ITRC (Interstate Technology & Regulatory Council). 2023. Managed Aquifer Recharge Guidance MAR-1. Washington, D.C.: Interstate Technology & Regulatory Council, MAR Team. https://mar-1.itrcweb.org/.

The Recharge Technologies section consists of five fact sheets. Each fact sheet will describe a method of recharge with multiple technology options. The technologies within a method will have many common features; however, where the technology details vary, the specific differences will be discussed in more detail at the end of the fact sheet. This approach was taken to reduce the amount of repeated material presented.

MAR technologies are divided into two categories, surface recharge and subsurface recharge. As a group of technologies, surface recharge systems (Fact Sheet FS-1 and Fact Sheet FS-2) are generally preferred for MAR because it is easier to control clogging of the aquifer and have the ability for contaminants to be attenuated in vadose zone processes that improve the water quality of recharge source water (Maliva 2020). Surface recharge technologies are also designed to passively recharge the aquifer (Herman Bouwer 2002), and sometimes natural features are used instead of engineered structures for surface recharge technologies.

Subsurface technologies involve recharge of the saturated zone of confined and unconfined aquifers and are covered in Fact Sheet FS-3, Fact Sheet FS-4, and Fact Sheet FS-5. Because the horizontal hydraulic conductivity of a given formation can be orders of magnitude higher than the vertical hydraulic conductivity, greater aquifer recharge rates can, in some instances, be obtained by recharging directly into an aquifer or vadose zone rather than by surface spreading (Maliva 2020). The subsurface recharge technology fact sheets provide information on technologies that recharge groundwater with wells and/or underground structures. Many of these technologies are well defined in other areas, such as stormwater control, but have been adapted to MAR by changing things such as scale and site selection.

Recharge technologies are often complemented by aquifer recovery technologies (for example, production wells; aquifer storage and recovery (ASR) wells; aquifer storage, transfer, and recovery (ASTR) wells) to more sustainably manage groundwater supplies and demands, spatially and temporally. Selecting the appropriate technology depends on many site-specific factors, including the target aquifer type, source water type, available land, overall project cost, and permitting and regulatory requirements. The costs of each of these technologies are highly site-specific and cannot be generalized. Some of the case studies provided include cost information, but these costs will not be relevant for all intended use cases. Surface recharge technologies typically are the most cost-effective method for recharging unconfined aquifers, while direct injection technologies provide a means for replenishing water into confined aquifers or aquifer zones located below low-permeability geologic material that would otherwise impede groundwater recharge. Table 4-1 shows which recharge technologies are applicable for various intended uses.

Table 4-1. Applicability of recharge technologies for intended uses

Intended Use	Surface Recharge Technology		Subsurface Recharge Technology		
	Fact Sheet FS-1: Infiltration Basin	Fact Sheet: FS-2: Diversion and Retention Structures	Fact Sheet FS-3: Injection Well	Fact Sheet FS-4: Dry Well	Fact Sheet FS-5: Infiltration Gallery
Water Supply Resilience	Yes	Yes	Yes	Yes	Yes
Subsidence Reduction			Yes		
Use of Floodwater	Yes	Yes			
Use of Stormwater	Yes	Ye		Yes	Yes
Mitigation against Saltwater Intrusion	Yes	Yes	Yes	Yes	Yes

Improving Groundwater Quality	Yes	Yes	Yes	Yes	Yes

Factors that distinguish surface and subsurface recharge technologies include:

- In general, better-quality, and higher compatibility source water is required for subsurface recharge technologies than for surface technologies because surface technologies typically provide an initial passive level of treatment (soil aquifer treatment) that occurs while water is being transported through the vadose zone and aquifer prior to and during recharging the saturated aquifer material.
- Factors that need to be considered when selecting, designing, and operating any of these recharge technologies include the potential impacts of the source water type(s) on the receiving aquifer and ambient groundwater quality. Impacts to the aquifer can be mitigated with careful planning, monitoring, and maintenance of facilities. Consideration should be given to assessing the variable frequency and duration of hydraulic loading to maintain optimal performance.

4.1 **Surface Recharge Technologies Overview**

The surface recharge technologies fact sheets provide information on infiltration basins and diversion and retention structures. Surface recharge technologies are conducted at or near ground level, designed to passively recharge the aquifer, and allow water to percolate into unconfined aquifers after the water has passed through the underlying sediments. This form of MAR technology typically filters the water prior to it reaching the aquifer. Streams, canals, or other surface water features are used for MAR, often in combination with reservoir releases in a measured, managed way. Also, extraction wells can be pumped to induce infiltration through the streambed and pretreat recharged surface water, resulting in a water supply from a process commonly referred to as riverbank filtration.

Infiltration basins (Fact Sheet FS-1) are typically shallow excavated impoundments with earthen walls that are used to pond water and can receive water of varying quality (for example, levels of pretreatment), intermittently or continuously, depending upon the source water type and availability, size of the basin, and the permeability (recharge capacity) of the underlying sediments and aquifer system. Retention structures (Fact Sheet FS-2) are other surface recharge technologies that are used to retain and divert available surface water into various natural geologic features (for example, ephemeral stream channels and sinkholes) by restricting surface water movement, which induces percolation of surface water through the subsurface. The water is retained behind the structure then percolates into the aquifer.

4.2 **Subsurface Recharge Technologies Overview**

The horizontal hydraulic conductivity of a given hydrogeologic material is often orders of magnitude higher than the vertical hydraulic conductivity of the same material, hence greater aquifer recharge rates can, in some instances, be obtained by recharging directly into an aquifer or vadose zone rather than by surface spreading (Maliva 2020). The subsurface recharge technology fact sheets provide information on technologies that recharge groundwater with wells and/or underground structures. The subsurface recharge technologies include injection wells (including ASR wells), dry wells, and infiltration trenches/galleries/pits.

4.2.1 Saturated Zone Technologies

Injection wells (Fact Sheet FS-3) are used to inject water directly into aquifers when the presence of confining layers prohibits recharge via percolation or unconfined aquifers when site-specific project conditions warrant their use. Injection wells penetrate the saturated zone and are used to directly recharge the aquifer. Injection wells, which are designed to recover water later (for example, during summer and/or droughts) from the same well, are defined as aquifer storage and recovery (ASR). An aquifer storage, transfer, and recovery (ASTR) project is similar in concept; however, injection and recovery occur at separate locations, with extraction or "capture" of water taking place downgradient of the injection well. Recharging directly into the saturated zone using injection wells is an attractive option where storage capacity has been enhanced by historical pumping, and the aquifer has sufficiently high transmissivity to accommodate target flow rates.

4.2.2 Vadose Zone (Variably Saturated) Technologies

Dry wells (Fact Sheet FS-4) are gravity-fed wells located within the vadose zone and operate similar to surface infiltration technologies, as they passively recharge an aquifer using boreholes filled with perforated casing and permeable fill (gravel) material. Water introduced into the dry well infiltrates through the vadose zone and is filtered to improve water quality. Dry wells can help recharge groundwater below low permeability layers that would make infiltration basins impractical. Dry wells are often used in stormwater management applications and in urban locations where infiltration basins are impractical. Dry wells, however, have some limitations. If improperly designed, they can be challenging to maintain and keep clear of sediments. Also, depending on the infiltration capacity of the soils at the site, multiple dry wells may be necessary for the requisite volume of water to be recharged.

Infiltration galleries, trenches (French drains), and shafts (Fact Sheet FS-5) are subsurface structures that allow for rapid infiltration of water to the unsaturated zone. Infiltration galleries can be placed at near-surface shallow depths or deeper within the bedrock and can be engineered using simple designs, such as gravel channels and French drains, or more complex subsurface structures. Infiltration galleries have similar limitations resulting from clogging due to TSS content in source water, which can be mitigated with adequate planning and maintenance.