III. TECHNICAL FACTORS AFFECTING RECHARGE PLANNING

Numerous technical and physical factors must be considered in siting recharge projects. Many of these issues were identified in the Regional Recharge Committee's Technical Report. Some of the key observations from the RRC Technical Report are included here.

A. Recharge Methods

Various methods are available for recharging water. Table 2 is reproduced from the RRC Technical Report and lists recharge methods identified by the RRC as appropriate for the Tucson area.

Table 2. Recharge Methods for the Tucson Area

(Reproduced from RRC Technical Report, Section III.H)

Method	Observations
Off-Channel Constructed Shallow Spreading Basins Spreading basins are designed to be operated in a wet-dry cyclic mode to maintain high infiltration rates. The dry cycle is used to control the development of a biological film at the surface which impedes the movement of water. The water depth during the wet cycle is not more than 5 feet.	The existing Sweetwater Recharge Project (which recharges treated effluent), the Avra Valley Recharge Project and the Central Avra Valley Storage and Recovery Project for CAP recharge are examples of this recharge method.
In-Channel Constructed Facilities A facility designed to function within the active floodplain of a watercourse. These may include inflatable dams, gated structures, levees and basins, compound channels, etc.	The proposed Tucson Airport Remediation Project (TARP) recharge facility would use constructed berms in-channel. The proposed Santa Cruz River at San Xavier District project is another example.
Managed In-channel Recharge This type of facility involves no construction (other than monitoring devices). The natural stream channel is used for "passive" recharge.	The City of Tucson has been pursuing a managed storage facility permit to recharge effluent in the Santa Cruz River. Credits from effluent storage at managed facilities are limited to 50% of the total effluent stored, and can be used to off-set groundwater pumpage but cannot be used for assured water supply purposes.

Method	Observations
Injection Wells Use of wells to inject water directly into the water-bearing unit of the aquifer.	This type of recharge generally requires source water that meets drinking water Maximum Contaminant Levels (MCLs). Injection recharge is the most direct method of limiting subsidence because the water is recharged directly to the aquifer. The City of Tucson is prohibited from using injection well recharge unless the injected water is treated to the same standards as Avra Valley groundwater. Entities other than the City are not precluded from utilizing this option.
Groundwater Savings Facilities Also called "in-lieu" recharge. Credits are accrued when a permit holder (such as a municipal provider) provides a renewable water supply to a facility which would otherwise have used groundwater (such as a farm). Groundwater credits are accrued by the permit holder.	Although the construction costs for this type of recharge are limited to delivery pipelines, such facilities may have a limited lifespan. As agricultural land is taken out of production due to urbanization or other factors, the acreage available for in-lieu projects will decrease. There are four in-lieu projects permitted in the Tucson AMA: BKW Farms, Cortaro-Marana Irrigation District, Kai Farms at Picacho, and Avra Valley Irrigation District.
Induced Recharge This method uses extraction wells along a river channel to draw down groundwater levels to prevent the water table from intercepting the land surface and sustain favorable infiltration rates. This method is only applicable in areas where the permeability and transmissivity of subsurface soils are favorable.	In the Tucson basin, this method would have the greatest chance for success along portions of the Rillito Creek, and upper Tanque Verde Creek.
Vadose Zone Recharge Wells Wells are designed to promote recharge by introducing water into permeable, unsaturated strata above the water table.	Vadose Zone Recharge Wells differ in design and construction from stormwater drywells which are commonly used to drain urban runoff into the vadose zone to comply with local detention/retention ordinances. The Scottsdale Water Campus is an application of this technique.
Deep Basins or Pits Recharge pits differ from drywells in size and shape; unlike wells, they are typically much wider than they are deep.	Pits are constructed to expose coarse-grained sediments of the vadose zone when fine grained overburden precludes use of shallow spreading basins. An example of a proposed deep basin site is the Tanner Gravel Pit.

Figure 2 demonstrates basic concepts associated with recharge and recovery. As recharged water infiltrates the unsaturated zone of the aquifer known as the vadose zone, it can encounter confining layers of fine sediment or clay, resulting in perched aquifers. Mounding can occur as water reaches the water table, either in a perched aquifer or the regional aquifer. Analyses of the extent of mounding projected to occur is required as part of the permit application in order to evaluate potential impacts of recharge on existing water users in the area. Some recharge projects have recovery well components.

Choice of an appropriate recharge method for a particular situation depends on various physical and institutional factors. While some of these institutional factors will be discussed in Chapter IV, physical factors such as hydrogeologic or economic constraints often dictate the choice of recharge method. Some of the issues identified in the RRC Technical Report are discussed below.

B. Hydrogeologic and Hydrologic Factors

1. Rate of Recharge

The standard (instantaneous) infiltration rate (feet per day), the rate at which water enters the soil, is fairly easily measured, but frequently yields a much higher rate than long-term rates. The long-term infiltration rate is difficult to estimate without long-term field testing. Other factors that affect the amount of water that can be recharged at a site include depth to groundwater and the ability of the aquifer to transmit water from the recharge site. The existence of impeding layers in the vadose zone can also affect infiltration rates.

Along principal stream channels in the Tucson AMA, short-term infiltration rates are controlled by the favorable permeability and large infiltration capacity of coarse-grained and well-sorted recent alluvium (river sediments). Long-term infiltration rates for a stream channel recharge project are controlled by the lower permeability of underlying basin-fill deposits. Downward movement of recharge water to the regional aquifer may be impeded at the contact between basin-fill deposits and recent alluvium. This situation could cause water to mound in the recent alluvium and eventually intercept the stream channel, resulting in rejected natural recharge, altered flood hydrographs, and potential risks to groundwater quality if there are contaminant sources near the stream channel.

2. Flooding

Artificial groundwater recharge projects located in floodplains may affect flooding through several processes: 1) decreased floodplain conveyance capacity, 2) modified flood hydrographs and 3) change in the amount and location of erosion and/or deposition. Floodplain conveyance is the ability of the channel to convey flow. A decrease in conveyance may result from vegetation or structures in the channel obstructing flow. The flood hydrograph refers to a picture of the amount of water flowing through the channel at a specific point over time during a flood event. It shows how quickly the water level rises and recedes and how high the level rises. Recharge projects can affect the shape of the hydrograph by decreasing infiltration rates during floods. A study of infiltration rates on a five-mile stretch of the Santa Cruz River indicated that if the

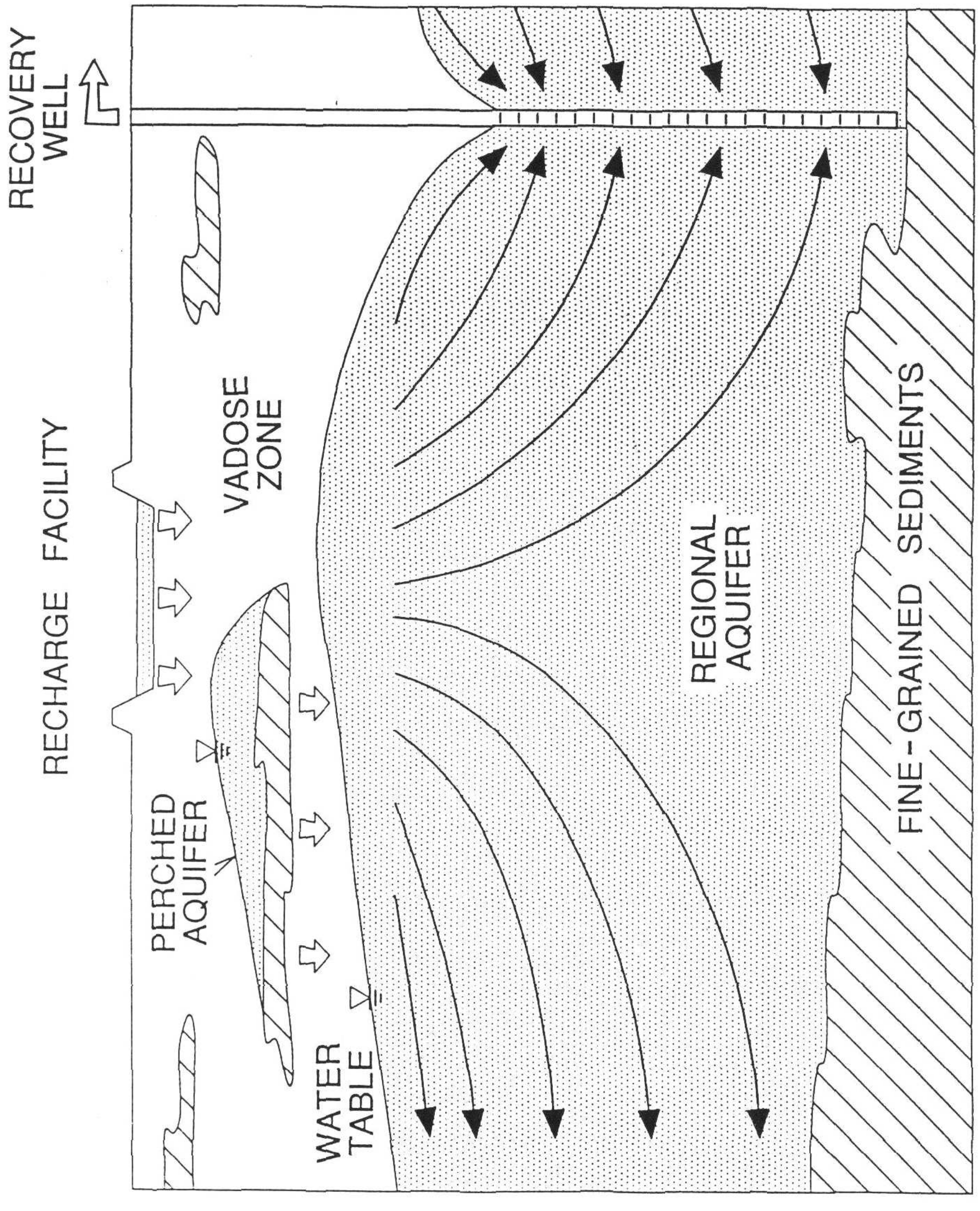

Figure 2. Conceptual Diagram of Recharge and Recovery

groundwater table were allowed to rise to the surface (a worst-case scenario), the change in the level of the water at its highest point during a flood would be too small to measure, but water would flow in the channel for a longer time at low levels. Structures and riparian vegetation that stabilize river banks in one place may be the indirect cause of increased erosion at other locations. A fuller description of what is known about the potential impacts of recharge projects on flooding can be found in the RRC Technical Report.

3. Subsidence

Subsidence is the downward movement or sinking of the Earth's surface caused by compaction of aquifer materials. Most of the subsidence in Arizona results from pumping more groundwater than is naturally recharged to the aquifer (Slaff, 1993). Subsidence can take place when the pressure of water that fills the pore spaces between grains of aquifer material (gravel, sand, silt and clay) is decreased. Water pressure (hydrostatic pressure) helps hold the grains in place by pushing against the weight of the material (geostatic pressure). When the pressure is reduced by removing water, the weight of material can push the grains together, filling in the spaces that once held water. Areas in which clay and silt make up a large percentage of the aquifer material are more susceptible to this compaction process than other areas. In the Tucson basin, the areas with the greatest thickness of silt and clay occur south of the Central Wellfield; this area also has the highest observed aquifer compaction per unit water level decline (Hanson, 1989). Subsidence potential in this area was projected to reach from 1.2 to 12 feet by the year 2024 (Hanson, 1994). Figure 3 dramatically illustrates the effects of severe subsidence resulting from the pumping of groundwater near Eloy, AZ in the Pinal AMA.

***Figure 3**. Dates on the pole mark 15 feet of pumping subsidence that occurred near Eloy, AZ between 1952 and 1985. Photo by the U.S. Geological Survey.*

Damage associated with land subsidence may include the formation of fissures and sinkholes, the alteration of drainage patterns, and damage to structures caused by differential subsidence. Observed land subsidence has been greatest where the regions of greatest water-level decline and greatest silt and clay thickness overlap. These areas are at the south boundary of the Central Wellfield near Interstate 10 and the areas of the Santa Cruz and Southside wellfields along

Figure 4. Earth fissure that formed in 1988 and damaged the CAP aqueduct in Pima County. The aqueduct (behind the embankment in the background) was cracked but not emptied. Photo by U.S. Geological Survey.

Interstate 19 (Anderson, 1988). Fissuring has also occurred locally near the CAP canal in the north Avra Valley (see Figure 4), and sink holes have developed near the Santa Cruz River within the San Xavier District.

Potential for subsidence can be reduced when water level declines can be stopped or reversed. This may be accomplished by 1) reducing the amount of pumping, and 2) recharging in the vicinity of the cone of depression. Artificial recharge may be used as a tool to mitigate land subsidence by reintroducing water into the pores between particles, thus increasing hydrostatic pressure. Recharge may reduce the amount of compaction and in some cases may result in some rebounding of the compacted layers. However, most aquifer compaction is “inelastic” and will not recover. To be most effective, water should be recharged as close as possible to the aquifer layer that is compacting. This indicates that well-injection recharge would be most effective in mitigating subsidence.

Surface methods of recharge may be less effective at mitigating subsidence than well injection, and in some circumstances they also may increase subsidence. The added weight of the water at and near the surface initially increases geostatic pressure above the compacting aquifer layer. Increased compaction may occur before the water can increase the pressure in the compacting layer.

C. Water Quality Factors

Water quality factors affecting recharge can be divided into three categories: the quality of the source water, the modification of water in its passage through the natural materials of the vadose zone and aquifer, and the results of potential contact of the water with contaminants existing in the aquifer.

CAP water, like all surface water, contains bacteria and viruses, some of which can cause disease. It has higher total dissolved solids (TDS, also called salinity) than most groundwater currently pumped for potable use in the Tucson AMA. CAP water is also harder, carries more suspended particles, and has more organic material, both dissolved and particulate. The presence of more organic material indicates a greater potential for the formation of trihalomethanes (THMs) when chlorine treatment is used for disinfection. On the other hand, groundwater has higher levels of certain potentially harmful constituents, such as arsenic and radon, which may be more stringently regulated in the future by the U.S. Environmental Protection Agency (EPA).

Like CAP water, effluent contains microorganisms and higher levels of TDS, hardness, suspended particles, and organic material than local groundwater. In addition, Tucson's effluent has higher concentrations of nitrogen, higher alkalinity, and lower pH.

Tables 5 and 6 of the RRC Technical Report, showing comparisons of water quality from various sources, are included in this report as Appendix G.

1. Source Water

The quality of water recovered after recharge depends on the nature of vadose zone and aquifer materials and native groundwater, and the way in which those materials and water interact with the source water. Given sufficient time and travel through soils and aquifer materials, organic materials and microorganisms can be filtered out of the water. Many organic compounds also degrade in the oxygen rich environment of the vadose zone, if the right organic-material-eating bacteria are present. Although it is possible under some circumstances for recharge to reduce hardness, such a result is extremely unlikely in the Tucson AMA. Thus, whether CAP water or effluent is used for recharge, the water that replenishes the aquifers is likely to have higher TDS concentrations than currently pumped native groundwater. In addition, recharge of effluent carries the potential for increasing nitrogen concentrations in groundwater.

The interaction of recharge water with surface and subsurface materials also will affect those materials. On the surface, sediment and algae can coat the surface of spreading basins and clog surface soil pores. At the interface of injection well and aquifer, suspended sediments, entrained air and dissolved oxygen, geochemical reactions, and bacterial growth can cause clogging of well casing perforations and aquifer pores. In the aquifer, geochemical and biological reactions with the introduced water also can clog aquifer pores. The operation of recharge projects can be hindered by these effects.

a. Water Quality Implications for CAP Water Recharge

The quality of the water that is recovered depends on where the water is recharged relative to the location of recovery, the nature of the aquifer materials, the degree to which it blends and chemically reacts with local groundwater, the distance the water travels in the subsurface, and the presence of any source of contamination.

There are several ways in which recharge using CAP water can reduce the quality of groundwater in the vicinity of the recharge project. CAP water has roughly twice the average TDS level of local currently pumped groundwater. It also contains certain organic compounds, referred to as precursors, which can, in combination with chlorine, react to form THMs. THMs have been shown to cause cancer in laboratory animals. Depending on the contact time and travel through aquifer materials, the filtration resulting from the recharge process tends to reduce the organics and disease-causing organisms, but does not reduce the salinity and hardness of the water. The implications of the presence of organic material in CAP water and the fate of such materials and THMs in recharge projects is the subject of a pending ADWR consultant report (see box this page).

Recharge of untreated CAP water is likely to increase the dissolved mineral content and hardness of the water in the aquifer, although there are some native groundwater wells with a higher TDS concentration than CAP water. To the degree that higher TDS water is recovered for delivery to customers, costs for end users in the municipal sector will increase, because higher salinity and hardness translates into the need to replace water-using appliances more frequently and increase the maintenance of irrigation and evaporative cooling systems.

Disinfection By-Products Study

A study in progress which will affect regional recharge planning is the study of the Transport and Fate of Disinfection By-Products (DBPs) and Their Precursors During Recharge and Recovery of CAP Water. DBPs have been identified as a potential health risk and the U.S. EPA is developing new disinfection rules which are likely to tighten the drinking water standards for trihalomethanes. Area water providers would like to confirm that recovered water will meet the anticipated stricter standards.

The need for this study was initially identified by the RRC in their technical report and was identified as a priority by IPAG and the GUAC. GeoSystems Analysis was hired to conduct the study and will characterize the organic water quality of CAP water likely to be delivered to the Tucson AMA, focusing on DBP precursors. Existing information on the transport and fate of DBP precursors and DBPs in desert soils will be identified, along with what is known about the contribution of algal blooms to DBP precursor and DBP formation potential in recharge ponds. After identifying the need for additional data, cost effective methods for gathering needed data, such as coordinating with sampling at recharge facilities in the AMA, can then be developed.

It is important to note that the TDS brought in with the CAP water will be spatially distributed in the aquifer differently depending on how the CAP water is used. If the water is recharged, the TDS will be distributed in the vicinity of the recharge facilities and could migrate over time to surrounding aquifer materials unless withdrawal facilities are in the same location. Once TDS are introduced into the aquifer, enhanced treatment (utilizing membrane technology) would be required to remove them from recovered water. The long-term effect of multiple recharge projects scattered over the AMA would be wide variability in water quality due to increasing TDS concentrations in some areas.

b. Water Quality Implications for Effluent Recharge

Although not fully evaluated as a part of this report, effluent recharge is a part of the total water management picture in the Tucson AMA. Because of the location of regional sewage treatment plant discharges in the lower end of the Tucson Basin, it is in this area that any major potential water quality impact of effluent recharge is likely to be most evident. Future sewage treatment plants, however, are planned to be non-centralized, in Rincon Valley, for example.

Other areas of potential water quality impact can be anticipated depending on the location of new treatment plants and recharge projects.

Constituents or parameters of concern in municipal wastewater effluent which could impact groundwater quality include the various species of nitrogen (nitrate, nitrite, ammonia and organic nitrogen), microorganisms, disinfection byproducts (THMs), organic chemicals of industrial origin, and metals. The latter two categories are not of much concern for groundwater where industrial discharge pretreatment programs are in effect. As in CAP water, the secondary water quality constituents named above, TDS, hardness, and chloride, are higher in effluent than in currently used groundwater.

Recharge facilities utilizing effluent and wastewater treatment plants producing effluent must both operate pursuant to an Aquifer Protection Permit (APP) issued by the Arizona Department of Environmental Quality (ADEQ) for the discharging activity. To secure an APP, wastewater treatment plant owners must demonstrate that they can meet Aquifer Water Quality Standards (AWQS) when the water reaches the aquifer and that the facilities are designed consistent with the Best Available Demonstrated Control Technology (BADCT). Meeting BADCT may impose more stringent treatment goals than simply meeting AWQS.

2. Contaminants

The location of potential sources of contamination will affect the selection of recharge sites and the operation of recharge projects. For example, there are many old landfills and wildcat dumps in the Tucson area along the major and secondary stream channels. Many of these facilities were used prior to development of modern facility design and waste disposal methods. Many of the old disposal sites were unlined. Types of wastes buried in the landfills, occurrence of potential groundwater contaminants, and potential for migration of contaminants to the groundwater system have not been documented for many of the landfills. However, most of the contaminated production wells are located in proximity to known landfills and other sites of past land disposal and have subsequently been shut off. Volatile organic compounds (VOCs) have been reported to occur in groundwater within one mile of the Silverbell (Jail Annex), Camino del Cerro and Broadway Landfills. Reported concentrations of VOCs exceed maximum contaminant levels established by the EPA for drinking water. Unless designed and operated to avoid impacts, recharge could result in a rise of groundwater levels beneath landfills high enough to mobilize contaminants from the vadose zone or directly from the landfills. An associated concern is that recharge may flush contaminants that are in the unsaturated vadose zone down to the regional groundwater table. The RRC Technical Report contains information on methods for avoiding risks when recharging near landfills.

Recharge in the vicinity of plumes of groundwater contamination could substantially influence the rate and direction of movement of contaminated groundwater. Therefore, projects must be designed and operated to avoid spreading or redirecting contamination in undesirable directions. On the other hand, recharge projects can be used to control the migration of contaminants. For example, recharging uncontaminated water down-gradient from a plume can slow its migration.

D. Environmental Factors

Although shared use of recharge projects for environmental enhancement is a popular concept, there is tension between ADWR's goals for recharge and the goals of environmental enhancement. The primary goal of a recharge project is to maximize the amount of water that reaches the aquifer. Projects designed to promote riparian vegetation decrease the amount of water traveling to the aquifer by making it available for plant use and evaporation. The tradeoff between water available for recharge and for riparian vegetation is not a one-to-one relationship; the actual relationship is dependent on the characteristics of the site. Projects with multiple benefits may be more likely to be supported by the public even if there are increased water costs. The RRC Technical Report contains design concepts for creating riparian habitat in conjunction with recharge projects.

E. Costs of Recharge

Costs associated with recharge projects are often substantial and may vary according to the type of facility to be constructed, its size, the volume of water to be recharged, and the location. Partially in order to investigate the technical constraints and uncertainties described above, projects take time to develop. The time required to move from conceptual phase to full-scale implementation has been underestimated in virtually every recharge project that has been developed, primarily due to unforseen institutional, political, or regulatory constraints. As a result, actual project costs have often varied widely from original estimates.

Table 3 lists possible categories of costs often associated with recharge projects. If land acquisition is necessary, it is often a substantial share of project costs. The cost of delivering water to the site can also be substantial. It costs about $1 million per mile to construct delivery systems (depending on the size of the pipeline and level of urbanization), and energy is often required to pump water to the site. Construction of a water recovery system can also add significantly to project costs. The existence and location of wellfields and distribution infrastructure will have a major effect on the cost of recovery. The high cost of conveying water from the CAP canal may be off-set, in some cases, by reduced cost of recovering and distributing the water though an existing system. There also are costs of compliance with environmental regulations which are difficult to estimate in advance. For example, the Section 7 Consultation required by the Endangered Species Act (ESA) for any project that might affect endangered species habitat is a major "wild card" for all recharge projects proposed in or near flood plains.

Estimated total costs per acre foot of water recharged, exclusive of feasibility study, permitting and water purchase costs, for projects evaluated by the RRC in 1996 varied from about $10 to $130 for direct recharge facilities and from $3 to $55 for indirect recharge facilities (see page VII-1 of the RRC Technical Report). The potential cost of recovery was included in these estimates, if appropriate, based on the design of the project at the time of analysis. Conditions and costs for many projects have changed since the RRC analysis, but these figures are representative of recharge costs.

Table 3. Summary of Potential Costs Associated With Recharge Projects

Cost Component	Possible Cost Sub-Category
Feasibility studies	Phase I assessments geologic investigations pilot studies
Permitting (state, local and federal)	mounding analysis (hydrologic modeling) impact evaluation on land and other water users water quality impact analysis
Monitoring and reporting	water level monitoring water quality analysis flow measurement reporting
Land acquisition or right of way costs	
Facility design and engineering	
Facility construction	monitor well drilling earth removal conveyance system construction berm construction water inlets, piping access road and ramp construction basin slope treatment for erosion protection site access control data acquisition
Facility annual operations and maintenance	monitoring data management control of basin flows/levels scraping to increase infiltration rate vegetation control injection well treatment/flushing
Purchasing water	
Transporting water	energy & operations and maintenance
Recovery of water	capital, energy & operations and maintenance; filtering and disinfection
Environmental constraints/mitigation costs	