Groundwater Pollution Primer
CE 4594: Soil and Groundwater Pollution
Civil Engineering Dept, Virginia Tech

Artificial Recharge of Groundwater

by Nayantara Nanda Kumar & Niranjan Aiyagari

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Introduction

The increasing demand for water has increased awareness towards the use of artificial recharge to augment ground water supplies. Stated simply, artificial recharge is a process by which excess surface water is directed into the ground – either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration – to replenish an aquifer. It refers to the movement of water through man-made systems from the surface of the earth to underground water-bearing strata where it may be stored for future use. Artificial recharge (sometimes called planned recharge) is a way to store water underground in times of water surplus to meet demand in times of shortage (NRC, 1994)

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Methods of Artificial Recharge

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Direct Artificial Recharge

• Spreading basins

This method involves surface spreading of water in basins that are excavated in the existing terrain. For effective artificial recharge highly permeable soils are suitable and maintenance of a layer of water over the highly permeable soils is necessary. When direct discharge is practiced the amount of water entering the aquifer depends on three factors - the infiltration rate, the percolation rate, and the capacity for horizontal water movement. In a homogenous aquifer the infiltration rate is equal to the percolation rate. At the surface of the aquifer however, clogging occurs by deposition of particles carried by water in suspension or in solution, by algal growth, colloidal swelling and soil dispersion, microbial activity ect. Recharge by spreading basins is most effective where there are no impending layers between the land surface and the aquifer and where clear water is available for recharge; however, more turbid water can be tolerated than with well recharge. The common problem in recharging by surface spreading is clogging of the surface material by suspended sediment in the recharge water or by microbial growth. In coarse grained materials removal of fine suspended sediment is difficult. Playa Lakes or wet weather lakes are depressions that collect water after rainfall or periods of snowmelt. Playa lakes in Texas, New Mexico and Colorado have been used in artificial recharge projects (O'Hare et al., 1986). Many Playa lakes have tight clay deposits that restrict leakage of water. Most of the water is lost by evaporation or by non-beneficial growth of vegetation in the lake. Heavy clay soils can be broken up and the lake bottom regraded for maximum recharge. In a demonstation project near Lubbock, Texas, playa lakes were modified by excavating concentration pits and using the excavated soil to raise the elevation of some of the previously flooded lands.

• Recharge Pits and Shafts

Conditions that permit surface spreading methods for artificial recharge are relatively rare. Often lenses of low permeability lie between the land surface and water table. In such situations artificial recharge systems such as pits and shafts could be effective penetrate the less permeable strata in order to access the dewatered aquifer. The rate of recharge has been found to increase as the side slopes of the pits increased.

Unfiltered runoff waters leave a thin film of sediment on the sides and bottom of the pits which require maintenance in order to sustain the high recharge rates. Shafts may be circular, rectangular, or of square cross-section and may be backfilled with porous material. Excavation may terminate above the water table level or may be hydraulic connectors and extend below the water table. Recharge rates in both shafts and pits may decrease with time due to accumulation of fine grained materials and the plugging effect brought about by microbial activity (O'Hare et al., 1986).


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●Ditches

A ditch could be described as a long narrow trench, with its bottom width less than its depth. A ditch system can be designed to suit the topographic and geologic conditions that exist at a given site. A layout for a ditch and a flooding recharge project could include a series of ditches trending down the topographic slope. The ditches could terminate in a collection ditch designed to carry away the water that does not infiltrate in order to avoid ponding and to reduce the accumulation of fine material (O'Hare et al., 1986).

●Recharge Wells

Schematic of an Injection Well

Recharge or injection wells are used to directly recharge water into deep water-bearing zones. Recharge wells could be cased through the material overlying the aquifer and if the earth materials are unconsolidated, a screen can be placed in the well in the zone of injection. In some cases, several recharge wells may be installed in the same bore hole. Recharge wells are a suitable only in areas where a thick impervious layer exists between the surface of the soil and the aquifer to be replenished. They are also advantageous where in areas where land is scarce. A relatively high rate of recharge can be attained by this method. Clogging of the well screen or aquifer may lead to excessive buildup of water levels in the recharge well. In ideal conditions a well will accept recharge water at least as readily as it will yield water by pumping. Factors that cause the build up of water levels in a recharge well to be greater than the corresponding drawdown in a discharging well may include the following.

- Suspended sediment in the recharge water, including organic and inorganic matter.
- Entrained air in the recharge water.
- Microbial growth in the well.
- Chemical reactions between the recharge water and the native groundwater, the aquifer material, or both.
- Ionic reactions that result in dispersion of clay particles and swelling of colloids in a sand-and-gravel aquifer.
- Iron precipitation.
- Biochemical changes in recharge water and the groundwater involving iron-reducing bacteria or sulfate-reducing organisms.
- Differences in temperature between recharge and aquifer water.

Factors that cause the build up of water levels in a recharge well to be less than the corresponding drawdown in a discharging well may include the following.

- Recharge water is warmer than native groundwater and therefore, less viscous.
- Increase in he saturated thickness and transmissivity of the aquifer due to the higher water levels that result when a water table aquifer is recharged.

- Recharge water that is unsaturated with respect to calcium carbonate. Such water may dissolve parts of a carbonate aquifer (O'Hare et al, 1986).

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Indirect Artificial Recharge

Enhanced Streambed Infiltration (Induced infiltration)

This method of induced recharge consists of setting a gallery or a line of wells parallel the bank of a river and at a short distance from it. Without the wells there would be unimpended outflow of groundwater to the river. When small amounts of groundwater are withdrawn from the gallery parallel to the river, the amount of groundwater discharged into the river decreases. The water recovered by the gallery consists wholly of natural groundwater. Each groundwater withdrawal is accompanied by a drawdown in the water table. For high recovery rates this drawdown tends to lower the groundwater table at the shoreline below that at the river. Thus, surface water from the river will be induced to enter the aquifer and to flow into the gallery. In areas where the stream is separated from the aquifer by materials of low permeability, leakage from the stream may be so small that the system is not feasible (O'Hare et al., 1986)

Conjunctive Wells

A conjunctive well is one that is screened in both a shallow confined aquifer and a deeper artesian aquifer. Water is pumped from the deeper aquifer and if its potentiometric surface is lowered below the shallow water table, water from the shallow aquifer drains directly into the deeper aquifer. Water augmentation by conjunctive wells has the advantage of utilizing sediment-free groundwater which greatly reduces the damage of clogging well screens.

Other benefits are:

- It reduces the amount of evapotranspiration water loss from the shallow water table.
- Reduces flooding effects in some places.

Environmental effects from the conjunctive well method must be carefully studied to assure that unwanted dewatering of wetlands or reduction of base flow will not occur. The possibility of coagulation due to mixing of chemically different groundwaters should also be investigated (O'Hare et al., 1986).

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Table: Some factors to consider for Artificial Recharge (O'Hare et al., 1986)

1. Availability of waste water

2. Quantity of source water available
3. Quality of source water available
4. Resulting water quality (reactions with native water and aquifer materials)
5. Clogging potential
6. Underground storage space available
7. Depth to underground storage space
8. Transmission characteristics
9. Topography/applicable methods (injection or infiltration)
10. Legal/institutional constraints
11. Costs
12. Cultural/social considerations

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Advantages:

Artificial recharge has several potential advantages:

- The use of aquifers for storage and distribution of water and removal of contaminants by natural cleaning processes which occur as polluted rain and surface water infiltrate the soil and percolate down through the various geological formations.
- The technology is appropriate and generally well understood by both the technicians and the general population.
- Very few special tools are needed to dig drainage wells.
- In rock formations with high, structural integrity few additional materials may be required (concrete, softstone or coral rock blocks, metal rods) to construct the wells.
- Groundwater recharge stores water during the wet season for use in the dry season, when demand is highest.
- Aquifer water can be improved by recharging with high quality injected water.
- Recharge can significantly increase the sustainable yield of an aquifer.

- Recharge methods are environmentally attractive, particularly in arid regions.
- Most aquifer recharge systems are easy to operate.
- In many river basins, control of surface water runoff to provide aquifer recharge reduces sedimentation problems.
- Recharge with less-saline surface waters or treated effluents improves the quality of saline aquifers, facilitating the use of the water for agriculture and livestock.

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Disadvantages:

Artificial Recharge has some disadvantages too:

- In the absence of financial incentives, laws, or other regulations to encourage landowners to maintain drainage wells adequately, the wells may fall into disrepair and ultimately become sources of groundwater contamination.
- There is a potential for contamination of the groundwater from injected surface water runoff, especially from agricultural fields and roads surfaces. In most cases, the surface water runoff is not pre-treated before injection.
- Recharge can degrade the aquifer unless quality control of the injected water is adequate.
- Unless significant volumes can be injected into an aquifer, groundwater recharge may not be economically feasible.
- The hydrogeology of an aquifer should be investigated and understood before any future full-scale recharge project is implemented. In karstic terrain, dye tracer studies can assist in acquiring this knowledge.
- During the construction of water traps, disturbances of soil and vegetation cover may cause environmental damage to the project area.

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Costs:

The cost of treating waste water to potable standards for agricultural purposes is generally prohibitive. Therefore, it is appropriate to consider whether an alternative approach would achieve reclaimed water storage needs without adversly affecting water quality, environmental, or public health.

The estimated cost of infiltration of surface water in Argentina, using basins and canals, is $0.20/m^3. The basins and canals used in the 1977 experiment in the San Juan River basin incurred a capital cost of $31,300. The comparable cost of watertraps in Argentina has been estimated at between $133 and $167. The capital cost of a 5,700 m^3 cutwater, equipped with a 14 m extraction well, is estimated at $6,325. The operation and maintenance cost is estimated at $248 per year. The production costs are estimated to be about $0.30/m for the first five years of operation, $0.17/m for the next five years (five to ten years of operation), and $0.15/m for the following five years (ten to fifteen years of operation).

In Jamaica, the initial capital cost of the sinkhole injection system was estimated at less than $15,000. This cost is primarily related to the construction of the inflow settling basin and channels conveying the runoff water to the sinkholes. Maintenance costs are low, less than $5,000 for the 18-month project (or under $3,500/year) (O'Hare et al., 1986)

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Regulations:

California has led the way in the development of draft state regulations (July 1992 draft) governing the use of reclaimed water for recharge of potable aquifers, wether through wells or surface recharge facilities. Under the draft regulations , all recharge waters would have to undergo biological oxidation and disinfection, with well injection also requiring filtration and organics removal.

Pollution-control permits that concern artificial recharge:

- To prevent ground-water pollution, permits issued to regulate the discharge, disposal and possibly the storage of waste and waste water should specifically take into account the vulnerability of the aquifer concerned and the provisions necessary for its protection. These provisions should apply to:
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    - Effluents and sludges produced by wastewater treatment plants;
    - Domestic-waste disposal sites.
    - Subsurface waste containment by deep-well injection or storage.
    - Surface storage of wastes potentially hazardous by virtue of their chemical composition.
    - In permitting activities such as artificial recharge, the hydrogeological situation of the area should be taken into consideration. On this matter the opinion of qualified specialists should be sought in all above-mentioned cases. Continuous monitoring programmes should be set up both to control water quality in aquifers as well as for checking compliance with permits granted.

- The disposal of waste water should not be an immediate and/or long-term hazard to ground water. Controlled sites should be equipped with protective installations according to the best available technology and monitored by competent authorities. Regulations or guidelines should be drawn up for the site selection of controlled waste-disposal sites, their operation, monitoring, shut-down and eventual rehabilitation, with particular emphasis on ground-water quality protection. The water which is used for recharge should not have compounds which are toxic, persistent, bioaccumulative or radioactive and which put ground water at risk. Such water should be subject to special treatment. Legislation should ban dumping of solid or liquid wastes at unauthorized sites.
- Application of treated waste water and resulting sludge on land should be subject to license and/or conform to nationally agreed codes of practice and be restricted to areas where there is no immediate or long-term hazard to ground-water quality. In this respect, particular care should be taken not to overload the self-purification capacity of the soil filter and corresponding natural processes therein. Special attention should be paid to hazardous substances, for example heavy metals.
- In principle, injection of liquid wastes into the ground should be prohibited. Deep-well injection

of liquid wastes of industrial origin and other water of objectionable quality into the ground should be authorized only case-by-case as ultima ratio, if the necessary precautions and controls for deep-well disposal can be specified, and if injected wastes cannot harm nearby aquifers. Control methods should include proper siting, design, construction, operation, abandonment and monitoring of deep-well injection.

Abstraction and recharge permits:

- Artificial recharge of ground water should be licensed and controlled by competent authorities according to specific requirements laid down in an appropriate permit system which should be flexible so as to adopt to site-specific conditions. The question of ground-water exploitability should be clarified on a case-by-case basis, taking into account all relevant aspects, including ecological ones. The relevant regulations should establish the extent to which exemptions can be allowed in cases of. Where compatible with national legislation, permits for ground-water abstraction and use as well as pollution control should not release the user of ground water from responsibility in case of detrimental effects on ground-water quality and quantity as a result of interventions covered by the permit granted.
- Authorization for artificially recharging the aquifer should be granted only if the hydrogeological situation, environmental conditions and the recharge-water quality permit injection, percolation or infiltration of water by artificial means into aquifers for storage and retrieval of good-quality water as well as for restoring over-exploited ground-water resources. For induced recharge from adjacent streams or lakes, appropriate security measures should be applied to forestall accidental pollution.
- Appropriate measures should be taken to combat saltwater encroachment into coastal aquifers. In such areas special regulations for ground-water abstraction should be enforced to avoid seepage into aquifers owing to overpumping and the resultant lowering of the ground-water table (Pyne, 1995).

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- Proceedings Of The Second International Symposium On Artificial Recharge Of Groundwater, 1994. Artificial Recharge Of Groundwater-2.
- Pyne, R.D.G., 1995, Groundwater Recharge And Wells

Links to relevant websites

http://www.mercedid.org/recharg.html

http://iwgf-sig.boku.ac.at/V-TECH94.HTM

● http://www.vki.dk/YEAR1996/UK/ADBUK2.HTM

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Student authors: Niranjan Aiyagari and Nayantara Nanda Kumar
Faculty Advisor: Daniel Gallagher, dang@vt.edu

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Student Authors:
Niranjan Aiyagari niranjan@vt.edu
Nayantara Nanda Kumar nakumar@vt.edu