities Criteria)

"Groundwater Recharge"

Part 631 National Engineering Handbook
Chapter 33

Release Date:
Jan. 2010

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

**Part 631
National Engineering Handbook**

Chapter 33 Groundwater Recharge

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Contents

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631.3300 Groundwater recharge

(a) Basic principles of recharge

Groundwater recharge is one phase in the management of a groundwater 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 stopgap measure. It may be possible to manage a groundwater reservoir like a surface reservoir so that water is placed in storage in periods of excess and withdrawn in periods of shortage.

Natural recharge may vary from practically none to nearly all of the runoff from a drainage area. When water is available, artificial recharge may be used to supplement naturally recharged amounts.

(b) Water rights and legal aspects

Water rights laws vary greatly from State to State. In the eastern half of the United States, most water rights are based on court decisions or on common law in which land ownership is the source of the right. In the Western United States, 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 groundwater, 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 that pertain to groundwater recharge must be followed. Some of the factors to consider are:

- prior appropriation of surface waters
- diversion of water from streams where a sustained flow is needed to remove waste, debris, or appropriation of surface waters recharge
- recharge of polluted, untreated, or otherwise undesirable water
- creation of an excessively high water table

(c) Hydrogeological aspects

Groundwater storage is a function of voids in earth materials capable of absorbing, transmitting, storing, and yielding water. Some voids 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 groundwater storage capacity is not measured by the porosity of the reservoir, but 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 section, 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:

- formations of sand, gravel, or highly fractured rocks either underground or exposed over a large area or in stream channels
- presence of solutioned limestone (karst or sinkhole topography), fractured or faulted zones, or numerous small cavities in rock formations, either underground or exposed on the land surface or stream channels
- absence of barriers to the horizontal or vertical movement of groundwater
- feasible locations for the installation of recharge wells, dams, diversions, or other recharge structures

These 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.

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

Groundwater 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, and availability of storage, etc.

The rates and amounts of recharge may be improved by:

- increasing opportunity time by regulating the flow of water over the intake area
- trapping sediment and removing materials or debris which might seal the intake area
- planting or improving the growth of deep-rooted vegetation, except phreatophytes, in intermittent spreading areas
- diverting runoff to more suitable intake areas

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

- water (availability, source, turbidity, quality)
- surface soils
- geologic structure and capacity of the groundwater reservoir
- presence of aquicludes
- movement of groundwater
- location of withdrawal area
- pattern of pumping draft
- potential off-site effects caused by groundwater recharge
- vertical and horizontal hydraulic conductivity values of the materials under the recharge area
- extent of area affected by recharge

An investigation to determine the location, extent, permeability, and other physical characteristics of the earth materials and their structure 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.

(1) 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 are controlled by the stratum that has the lowest quotient of permeability divided by thickness, considering the head of water applied to be constant. Identifying the controlling stratum may entail some drilling, testing, and sampling.

After the controlling stratum has been identified and physical properties determined, the depth, attitude, areal extent, and location and elevation of outcrops must be determined. The controlling stratum can be the sediment deposited in a surface reservoir.

If the controlling stratum limits the amount of water that will pass through, recharge may be possible only through the use of injection wells set through the controlling stratum. Injection well construction and maintenance are described 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.

(2) Effect of the potentiometric water table

When the potentiometric surface is near the ground surface, there is 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 potentiometric surface may be partially offset if the groundwater 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 examples of hydrogeology that may be conducive to groundwater recharge.

Cavernous rocks—a typical situation where recharge to cavernous rocks may be feasible is illustrated in figure 33–1.

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 unconsolidated deposits with a deep water table are illustrated in figure 33–2.

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

Occluded aquifer—an example of an occluded aquifer is illustrated in figure 33–3.

Figure 33–1 Groundwater pathways in solutioned limestone (karst topography)

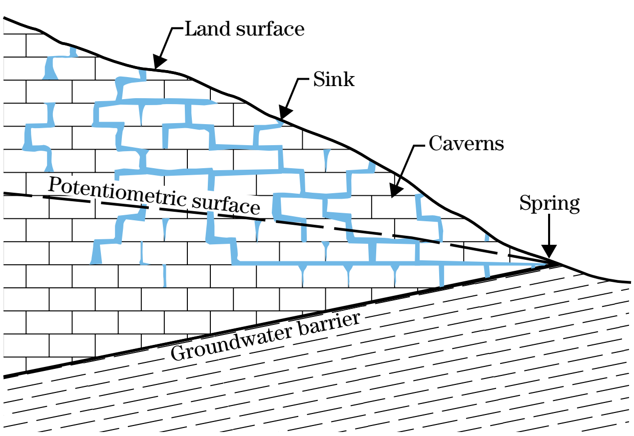


Figure 33–2 Potentiometric surface in unconsolidated deposits

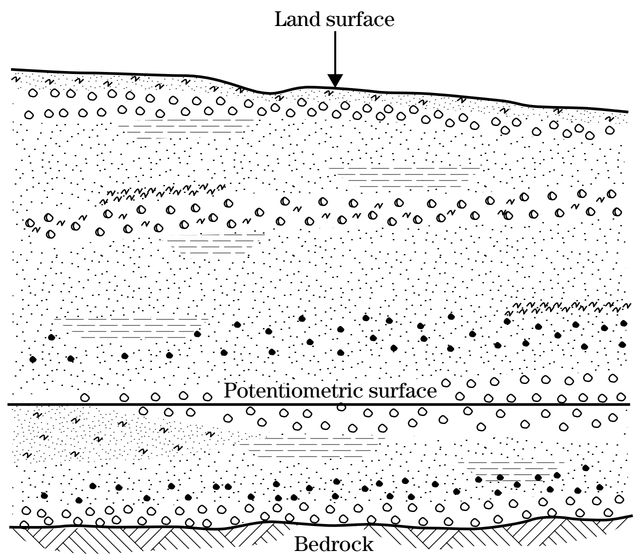
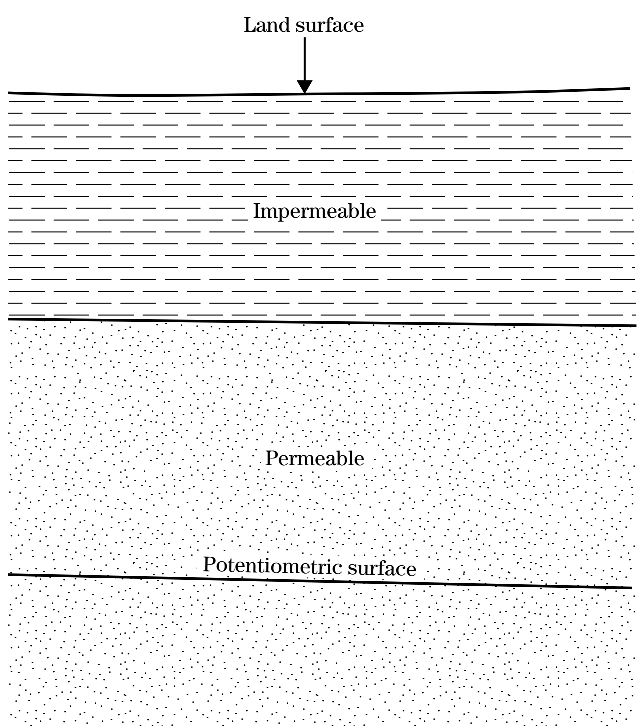


Figure 33–3 Occluded aquifer



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

Artesian aquifers—under some conditions, artesian aquifers, as shown in figure 33–4, 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 is 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 in figure 33–5.

As shown, the rate of recharge is limited by seepage through the semipermeable formation, unless recharge wells are used. Recharge reaches 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:

$$Q = kIA \quad \text{(eq. 33–1)}$$

where:

Q = maximum rate of recharge if adequate supply of water is available (ft^3/d)

k = hydraulic conductivity of the controlling stratum ($ft^3/ft^2/d$)

A = πr^2 = an approximation of the area of the upper surface of the controlling stratum over which the recharge water will be applied (ft^2)

π = 3.14

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

I = h/ℓ = effective gradient of the recharge water (dimensionless)

h = approximately equal to the thickness of the controlling stratum, plus one-third the depth of the top of the controlling stratum below the surface (ft)

ℓ = thickness of the controlling stratum (ft)

d = depth of potentiometric

All items must be in compatible units.

Figure 33–4 Artesian aquifer

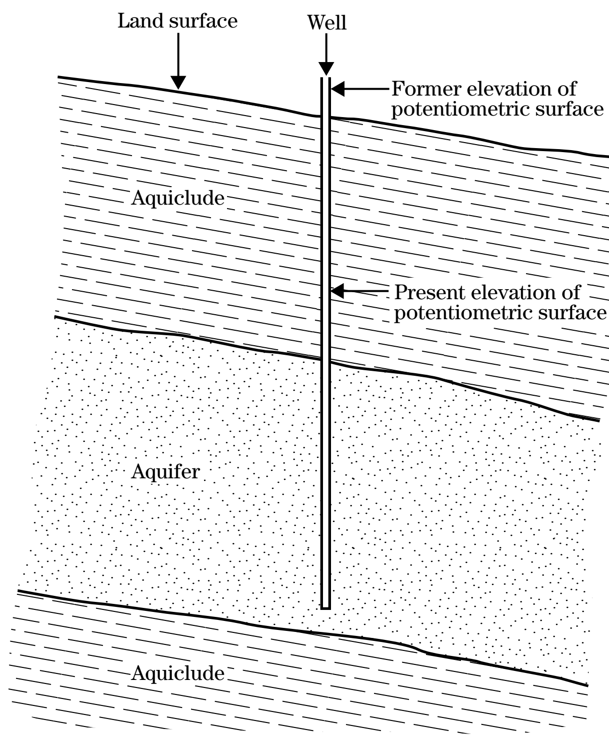
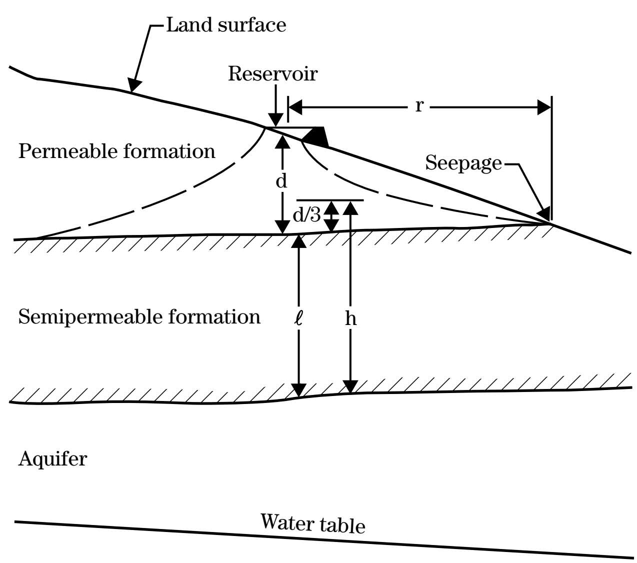


Figure 33–5 Semipermeable formation limiting recharge opportunities



(d) Measures for ground water recharge

Groundwater 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 is seldom considered a purpose of these measures.

(1) 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. Excavating 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 for the purpose of recharge. 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.

(2) Special structures for recharge

Several types of structural measures for groundwater 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. They usually can be classified under one of the following methods:

- a series of small basins for impounding water throughout the intake area
- a series of shallow, flat-bottomed furrows or ditches, closely spaced and on a low grade, to spread water throughout the intake area
- 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 on the topography. The surface should be disturbed as little as possible when flooding is used. The water should be as clean as possible, especially where detention 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, a decrease in rate of intake results, largely from microorganism activity within the soil. Spreading of water containing large quantities of fine sediment causes a rapid decrease in infiltration rate and may overshadow any effect of microorganism activity. Initial infiltration rates can sometimes be recovered by interrupting spreading operations and by 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 can 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, sediment, and other pollutants where necessary.

Dams and diversion—incidental recharge whereby large volumes of recharge may be accomplished at no extra cost has previously been described. In addition, small dams may be very effective in impounding streamflow for recharge through large openings in or near the channel. 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 potentiometric surface, 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. Wells that normally are pumped during the growing season may be used for recharge during other seasons. Recharge wells, often referred to as injection wells, have been in use in almost every part of the United States in connection with irrigation, heat pumps, and saltwater 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 gypsum, recharge wells may be placed upstream from a floodwater retarding structure. The intake should be well below the crest of the principal spillway elevation, but several feet above the bottom to aid in trapping sediment. Recharge begins 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 affect the life and efficiency of a well. These are most important in aquifers with moderately permeable 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 sediment.

Natural openings—in cavernous limestone and gypsum areas, natural openings along the stream channel may be used in lieu of recharge wells. Recharge water may be directed to these openings 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.

(3) Maintenance of recharge structures

Some types of recharge structures require frequent attention to maintain their efficiency. This is especially true for injection wells and, to some extent, for pits or shafts where chemical treatment and the control of sediment, bacteria, algae, and air entrainment are involved.

Maintenance generally includes:

- removing trash and repairing debris guards
- maintaining filtration, flocculation, or other water treatment facilities
- backflushing recharge wells, with or without the use of detergents, to remove introduced fine sediment from the aquifer
- normal structural and mechanical maintenance

(e) Quality of water for recharge

Recharge water must be of suitable quality for ultimate recovery and use for its intended purpose. Any water proposed for recharge should be tested.

(1) Sediment and debris

Sediment introduced into a well clogs the gravel pack around the well or at the interface between the gravel pack and the aquifer.

Accumulations of organic matter and other debris may reduce the rate of recharge. 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. Organic matter that enters caverns is also a critical food source for the cave ecosystem.

(2) Chemical pollutants, bacteria, algae

Pollution must be avoided in recharging groundwater. 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.

(i) 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 on the time and amount of precipitation, the chemical changes that take place in the earth materials, and availability of soluble substances.

Water solubility of oxygen, carbon dioxide, sulphur dioxide, ammonia, and other gases varies with the physical and biological environment and changes with temperature and pressure. Presence of dissolved oxygen affects the habitat of aerobic bacteria, which influences 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 influences 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 varies with the chemical quality of water.

Chemical and mineral wastes from mining and industrial areas often are toxic to plants and animals. Water containing a high concentration of sodium salts causes infiltration problems. Reactions between chemicals in recharge water and chemicals in the groundwater or the mineral makeup of the aquifer may produce precipitates. These conditions could reduce the rate of recharge or the quality of the water.

(ii) Temperature and dissolved gases

The solubility of air in water is strongly influenced by temperature as illustrated in table 33–1.

Surface water (except for industrial effluents) is normally saturated with air. An injection well pumping 500 gallons per minute of water at 20 or 30 degrees Celsius into an aquifer, where the temperature might be raised by 10 degrees Celsius, 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 groundwaters contain much dissolved gas, which might be freed if the injected water is too warm.

(iii) Measures for improving quality

Debris guards, sediment basins, or both should be installed to remove debris and sediment from recharge water. These measures avoid contamination of the underground water, keep the intake areas open, and prevent clogging of the aquifer. Flocculants may be used to hasten the removal of suspended sediment.

Aeration may reduce some chemical and bacterial contaminants, but may increase the growth of algae. Chlorination of the recharge water, either continuously or in slugs, reduces the growth of aquifer-clogging microorganisms.

Table 33–1 Solubility of air in water as a function of temperature

Temperature		Dissolved air at 1 atmospheric pressure, volume of air/ volume of water
°C	°F	
0	32	0.029
10	50	0.023
20	68	0.019
30	86	0.016
40	104	0.014

(f) Benefits of recharge

Following are several types of benefits from groundwater recharge:

- storing water in underground reservoirs which may be recovered for beneficial use
- raising the water table to increase water supply from shallow wells, reduce pumping costs in wells, and maintain water levels
- decreasing runoff, thereby directly reducing damages from flooding, erosion, and sedimentation
- creating fresh water barriers against the intrusion of saltwater along coastal areas or against the intrusion of undesirable water in inland areas
- recharging good quality water to dilute undesirable groundwater or to assist in flushing undesirable water from cavernous or very porous aquifers
- 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
- increasing streamflow to supply water for agricultural purposes, wildlife, recreation, and to assist in removal of pollutants or undesirable debris
- maintaining a high water table in marsh areas to ensure permanent pools or marshes for the breeding or resting places for waterfowl, fish, and other aquatic animals
- replenishing groundwater 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

(1) Induced damages

The following conditions may be caused or increased by groundwater recharge and may be either agricultural or nonagricultural:

- Mass movements such as slumps, slides, or earth flows commonly cause damage, especially to roads, railroads, buildings, and agricultural works of improvement.
- Groundwater problems may be associated with seasonal high water tables or fluctuating water tables associated with flood events.
- Groundwater recharge that raises the potentiometric surface locally may have an adverse impact on adjacent properties; e.g., wet basements, subirrigated cropland (swamping), increased salinity of surface soils through pumping by capillary fringe, etc.

631.3301 References

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