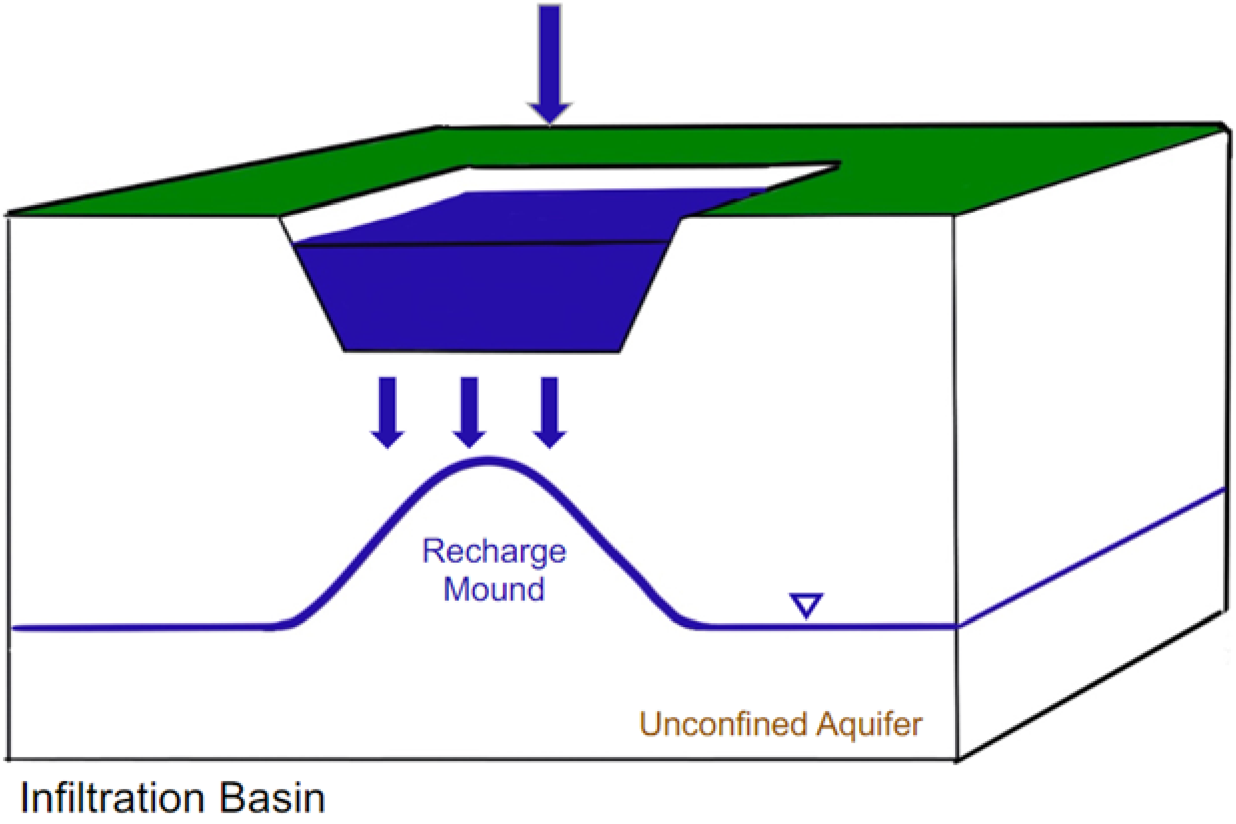
Introduction

Infiltration basins (see figure below), including recharge basins, percolation ponds, rapid infiltration basins, and spreading basins, are types of managed aquifer recharge (MAR) used to passively recharge unconfined aquifers through infiltration and percolation from the ground surface. Infiltration basins are designed to add water to the aquifer throughout the year or over intermittent periods of time and are used to augment water supply, enhance declining water tables, or increase streamflows for environmental purposes, such as wetland rehabilitation and habitat protection. According to the (National Research Council 2008), surface spreading generally requires a diversion and retention structure, and an unconfined aquifer with infiltration capacity or storage capacity that can accommodate the required recharge scheme. Infiltration basins can vary in size from many acres of land to small ponds, pits, trenches, and channels. In parts of Arizona dry washes are used for enhanced recharge by placing source water into a normally dry river channel and letting the water percolate into the vadose zone.



Applicability

Infiltration basins are constructed when impermeable layers are not present below the intended recharge area. The construction of a basin requires a retention structure, such as an earthen bank surrounding the site, or by excavating into the ground. Basins can operate with minimal maintenance when high-quality water is the intended recharge source; however, compaction of the surface must be kept to a minimum to maintain the permeability of the unsaturated zone. Recharge water with high loads of suspended solids commonly requires maintenance to remove the clogging layer and restore infiltration rates.

Advantages

Infiltration basins are generally cost-effective when compared to other forms of MAR, such as injection wells (including aquifer storage and recovery (ASR wells) and aquifer storage, transfer, and recovery (ASTR wells), since infiltration basins recharge the aquifer by percolating water through the vadose zone (soil aquifer treatment). Soil aquifer treatment improves water quality through many physical and biological processes and generally helps minimize the need for pretreatment. Treatment (and recharge) of treated wastewater can be maximized as a result of soil aquifer treatment in infiltration basins by installing a layer of soil in the infiltration basin (Maliva 2020). Research has shown that certain organic materials are effective in reducing high nitrate concentrations in source water (for example, agricultural runoff) (for example, Schmidt et al. 2011; Gorski et al. 2020).

The main advantages of infiltration basins are:

- They are robust and usually fail safe.
- Less operator technical expertise is required for their operation.
- They provide some underground storage to absorb seasonal or other differences in supply and demand.
- They enhance the public acceptance of reuse by breaking the pipe-to-pipe connection between the treatment plant and reuse activity (the water loses its identity as sewage water) ((H. Bouwer, Rice, R. C., and Bouwer, E. J. 1983); Herman Bouwer 1991).
- They are usually less costly than injection well systems.
- Operation and maintenance are easy.

Limitations

Utilizing infiltration basins to recharge an aquifer is a passive approach that requires minimal utility cost compared to other MAR methods. However, project objectives often depend on proper site-specific characterizations because the size of the infiltration basin will vary based on subsurface material properties, which can be challenging to predict since subsurface characterization is often unknown or expensive to investigate. The most important characterizations include determining correct infiltration rates of soils, the unsaturated zone, and the aquifer. Other aquifer characteristics and hydrogeologic investigations include determining the aquifer thickness, specific yield, hydraulic conductivity, heterogeneity, depth of the water table, and the timing of recharge. Each of these factors plays a role in determining a site plan and infiltration basin size. Basins that are improperly sized (too small) or have limited infiltration capacity can cause flooding. While large basins may be costly due to land acquisition, they may be cheaper to operate in the long term (Ross and Hasnain 2018). It is also important to make sure the vadose zone does not contain undesirable chemicals or contaminants that could leach into the receiving aquifer.

Clogging is also a limitation associated with infiltration basins because the performance of a basin deteriorates when clogging of the recharge areas increases. Clogging of basin sediments can occur due to settling of suspended solids and growth of algal biofilms (especially in the summer). Managing operational costs can be problematic when extensive clogging occurs but can be reduced through maintenance of the basin, such as drying and scraping the clogged layers from the surface. The scraped layers can be used to build the bank of the basin or may need to be hauled away from the site. Clogging layer removal and mitigation of excessive mounding of groundwater levels often require intermittent periods of dry basin conditions (no recharge occurring).

Disadvantages of infiltration basins include:

- They require large land areas, which can be a major constraint in already developed (for example, suburban and urban) areas.

- Soil aquifer treatment does not remove all organic contaminants.
- Soil aquifer treatment does not remove salts, and a modest salinity increase can occur due to evaporation, leaching of salts in the soil, and the atmospheric deposition of salt as dust and aerosols.
- There’s a potential for insect production (midges, mosquitos) and odors.

Performance

Infiltration basin performance is often monitored using the following metrics:

- cumulative recharge volume (for example, total recharge in acre-feet)
- volumetric recharge rate (for example, acre-feet per year, millions of gallons per day, and cubic feet per second)
- infiltration (percolation) rate (for example, feet per day)

Each performance metric has advantages and limitations. Cumulative and annual recharge volumes are useful for big-picture performance tracking and planning fiscal year budgets by determining what the marginal cost of water per acre-foot ($/acre-foot) for ratepayers should be to evaluate the cost/benefit for developing, operating, and maintaining MAR projects, programs, and portfolios. In California, some water agencies must prepare and defend their capital improvement program budgets with the California Public Utilities Commission. Daily volumetric and infiltration rates are useful for understanding current and recent trends in basin performance.

Typical recharge rates of infiltration basins vary in the range of 20–300 acre-feet/year (USEPA 2003). Recharge performance can be impacted by clogging layer development, seasonal temperature, and development (mounding) of shallow water tables. Bouwer (2002) described a conceptual model that supports the idea that excessively deep ponded water can compress the clogging layers and further reduce infiltration rates. Academic research projects have used various combinations of site-specific data (for example, sediment cores and grain size distribution analysis, infiltrometer tests, chemical tracers such as SF6 (Gerenday et al. 2020), temperature as tracers (Racz et al. 2011; Becker, Bauer, and Hutchinson 2012; Mawer et al. 2016; O'Connell, Patrick James 2019; Medina et al. 2020), water level data, and inflow rates) and modeling (Frei et al. 2009; Yonatan Ganot et al. 2016) to better understand the dynamics that impact infiltration basin performance. Research has shown that there is a benefit to measuring and monitoring infiltration rates (for example, using temperature as a tracer) with water level data (for example, surface water stage and groundwater levels) to track changes in hydraulic conductivity (Lamontagne et al. 2014).

The performance of infiltration systems depends on a variety of factors, including areal extent, source water quality, and hydrogeologic setting. Table 1 of Orange County Water District (OCWD) Surface Recharge System Operations Manual (OCWD 2021) shows that maximum recharge rates range from 3 to 120 cubic feet per second (cfs) among their 22 recharge basins. One of the highest performing recharge basins is the La Palma recharge basin, largely due to using almost entirely highly treated recycled water from the OCWD Groundwater Replenishment System (GWRS) with essentially no total suspended solids (TSS) content (minimal clogging potential). In the Kings Subbasin of the San Joaquin (Central) Valley of California, the 15 recharge basins covering 600 acres exhibit recharge performance varying between 360 and 2,200 acre-feet per year (KRCD 2021).

Regulatory Considerations

Regulatory considerations vary by state but may require a water right or permit to divert and/or recharge water, in addition to possible regulatory oversight to recover recharged water. Because recharge is conducted through infiltration, rather than injection, the U.S. Environmental Protection Agency (USEPA) does not regulate infiltration basins as they do with ASR wells; however, some states have requirements for groundwater level depths beneath basins.

Some examples of state requirements for minimum vadose zone thickness between the basin land surface; travel times; and water table to be considered adequate for nitrogen and contaminant removal of source water that consists of recycled wastewater (Maliva 2020) include:

- **Delaware**—At least a 2-foot thickness between the basin surface and mounded water table (Turkmen et al. 2008).
- **Nevada—**At least 10-foot-thick vadose zone, and at least 40 feet depth to an impermeable layer (BWPC 2017).
- **Florida**—Demonstrate that the mounded water table will not intercept the ground surface or interfere with reasonable uses of nearby properties.
- **California**—The permitting of a recharge basin (a discretionary project) that is not exempt from the California Environmental Quality Act requires the lead agency to prepare an initial study to determine whether the project may have a significant adverse impact on the environment. Typically, this results in a Mitigated Negative Declaration or requires an Environmental Impact Report; however, due to the extreme drought conditions exhibited in the greater southwest U.S., the California governor issued an executive order on March 10, 2023, to temporarily bypass these environmental regulations to make it easier to capture floodwater associated with rainfall and anticipated snowmelt from above-average winter snowpack to recharge groundwater (Governor Newsom Issues Executive Order to Use Floodwater to Recharge and Store Groundwater | California Governor).

If recycled water is used in the infiltration basin, the siting must be provided for a 6-month travel time to the nearest drinking water well as required by California Code of Regulations Title 22 Groundwater Replenishment Reuse Project Regulations. Because of the long travel times to drinking water well receptors, California allows a default credit of 1-log virus reduction for every month of retention time. The travel time estimated can be modeled initially; however, after the project is constructed, the travel time is required to be verified with a tracer study.

Riverbank filtration can be used to help utilities meet the USEPA Long-Term 2 Enhanced Surface Water Treatment Rule to protect against the health effects associated with *Cryptosporidium* in surface water used as a drinking water supply (USEPA 2022a).

Stakeholder Considerations

Infiltration basins generally require a large footprint of land to recharge high volumes of water for subsequent recovery. Stakeholders can take a position of opinion on many aspects of a MAR project, such as concerns with surface water diversions, land acquisition, and groundwater quality. Points of contention can also arise anytime throughout the duration of a project. Research suggests stakeholders, including the public, require project transparency. This includes consideration of communicating technical knowledge in a manner that is accessible to those without technical backgrounds and consideration to those whose cultural heritage is tied to land (Kurki and Katko 2015).

Lessons Learned

MAR involving passive infiltration is a common approach to recharging unconfined aquifers; however, site-specific characterization of the aquifer and the unsaturated zone is important to estimating an infiltration basin size with respect to the desired recharge volume. Although infiltration basins are less expensive to operate than injection wells, soil compaction and clogging will reduce infiltration capacity. Regular maintenance to retain infiltration and percolation rates is common and routine. This usually consists of scraping the biofilm/fine layer that accumulates on the bottom of the basin.

When it comes to using advanced treated wastewater (ATW), the OCWD learned after the first couple years of operation of their La Palma recharge basin that the ATW delivered 14 miles inland from the advanced groundwater Treatment Facility, via the groundwater replenishment system, contains such low levels of impurities (for example, TDS) that it leaches mineral content from the concrete distribution line. The lesson learned is that it is important to consider investing in epoxy lining for concrete distribution lines that use ATW (for example, reverse-osmosis-level treated wastewater or desalinated seawater). While mineral leaching is not unique to MAR, it is an important consideration for any project dealing with very low TDS waters.

Case Studies (FS-1)

- Orange County, California—Maximizing Infiltration Rates by Removing Suspended Solids: Results of Demonstration Testing of Riverbed Filtration in Orange County, California
- Central Arizona—Central Arizona Project (CAP) Recharge Program—Increasing the reliability of water supplies
- Walla Walla, Oregon—The Walla Walla Basin Watershed Council (WWBWC) managed aquifer recharge program (see also Walla Walla Water Basin Case Study 5.9).