Exhibit 46A: Detailed Discussion of Alternative 46—Aquifer Storage

Acknowledgements: This discussion, which follows the same basic format as the fact sheet it accompanies, provides additional details and information that support the conclusions presented in the fact sheet. It was written by Mark Miller of Daniel B. Stephens & Associates, Inc. as part of the "Evaluation of Alternative Actions for Technical, Physical, Hydrological, Environmental, Economic, Social, Cultural, and Legal Feasibility and Water Quality Issues and Legal Overview" contracted to Daniel B. Stephens & Associates, Inc. The format of the fact sheet and the definition of the alternative were developed by the Water Assembly.

1. Definition of Alternative

A-46: Inject water treated to drinking water standards for aquifer storage in appropriate locations throughout the water planning region.

2. Summary of the Alternative Analysis

Aquifer storage and recovery (ASR) applications could potentially prove beneficial for water supply in the Middle Rio Grande (MRG) water planning region. ASR is traditionally defined as the injection and recovery of water using dual-purpose ASR wells (Pyne, 1995). However, this analysis considers a broader definition of ASR applications, including additional approaches to increase aquifer recharge. A variety of aquifer recharge methods have been successfully implemented in ASR projects nationwide.

ASR can be used as a tool for better management of existing supplies, such as saving water lost to evaporation or reusing treated wastewater. In general, water in the Rio Grande is fully appropriated; however, ASR approaches may help to improve the management of available supplies.

The analysis of ASR feasibility for the MRG water planning region includes the following:

- Potential water sources for ASR were examined that may provide increased wet water supplies. Such sources may include under-utilized surface water, evaporative savings, or treated wastewater.

- Applications of alternative ASR groundwater recharge methods were examined, including:

  - Injection wells (wells penetrating the aquifer, vadose zone or "dry" wells, and horizontal infiltration galleries)
  - Infiltration basins (also referred to as soil aquifer treatment or SAT)

- Successes and drawbacks of similar ASR projects in the western U.S. were investigated.

- The determination of ASR feasibility by the City of Albuquerque and plans to implement the ASR water treatment and injection system were examined.

- A preliminary cost assessment was completed using cost data from comparable projects. Costs for the following scenarios were considered:

  - Enhanced arroyo recharge using infiltration basins
  - Wastewater treated to sufficient standards for recharge with infiltration basins (SAT)
  - Rio Grande surface water recharged with infiltration basins to transfer Elephant Butte evaporation savings to aquifer storage

3. Alternative Evaluation

3.1 Technical Feasibility

Enabling New Technologies and Status

ASR is being used increasingly in the U.S. to assist in managing water resources, particularly in the arid southwest and in coastal areas. In the southwest, projects have been implemented in El Paso, Texas; Phoenix and Tucson, Arizona; Orange County, California; Las Vegas, Nevada; and Salt Lake City, Utah. In the region around Phoenix, Arizona, more than 20 full-scale artificial recharge projects are currently operating, with several of these having storage capacities in excess of 100,000 acre-feet (ac-ft) (Unangst et al., 1999). Source water for these projects is derived either from surface water or treated wastewater effluent. ASR has not yet been implemented on a large scale in New Mexico, but the City of Albuquerque is currently developing an ASR project to recharge treated San Juan-Chama water using the City's existing well field. The City of Alamogordo is developing plans for ASR, and has conducted pilot studies to recharge winter flow from springs that otherwise flows into the Tularosa Basin where it is lost from possible use. In the coming years, ASR is likely to become increasingly important in New Mexico, as it has in other parts of the southwest.

ASR can provide a tool for conjunctive use of groundwater and surface water resources, and can offer several advantages for improved water management. Potential benefits of ASR include:

- Replenishment of aquifer depletions
- Reduction of land subsidence rates
- Storage of excess surface water including flood flows
- Storage of water during low-demand seasons for use during high-demand seasons
- Reuse of treated wastewater effluent
- Storage of water without the evaporative losses of surface reservoir storage
- Acquisition of return flow credits to groundwater
- Improved water quality during the transport of water through a porous geologic medium

Enabling legislation that allows for ASR was passed by the New Mexico Legislature in 1999. The Ground Water Storage and Recovery Act, NMSA 1978, §72-5A-2 (Act), provides the legal mechanism for public entities to retain rights to withdraw water that is recharged to an aquifer. In enacting the Act, the Legislature specifically found that the "conjunctive use and administration of both surface and ground waters are essential to the effective and efficient use of the state's limited water supplies" and that ground water recharge, storage and recovery have the potential to reduce the rate of aquifer decline, promote conservation, serve public welfare, and lead to more effective use of water resources. Water stored pursuant to the Act is exempt from forfeiture (NMSA 1978, §72-5A-8). Water can be stored pursuant to this statute only by permit, and a number of criteria must be met before a permit will issue (NMSA 1978, §72-5A-6).

ASR must be conducted in conformance with the requirements of the New Mexico Office of the State Engineer (OSE) Underground Storage and Recovery Regulations (19.25.8 NMAC, effective January 31, 2001). These regulations govern the application process, the hydrologic, technical and financial capability report requirements, and the permit terms and conditions authorized under the Act. The OSE will decide whether recharged water is fully recoverable or whether an unrecoverable loss occurs. The OSE will also have to approve appropriations and/or examine possible surface flow impacts, depending on the type of ASR project considered.

Additional discussion of the enabling new technologies for ASR is presented in the following section on infrastructure development.

Infrastructure Development Requirements

ASR involves artificial recharge to an aquifer and subsequent recovery of the water for later use. Artificial recharge facilities include infiltration basins (recharge basins or spreading basins), infiltration galleries (recharge trenches), vadose zone recharge wells (dry wells), and combination groundwater recharge/recovery wells (ASR wells) (Bouwer, 1996). The various types of artificial recharge facilities are described below.

Infiltration basins: Infiltration basins, also know as spreading basins or recharge basins, are shallow ponds with permeable bottoms that are designed to maximize the downward infiltration of water. Where favorable geology exists, infiltration basins are generally the least costly means of recharging groundwater. Basins require (1) the presence of permeable soils or sediments at or near the land surface (2) an unconfined aquifer beneath, and (3) sufficient depth to groundwater. Shallow basins are generally used in order provide for periodic maintenance, consisting of draining the basin to remove the thin layer of sediment that accumulates on the basin floor, in order to maintain rapid infiltration rates.

Although evaporation is sometimes perceived as a drawback of infiltration basins, evaporative losses for properly functioning infiltration basins total no more than 1 to 2 percent of inflow. Infiltration rates from basins are generally in the range of 1 to 10 feet per day during periods of inundation (Bower et. al., 1990). Considering an average infiltration rate on the order of 2 feet per day for planning purposes in the MRG water planning region (Hansen and Gorbach, 1997) and typical evaporative losses of approximately 0.25 inch per day, then the evaporative loss amounts to just 1 percent of inflow.

Infiltration basins also provide a beneficial effect on water quality as a result of soil-aquifer treatment (Bouwer, 1992). Among the more important processes are reduction in the concentrations of nitrogen, organic carbon, bacteria, and viruses, and removal of taste and odor. Nitrate, if present in the supply water, may be removed by denitrification in the soil, and pathogenic bacteria and viruses tend to become adsorbed onto the soil matrix and thereby immobilized. Because of the water quality improvement provided by infiltration basins, recharge of surface water from the Rio Grande or other rivers in the MRG water planning region could potentially be performed without further treatment. Infiltration basins are also the most common recharge method used for treated municipal wastewater.

A disadvantage of infiltration basins is that they require relatively large areas of land to construct, as compared with recharge wells. Hansen and Gorbach (1997) indicate that the recharge required to balance withdrawals from the Middle Rio Grande Basin is 86,000 acre-feet per year (ac-ft/yr), which would require infiltration basin areas covering approximately 120 acres (or 717 ac-ft recharge per acre per year). Similar acreage requirements are shown for operating infiltration basins in Arizona, as described in more detail in Section 3.2.1.

Depending on their proximity to surface water channels, infiltration basins may be categorized as either in-channel or off-channel. Where arroyos or stream valleys are underlain by permeable sediments, in-channel recharge basins could be viable options to increase recharge of storm water flows. In-channel recharge is being successfully performed at several locations in Arizona and California.

Injection wells: Injection wells may also be used for aquifer recharge. Injection wells are categorized into three basic types:

- Vadose zone wells (also called “dry wells”)
- Infiltration galleries (also called seepage trenches)
- Groundwater injection/withdrawal wells (also called ASR wells)

Vadose zone wells (dry wells): Vadose zone recharge wells, also known as dry wells, are large-diameter wells completed above the water table. Recharge water is delivered to a vertical well screen or perforated pipe that permits water to enter permeable sediments within the vadose (unsaturated) zone. Well diameters of 3 or 4 feet and well depths of 100 to 200 feet are common. Thus, dry wells can be used in settings where low-permeable sediments may be present at shallow depths. Vadose zone wells require only a minimum amount of land, which is a particular advantage in urban settings.

The infiltration capacity of injection wells can be impaired by long-term clogging, which must be avoided since only limited maintenance of vadose zone wells is possible. For this reason, it is imperative that the turbidity and organic carbon content of the influent water be as low as possible to preclude premature clogging of the well with fine sediment or biological solids. Pretreatment of treated wastewater effluent or turbid surface water would therefore be required.

Infiltration galleries (seepage trenches): Infiltration galleries or seepage trenches for recharge purposes are typically excavated using a trackhoe to depths of up to 15 or 20 feet below surface. The trench is backfilled with permeable coarse sand or gravel. Perforated pipe laid within the backfill in the trench allows the introduction of water along its length. Similar to infiltration basins, seepage trenches require the presence of permeable soil close to land surface. Less land is required for trenches than for basins, and trenches are much less conspicuous because they can be covered to blend in with the surroundings. Unlike basins, which can be easily cleaned, little can be done to reverse the effects of clogging of trench walls, aside from installing additional lengths of trench.

Groundwater injection/withdrawal (ASR) wells: Groundwater recharge wells penetrate an aquifer and can be used either for injection or withdrawal of water. These wells are also referred to as ASR wells (Pyne, 1995). Because water can also be pumped out of the well, maintenance by periodic well redevelopment is possible. Existing water supply wells can be converted to allow injection as well as recovery, providing dual-use wells at a low cost. As with all wells, land requirements are minimal.

Water injected directly into the aquifer must comply with U.S. Environmental Protection Agency () drinking water standards or New Mexico Water Quality Control Commission (NMWQCC) groundwater standards. To meet these standards, water from surface water sources or wastewater effluent requires treatment prior to injection. For wastewater effluent, tertiary treatment is required, using methods such as reverse osmosis or other membrane filtration. Surface water, treated to drinking water standards can be injected and withdrawn from the same well. Treated wastewater is never withdrawn from the same well where it is injected; instead it is used to recharge groundwater that is withdrawn at some distance away, providing additional treatment and mixing of the injected water.

Total Time to Implement

Because of the importance of site-specific hydrogeologic variables, experience has shown that ASR projects are best implemented using a phased approach that begins with pilot studies and progresses to implementation of the full-scale system (ADWR, 1999). A pilot recharge study is first performed to demonstrate proof of concept and to select the most appropriate technology (e.g., basins or wells). The pilot system can then be safely expanded with assurance that it will function as expected. A pilot scale project is required under the OSE regulations (19.25.8 NMAC) prior to full-scale implementation.

The timeframe to implement an ASR project varies depending on the nature and scale of the project. A range of example projects illustrates typical timeframes for planning purposes.

- *Enhanced arroyo recharge (1 to 2 years).* Project involves excavation of shallow basins and construction of small check dams, to retain and spread storm flows for increased recharge. Recovery would be indirect from existing supply wells in the area. The project would benefit the aquifer and reduce depletions; however, credit for the recharged water might not be sought from the OSE under the Underground Storage and Recovery Regulations.

- *Recharge treated municipal or industrial wastewater with recharge through infiltration basins (4 to 6 years).* Project involves design and construction of treatment works and infiltration basins. Land must be acquired for the basins and pipelines constructed. A supply well network must be designed and constructed to recover the water. A permit for the project must be obtained from the OSE, including the pilot test phase.

- *Recharge treated Rio Grande water through groundwater injection/withdrawal wells (5 to 10 years).* This is the approach planned by the City of Albuquerque, which involves design and construction of a water treatment plant and pipelines to existing supply wells that will be converted to injection wells. A diversion from the Rio Grande is required using a check dam or subsurface infiltration gallery. A permit for the project must be obtained from the OSE for the ASR aspects of the project, as well as approval for the water appropriation. The City of Albuquerque is about midway through a 7 year schedule for this project (COA, 2002).

Thus, simple enhanced recharge projects could be implemented quickly. However, any large scale ASR project will require several years for the design, permitting, and construction efforts.

3.1.1 Physical and Hydrological Impacts

Effect on Water Demand

ASR will not affect water demand, except in a minor way, if demand is reduced because of the incrementally higher cost for this water under some scenarios (see Alternative 21, Urban Water Pricing).

Effect on Water Supply (surface and groundwater)

ASR may enable improved for management of water supplies within the MRG water planning region, allowing beneficial use of water sources that otherwise may be underutilized. Water sources that may be available in the region for potential ASR management include:

- San Juan-Chama Project water
- Seasonal surface water and storm water flow
- Water transferred from surface reservoirs to subsurface storage
- Treated municipal and/or industrial wastewater

ASR can provide a tool for improved management of existing water supplies, within the context of existing water rights, by storing water available during wet seasons or years, making this water available when needed. For example, the City of Albuquerque's planned ASR project provides for use of San Juan-Chama Project water, which will be injected during winter months, when demand is low, and pumped from the aquifer during summer months when demand is high. ASR can capture seasonal surface water flows, by increasing recharge of storm-water flows in arroyos. Certain ASR projects may reduce surface water flows, by capturing storm water or reducing wastewater return flows.

Because evaporative losses at Elephant Butte reservoir and other reservoirs are high, there could be potential water savings by lowering the lake level to reduce evaporative losses, making the evaporation savings available for other uses. The magnitude of evaporative losses that could be saved by changing surface reservoir storage is presented in the fact sheet for Alternative 45, Reservoir Management. ASR could also potentially be used to store excess Rio Grande flows and/or tributary flows, during times of flood conditions, when a spill is expected or occurring at Elephant Butte dam, and Rio Grande Compact credits and debits are not computed for the spill year. Additional information regarding the frequency and magnitude of Elephant Butte spills is provided in S.S. Papadopulos & Associates (2000).

Water Saved/Lost (consumption and depletions)

The effectiveness of ASR at sites around the U.S. and the world is well documented. ASR can provide water savings from improved conjunctive use management schemes, and ASR can save and store water that would otherwise be lost to evaporation or lost downstream when surface flows are under-utilized. ASR is effective at storing large volumes of water underground for subsequent use at costs that are much less than the equivalent storage in surface reservoirs, and with the added benefit that evaporative losses are nearly eliminated. Storm-water flood flows represent another potential water source for recharge of aquifers using ASR (Bouwer and Rice, 2001).

There may be legal limitations (i.e. Rio Grande Compact and water rights) to the use of water from ASR projects, as discussed in the legal fact sheets. The estimates provided in this section address only the physical availability of additional supplies. The amount of water saved depends on the type and scale of the ASR project:

- Small-scale enhanced recharge projects can potentially provide recharge on the order of 100 to 10,000 ac-ft/yr, a fraction of the annual flow measured in some of the MRG water planning region's larger arroyos (Thorn et. al., 1993). The enhanced recharge would add to the 10,000 to 30,000 ac-ft/yr recharge estimated under natural conditions from mountain front arroyos in the region [Anderholm, 2001]). These savings are based on the assumption that any water recharged results in additional water supply to the region, because normally, much of the flow in arroyos is lost to evaporation without reaching the Rio Grande or groundwater supplies (Hansen and Gorbach, 1997). Hence, any additional supply from this alternative represents a net gain. Additional information on the potential magnitude of recharge is provided in Section 3.2.3.

- Large scale ASR projects can potentially recharge on the order of a 100,000 ac-ft/yr (comparable to the difference in evaporative loss from Elephant Butte Reservoir of 50,000 ac-ft/yr evaporation at low lake levels to 250,000 ac-ft/yr evaporation at high lake levels [S.S. Papadopulos & Associates, 2000]).

- ASR is one method of that could potentially store a portion of the excess water available during Elephant Butte spill years, when Rio Grande Compact credits and debits are not computed. Discussion of the magnitude of spills is provided in Alternative 38, Surface Modeling.

Perhaps the greatest water savings that could be provided by ASR in the MRG water planning region would be to reduce Elephant Butte evaporation by maintaining consistently lower lake levels and store the water saved in subsurface aquifers. This type of large scale project would involve not only technical challenges, but would also have to overcome complex institutional issues such as recreational, agricultural, and environmental concerns, as well as legal issues such as Compact water delivery obligations.

Evaporation from Elephant Butte Reservoir amounts to approximately 20 percent of all water depletions in the Middle Rio Grande from Cochiti to Elephant Butte Reservoir (S.S. Papadopulos & Associates, 2000). Reducing storage in Elephant Butte Reservoir and transferring the evaporative savings to storage in the Albuquerque Basin could provide a significant quantity of water that is available for use. This approach would substantially reduce the water in storage in Elephant Butte Reservoir, and water would be withdrawn from the Rio Grande upstream for aquifer storage. S.S. Papadopulos & Associates (2000) shows that during the period of 1950 to 1980, storage in Elephant Butte was maintained at relatively low levels that kept evaporation losses in the range of approximately 30,000 to 130,000 ac-ft/yr. However, since 1980, storage has been maintained at much higher levels, with evaporation losses in the range of approximately 130,000 to 260,000 ac-ft/yr (S.S. Papadopulos & Associates, 2000). Annual evaporation losses are variable, but exceed 10 percent per year (see Alternative 45, Reservoir Management). Therefore, reducing surface reservoir storage by approximately 1,000,000 ac-ft and maintaining consistently lower average water levels in Elephant Butte, can save on the order of 100,000 ac-ft/yr. This is an average evaporative savings, which will be variable from year to year depending on surface water availability and seasonal reservoir management needs.

Many hurdles would have to be overcome to make this approach a reality. The infrastructure would have to be developed to draw Rio Grande water and recharge the water to the aquifer. A system of wells would also be needed to pump water to the river in order to deliver water downstream to meet Compact obligations during low-flow years, since less storage would be available for release from Elephant Butte. A drawback to this approach is that the rights to water saved from evaporation are not clearly defined at this time, and legislation addressing this issue may be needed. Using ASR in conjunction with transfers from Elephant Butte could be viewed favorably by the Interstate Stream Commission, because of the advantages obtained in managing instream flows to meet Compact obligations. Additional discussion of reservoir storage options is provided in Alternative 45, Reservoir Management.

Impacts to Water Quality (and mitigations)

Treatment requirements for stored water must meet drinking water standards at the point of use in the aquifer. This can be done in two ways:

- Water that will be injected directly to an aquifer through recharge wells, must be treated to meet drinking water standards before injection, or

- Water that will recharge through infiltration basins will be “polished” to achieve drinking water quality at the compliance point in the aquifer (Bouwer, 1996).

ASR provides an effective means of improving or “polishing” water quality with removal of contaminant as the water migrates through porous geologic media. Water quality improvements can be achieved by two mechanisms:

- Recharge using infiltration basins has been shown to reduce some trace constituents through soil aquifer treatment (SAT) as the water seeps from the basin to the aquifer (Nellor et al., 1984; Amy et. al., 1993; Sloss et al., 1996).

- Travel of injected water through an aquifer provides water quality improvement by mixing and dispersion within the native groundwater and chemical equilibration of the injected water with the native aquifer materials.

From a water quality standpoint, aquifer storage must comply with the requirements of the NMWQCC and the Underground Injection Control (UIC) Program. These regulatory requirements are administered by the New Mexico Environment Department (NMED) under the Water Quality Act (NMSA 1978, §74-6-1 et seq.), and the NMWQCC and UIC regulations (20.6.2.5000 NMAC). The regulations control liquid discharges to protect groundwater that has an existing concentration of 10,000 mg/L or less of total dissolved solids. If the water source contains contaminants that have a potential to impact groundwater, as determined by NMED, an approved groundwater discharge plan is required. The following summary presents general discharge plan requirements for ASR projects, subject to a final determination by NMED.

- Recharge to injection wells: Surface water or wastewater sources will require treatment to meet drinking water standards prior to discharge to the subsurface.

- Recharge of treated wastewater to infiltration basins: Municipal or industrial wastewater will require treatment prior to discharge to infiltration basins. Treatment to drinking water standards may be required, or treatment to a lesser standard may be permissible if SAT is demonstrated to provide sufficient treatment before the water reaches the aquifer.

- Recharge of surface water to infiltration basins: Treatment requirements for surface water diverted to infiltration basins will depend on the water quality and site-specific hydrogeologic setting where recharge will occur. This type of recharge may be considered by regulators to be similar to the recharge that occurs naturally in arroyos or seepage from irrigation canals.

The environmental implications of ASR projects depend largely on the quality of the proposed influent water. ASR projects using source water with relatively good quality, such as enhanced storm-water recharge, can be conducted without treatment of the recharged water (Bouwer et al., 1990). Projects involving reuse or recharge of wastewater effluent are receiving increasingly favorable public perception, because of the environmental benefits of recycling water for multiple uses. In this regard, ASR is quite attractive in that it offers the possibility that treated effluent undergo some degree of cleansing and blending with natural groundwater in the subsurface prior to reuse (Bouwer, 1991, 1992).

Assuming permitting issues for recharge of treated effluent can be resolved, ASR may potentially be an inexpensive and effective means of "polishing" water quality, using SAT, to remove trace constituents prior to consumption. Two major health effects studies in California have shown that such a potable water supply that contains an appreciable component of reclaimed water has no adverse human health effects (Nellor et al., 1984; Sloss et al., 1996). However, some public concerns may be raised about the prudence of blending treated wastewater with a limited supply of clean groundwater.

Even if the treated influent water meets all drinking water standards, there may still be concerns over the possible presence of pharmaceuticals and endocrine disrupting chemicals in the treated surface water or effluent and consideration of the need for reverse osmosis treatment to remove them (Sedlak, 1999). These concerns over unregulated trace constituents are probably most significant for influent sources from treated wastewater, Rio Grande water, or storm water from developed areas. However, in the MRG water planning region, the recent analyses of Rio Grande surface water and City of Albuquerque wastewater effluent has shown the concentration of nearly all measurable synthetic organic compounds to be below detection limits (Thompson and Chwirka, 2002). Recharge of storm water flow in arroyos in relatively undeveloped areas will pose little concern with regard to trace pharmaceuticals. Additional discussion of wastewater treatment is provided in Alternative 27, Reuse Treated Effluent.

Watershed/Geologic Impacts

ASR can offset water level declines and reduce land subsidence rates (Bouwer, 2002). Areas with significant drawdown will benefit from increased recharge. These areas with substantial water level declines are conducive to ASR, because the water table conditions will fully capture the recharge (Thorn et al., 1993).

The technical feasibility of ASR within the study area depends primarily on (1) locating a suitable water source and (2) identifying a hydrogeologically suitable recharge site. In particular, arroyos and stream channels containing thick sequences of coarse-grained alluvium are ideal candidates. The extensive area of water table declines underlying the eastern portion of Albuquerque provide a basin that will capture recharged groundwater. The City of Albuquerque is considering this area for its ASR project. Suitable ASR project areas are potentially available at sites throughout the MRG water planning region.

Assuming that a suitable water source is available, the technical feasibility of ASR depends largely on hydrogeologic conditions underlying the area of interest, and site-specific hydrogeologic studies will be required within a given sub-basin to identify the preferred sites. Pilot testing is required to meet OSE regulations and to provide information necessary for developing a full-scale system that ensures that the chosen design will work at the site. Pilot testing provides information regarding hydraulic capacities, water table responses, water travel times, and water quality changes that may occur in the vadose (unsaturated) zone.

3.1.2 Environmental Impacts

Impact to Ecosystems

ASR could impact flows in the Rio Grande and its tributaries, and specific projects should be evaluate these impacts. Using ASR to replace storage in surface reservoirs will impact the habitat associated with the reservoir.

Implications to Endangered Species

ASR projects should not have a direct impact on endangered species. However, depending on the source water and the timing of releases to and from storage, there is a potential for either positive or negative impacts to endangered species in the Rio Grande. Reduced flows in the Rio Grande could potentially affect endangered species and should be managed to avoid adverse affects. Endangered species could potentially benefit from an ASR project to transfer Elephant Butte evaporative savings to aquifer storage, by including an option to pump water to the river during low flow periods.

3.2 Financial Feasibility

3.2.1 Initial Cost to Implement

The cost to implement an ASR project will depend on many site-specific factors, including site hydrogeology and the water quality of the proposed influent. Infiltration basins are generally the least expensive option, followed by recharge trenches and vadose zone wells, with groundwater recharge wells being the most costly, although costs for groundwater recharge wells are reduced substantially when existing water supply wells are converted to ASR wells (Pyne, 1995).

Costs to implement ASR at a given location may include expenditures associated with:

- Pilot testing
- Land acquisition
- Influent water pretreatment
- Permitting
- Design and construction

Permitting costs include both OSE and NMED permit requirements. OSE permits for ASR projects include requirements for pilot testing of the proposed technology at the site. While this is a cost factor for consideration, the information gained from pilot testing can result in much larger savings during implementation of full-scale ASR. OSE permitting for ASR projects is only allowable under New Mexico law, for government entities that meet certain financial capability requirements described in 19.25.8 NMAC. It is assumed for the purposes of this analysis of options, that local government entities within the MRG water planning region will be able to meet the financial capability requirements. Costs to obtain NMED permits for recharge of treated waste water effluent or surface water should also consider long-term permit compliance, including monitoring and permit renewals.

Table 46-1 outlines costs for three active projects in Arizona. These costs can be used to approximate design and construction costs for a system of infiltration basins.

Table 46-1. Example Infiltration Basin Costs

Project Name	No. of Basins	Total Basin Acreage	Infiltration Rate (ac-ft/yr)	Approximate Project Costs [a] ($)		
				Design	Construction	O&M
GRUSP [b]	6	211	100,000	NA	NA	250,000/yr
CAVSARP [c]	9	290	100,000	1.3 million	8.0 million	NA
Sweetwater [c]	4	14	14,000	0.5 million	1.5 million	NA

[a] Does not include delivery pipeline, recovery wells, or monitoring network.
[b] Granite Reef Underground Storage Project (Lluria, 1999;Bouwer, 2002)
[c] Central Avra Valley Storage and Recovery Project (CAVSARP) and Sweetwater Project information from Marie Light (Tucson Water), personal communication, 1999.

ac-ft/yr = Acre-feet per year
O&M = Operation and maintenance
NA = Information not available

The capital costs for design and construction for two infiltration basin ASR projects have the following costs:

- Central Avra Valley Storage and Recovery Project: $9.3 million for 100,000 ac-ft/yr project or infrastructure cost of $94 per ac-ft/yr

- Sweetwater Project: $2 million for 14,000 ac-ft/yr project or infrastructure cost of $143 per ac-ft/yr

These typical costs for actual ASR projects are on the order of $100 to $150 per acre-foot of recharge water. Cost details for ASR scenarios that may be applied in the MRG water planning region are discussed below.

3.2.2 Potential Funding Source

- New Mexico Legislative appropriation
- New Mexico Finance Authority loan
- NMED Construction Programs Bureau loan
- U.S. Department of Agriculture Rural Utilities Service
- Local financing (revenue bonds)

3.2.3 Ongoing Cost for Operation and Maintenance

Operation and maintenance (O&M) costs for the Granite Reef Underground Storage Project infiltration basins in Arizona are $250,000 per year for 100,000 ac-ft/yr recharged or $2.50 per ac-ft/yr. Additional O&M cost details are provided below.

Cost Evaluation Scenarios

To provide a preliminary basis for determining the cost feasibility for ASR projects in the MRG water planning region, a variety of cost evaluation scenarios were established for a range of possible projects that may be considered. The hypothetical projects include small- scale and large-scale projects that may be used to augment water supplies and increase water management options. These cost evaluation scenarios are intended to provide a preliminary examination of the expected costs for various ASR projects. However, the cost evaluation completed for this analysis does not represent an analysis of actual project plans and is not intended as a complete feasibility analysis.

Detailed evaluations of ASR projects have been completed by the City of Albuquerque. The projects evaluated include:

- Treating Rio Grande water to drinking water standards with injection and recovery of the water using ASR wells. This project is currently being implemented by the City of Albuquerque.

- Treating municipal waste water for ASR. This project was analyzed in 1995, but has not been pursued.

Because these projects have been evaluated in detail, they are not included in the cost evaluation scenarios presented here. Three hypothetical ASR project scenarios are described below that are representative of other projects that may be feasible and warrant more detailed consideration. Table 46-2 summarizes preliminary project cost estimates.

Comment: Table 46-2 Preliminary Cost Projection, Cost Evaluation Scenarios for Aquifer Storage and Recovery Projects, Mid-Region Council of Governments

Enhanced Arroyo Recharge

The cost evaluation scenario for enhanced arroyo recharge considers capture of storm water along one or more major arroyos in the MRG water planning region. Infiltration basins would be constructed adjacent to the arroyo(s) and small diversion structures would be used to divert storm flows into the basin. Bouwer et al. (1990) indicates that hundreds of successful enhanced recharge projects are in use in California. The project would provide enhanced aquifer recharge to improve the production and longevity of existing supply wells, but new supply wells are not assumed to be added as a component of the project. The project would benefit the aquifer and reduce groundwater depletions, but water rights credits would not be sought through OSE permitting of an ASR system. An OSE diversion permit would be required to capture the storm water. The project could be implemented at many locations in the region, but mountain front arroyos with the largest and most frequent flows may be the best candidates for an enhanced arroyo recharge project.

The enhanced arroyo recharge scenario considers the following project components:

- *Infiltration basin construction:* An infiltration basin that covers 4 acres would be excavated to a depth of 15 feet, providing a maximum storage capacity of approximately 50 ac-ft. In addition, a 0.5 acre sediment catch basin would be excavated to provide retention time to collect a majority of the suspended sediment to prevent clogging and reduced infiltration capacity in the main basin. Construction would involve primarily earthwork with only minor additional facilities such as site fencing and an access road.

- *Diversion structure:* A diversion structure would be constructed across the arroyo to route storm water into the sedimentation basin and infiltration basin. The diversion structure would be sized to capture most storm water, except providing a spillway for extreme flood events. A flow return from the infiltration basin to the arroyo would also be provided to prevent the basin from overtopping in flood events.

- *Land purchase:* A 10 acre tract of land would be purchased for a cost assumed to be $5,000 per acre. (In many cases, public entities may already own suitable property to eliminate the land purchase cost.)

- *Design and permitting:* The engineering design for the infiltration basin is assumed to be 10 percent of construction cost and permitting is assumed to be 5 percent of construction cost.

- *Operation and maintenance:* O&M would consist of annual cleaning of accumulated sediments by scraping a thin soil layer from the infiltration basin and removal of more extensive deposits from the sedimentation basin. Basin cleaning would be accomplished during a dry portion of the year. It is assumed that off-site uses of the sediment for fill purposes are available.

Enhanced arroyo recharge performance. Enhanced arroyo recharge could potentially provide significantly higher recharge to the underlying aquifer than experienced under natural infiltration through arroyo bottoms. Previous studies of recharge from arroyos shows that short-duration storm events contribute little recharge, but the impoundment of water in deeper basins can recharge significant volumes (Hansen and Gorbach, 1997). Estimates of mountain front recharge under existing conditions on the east side of the Middle Rio Grande Basin range from 11,000 to 38,000 ac-ft/yr (Anderholm, 2001). However, this is only a small fraction of the overall storm water flows, with recharge rates being quite low due to the losses to evaporation and plant transpiration. By diverting the flow into a relatively small and deep infiltration basin, with no vegetation, the majority of storm water diverted to the basin will become deep infiltration and continue downward migration to the aquifer.

Most arroyos in the MRG water planning region are not gauged, leaving uncertainty as to the amount of storm water potentially available for enhanced recharge. Of the three largest arroyos in the Albuquerque Basin, only Tijeras Arroyo is gauged, while Abo Arroyo and Las Huertas Creek are not (Thorn et al., 1993). No arroyo draining the west side of the Albuquerque Basin is gauged (Thorn et al., 1993). The average annual flow for Tijeras Arroyo at the gauging station approximately 1.5 miles upstream of the Rio Grande is 432 ac-ft/yr (Thorn et al., 1993). The Abo Arroyo flow was gauged for a period of one year from October 1996 to September 1997, when a total flow of 12,400 ac-ft/yr was measured (Anderholm, 2001). Additional arroyo flow data are available for the Albuquerque metropolitan area, where storm water from many small arroyos is captured by two main storm conveyance channels. The North Floodway Channel carries an average annual flow of 5,900 ac-ft/yr and the South Diversion Channel carries an average annual flow of 520 ac-ft/yr (Thorn et al., 1993).

Enhanced arroyo recharge would only be able to capture a portion of the total storm flow, with the efficiency affected by the location and design of the facility. Also, a small portion of the flow already contributes to recharge under natural conditions. Where suitable soil conditions exist, infiltration from the basins may be on the order of 1 to 10 feet per day (Bouwer et al., 1990; Hansen and Gorbach, 1997). Evaporative losses from the free water surface will occur when water is present, and evaporative losses will also occur from the soil during dry periods. If a possible goal of 50 percent of the storm flow in an arroyo is captured and converted to recharge, enhanced arroyo recharge projects may provide recharge to the aquifer on the order of a few hundred to a few thousand ac-ft/yr, depending on the location and scale of a selected project.

Treated Municipal Wastewater Recharged via Infiltration Basins

The cost evaluation scenario for recharging treated municipal wastewater using infiltration basins considers the addition of tertiary treatment capabilities to an existing wastewater treatment plant, construction of infiltration basins, and installation of extraction wells to recover the recharged water. A permit for the project would be obtained from the OSE to protect the rights of the project owner to recover the recharged water. Treatment would provide for water quality that meets primary drinking water standards for the influent to the infiltration basins.

Under this scenario, SAT would provide for polishing of the water quality for secondary parameters, so that water quality in the aquifer and water derived from extraction wells is in compliance with all drinking water standards. Because existing wastewater treatment plants tend to be located in areas with relatively shallow water tables, where recharge basins will not perform well, the treated effluent would be pumped to a suitable location in an upland area, where the infiltration basins and extraction well field would be constructed.

The cost evaluation scenario for treated municipal wastewater recharged via infiltration basins considers the following project components:

- *Tertiary wastewater treatment additions:* Tertiary wastewater treatment would be added to an existing wastewater treatment plant with an average flow rate of 10 million gallons per day (mgd). However, because of obligations to return water to the Rio Grande system, it is assumed that only 5 mgd is available for ASR. Wastewater treatment standards for effluent reuse are described further in Alternative 27, Reuse Treated Effluent.

- *Pipeline:* A conveyance pipeline would be constructed to carry treated wastewater from the treatment plant to the infiltration basins. The pipeline is assumed to be 5 miles long and constructed of 18-inch diameter pipe with one pump station.

- *Infiltration basin construction:* A series of infiltration basins would be constructed that cover a total of 15 acres, subdivided by interbasin berms to provide operating flexibility. On-site facilities would consist of flow distribution piping, flow control systems, access roads, fencing, and a small operations building.

- *Extraction wells:* A well field of assumed to consist of 6 supply wells would be installed to recover the recharged groundwater. The wells are assumed to be installed to a depth of 1,000 feet, with each capable of producing flows of up to 1,000 gallons per minute (gpm).

- *Land purchase:* A 40 acre tract of land for the treatment plant would be purchased for the plant site at a cost assumed to be $10,000 per acre. It is assumed that existing municipal easements are available to allow installation of extraction wells and water lines. (In many cases, public entities may already own suitable property to eliminate the land purchase cost.)

- *Design and permitting:* The engineering design for the infiltration basin is assumed to be 10 percent of construction cost and permitting is assumed to be 5 percent of construction cost.

- *Operation and maintenance:* O&M would consist of cyclic flooding and drying of the basins, with periodic restoration of infiltration capacity by tilling or scraping a thin soil layer from the basin. O&M would also include operation of the tertiary wastewater treatment system, effluent pumping, pipeline maintenance, and groundwater pumping.

Treated municipal wastewater recharge performance. ASR with treated wastewater potentially provides a method to use wastewater for future groundwater supply, following additional polishing of the water quality through SAT. This scenario describes is a mid-sized project with a total flow to the infiltration basins of 5,600 ac-ft/yr. Evaporative losses are expected to be in the range of 50 to 100 ac-ft/yr or 1 to 2 percent of total flow. For a site in the Middle Rio Grande Basin, where potable groundwater is present in the aquifer, the entire recharge volume is expected to be recoverable from the aquifer (Pyne, 1995). The extraction wells may pump a total volume even greater than the recharge, producing a mix of native and recharged water under a combination of water rights for aquifer pumping and recharge. Treated wastewater ASR projects of various sizes may potentially be feasible, depending on the wastewater flow rates available in a give community and the community's balance of groundwater rights and return flow requirements to surface water.

Aquifer Storage for Elephant Butte Evaporation Savings and Rio Grande Flood Waters

This cost evaluation scenario to use aquifer storage for Elephant Butte evaporation savings from reduced surface reservoir storage and for capture of Rio Grande flood waters, envisions a significant change in water management practices for the MRG water planning region. Additional discussion of Elephant Butte reservoir storage options is provided in Alternative 45, Reservoir Management, and a discussion of Compact delivery requirements is provided in S.S. Papadopulos & Associates (2000).

The scenario involves lowering the average Elephant Butte lake level to reduce average reservoir storage by approximately 1,000,000 ac-ft, which would provide an average evaporative savings of approximately 100,000 ac-ft/yr. This may prove feasible from the standpoint of Compact compliance, since the lake was at this lower average lake level for a 30 year period from about 1950 to 1980 (S.S. Papadopulos & Associates, 2000). The estimated evaporation savings would be diverted from the Rio Grande far upstream of the reservoir, and recharged in the Albuquerque Basin aquifer. This scenario represents the probable upper limit of evaporative savings that could be achieved, with ASR providing storage of the water saved. Alternative 45 (Reservoir Management) also presents a smaller scale ASR project, with reductions in Elephant Butte reservoir storage of 50,000 to 100,000 ac-ft to provide evaporative loss savings of approximately 5,000 to 13,000 ac-ft/yr.

In addition, under this scenario some supplemental water might be captured from excess flood flows in the Rio Grande during years when spills are forecast at Elephant Butte dam, and no Compact credit or debit is computed. These spills have occurred during just six years since 1940 (S.S. Papadopulos & Associates, 2000); therefore, these additional gains would occur only rarely, as a secondary component of the aquifer storage project.

To collect 100,000 ac-ft/yr of Rio Grande water, this scenario assumes that this could be achieved using infiltration galleries parallel to the river (Hansen and Gorbach, 1997). However, other approaches for diversion may prove more advantageous, and the feasibility of infiltration galleries would depend on hydrologic conditions in the locations selected for the infiltration galleries. In this scenario, infiltration galleries were selected in order to collect water that is free of suspended sediment and suitable for recharge (Hansen and Gorbach, 1997). Water withdrawals would be continuous, not just during flood flows. During low flow periods of drought, withdrawals from the infiltration galleries might need to cease to minimize river depletions.

The water would be recharged through a series of infiltration basins at various locations selected for their suitable soils and geologic conditions and to distribute the recharge within the basin. The water is assumed to be recovered by existing supply wells, so no new recovery wells are included in the scenario.

In addition, new production wells would be needed to deliver water from aquifer storage to the Rio Grande during times of low flow, to meet Compact obligations and make up for the reduced surface reservoir storage downstream. During the Compact history, debits have exceeded 70,000 ac-ft/yr only five times (S.S. Papadopulos & Associates, 2000). This scenario assumes a capacity to provide a flow rate of 50,000 ac-ft/yr as a reasonable expectation of the delivery rate to the Rio Grande, with debits occurring in years with higher delivery requirements. Management of the Rio Grande's surface reservoirs would be altered (see Alternative 45, Reservoir Management) and combined deliveries of surface water and groundwater would need to be sufficient to meet long-term Compact delivery obligations. Additional evaporative losses would occur during downstream delivery of water pumped from aquifer storage.

The cost evaluation scenario for transfer of Elephant Butte evaporation savings and Rio Grande flood water to aquifer storage considers the following project components:

- *Infiltration galleries:* A series of infiltration galleries would be constructed to collect Rio Grande water from shallow alluvium near the river. Based on a flow rate of 21 cubic feet per second (cfs) per mile (Hansen and Gorbach, 1997) a minimum of 7 miles of galleries would be needed to collect 100,000 ac-ft/yr. Costs are $500,000 per mile (Hansen and Gorbach, 1997).

- *Pipelines:* Conveyance pipelines would be constructed to carry water to the infiltration basins. Five pipelines are assumed to be constructed to the various basins, with each pipeline averaging 10 miles in length and constructed of 36-inch diameter pipe with two pump stations. Each pipeline is assumed to be capable of providing a flow of 20 million gallons per day (gpd) or 22,000 ac-ft/yr.

- *Infiltration basin construction:* Five infiltration basins would be constructed so that each would include 50 acres of basin area, subdivided by interbasin berms to provide operating flexibility. On-site facilities would consist of flow distribution piping, flow control systems, access roads, fencing, and a small operations building.

- *Extraction wells:* A series of 40 supply wells would be installed to produce water for discharge to the Rio Grande during times of low flow. The wells would be located in the inner valley in close proximity to the river. The wells are assumed to be installed to a depth of 700 feet, with each capable of producing flows of 1,000 gpm. Discharge to the river would be either by direct outfalls or existing irrigation drains.

- *Land purchase:* Five 100 acre tracts of land would be purchased for the infiltration basins at an assumed average cost of $10,000 per acre, with some basins constructed within existing public property. It is assumed that existing municipal easements are available to allow installation of extraction wells and water lines.

- *Design and permitting:* The engineering design for the infiltration basin is assumed to be 10 percent of construction cost and permitting is assumed to be 5 percent of construction cost.

- *Operation and maintenance:* O&M would consist of the following:

  - Periodic maintenance of the infiltration galleries.
  - Pipeline pumping from the infiltration galleries via a pump station at the source and second pump station along the pipeline. Periodic pipeline maintenance would be required.
  - Cyclic flooding and drying of the basins, with periodic restoration of infiltration capacity by tilling or scraping a thin soil layer from the basin.
  - Periodic groundwater pumping and discharge to the Rio Grande during low-flow years. Periodic well maintenance would be required.

A 40-year operating life is assumed in the cost evaluation scenario for O&M of the system. O&M costs include: electric power for all pumping components, labor, parts, equipment, and other expenses.

In addition to the costs listed above, there would also be costs to address institutional, legal, economic, and social issues that would result from a large-scale water management change of this type.

Performance of Aquifer Storage for Elephant Butte Evaporation Savings and Rio Grande Flood Waters

Transferring evaporation savings from reduced surface reservoir storage to groundwater storage could potentially provide, perhaps, the greatest quantity of additional water supply of any alternative that might be implemented in the MRG water planning region. Eliminating evaporative losses of 100,000 ac-ft/yr represents an increase in available water supply of 25 percent, over the average allocation to the region under Compact delivery requirements of approximately 400,000 ac-ft/yr (S.S. Papadopulos & Associates, 2000). In order to implement this alternative, significant legal and Compact issues would need to be addressed that establish the region's right to use evaporative savings for actual wet-water uses. Additionally, concern's regarding recreational use of the Elephant Butte supply and economic impacts to the area surrounding the reservoir would need to be addressed. The project described in this scenario would be a very large scale project, but the transfer of Elephant Butte storage to groundwater storage could also be done on a smaller scale, or could be implemented in various stages.

An important aspect of aquifer storage would be the added ability for water supply managers to use this water during drought years, when surface supplies are depleted. The scenario envisions an ability to pump stored groundwater to the Rio Grande to sustain flows during drought. The proposed well field of 40 wells is assumed to provide a flow to the Rio Grande of approximately 80 cubic feet per second (cfs). This could potentially benefit the silvery minnow and other endangered species, by providing this water from evaporative savings, rather than using other stored water supplies. Storage could be released from the aquifer at anytime, whereas supporting the endangered species with surface supplies during drought increases demand on already strained supplies.

Cost Summary

The cost evaluation scenarios are summarized in Table 46-2. This preliminary evaluation of the costs for ASR projects provides an initial estimate of the expected cost range. The cost estimates are preliminary and intended for planning purposes only; therefore, the cost estimates for ASR and each alternative considered are based on 2003 costs for comparison, and adjustments for present worth have not been considered.

The two lowest cost scenarios are for enhanced arroyo recharge and transfer Elephant Butte evaporation savings and flood waters to aquifer storage. These cost scenarios would provide water storage, but do not include pumping of the water to put the water to use. For aquifer storage, these scenarios have costs in the range of \$0.24 to \$0.31 per 1000-gallons (\$78 to \$101 per ac-ft). The scenario for treated municipal wastewater recharged via infiltration basins includes extraction wells that deliver produced water for use. The cost projection for this scenario is \$2.38 per 1000-gallons (\$775 per ac-ft). The major cost under this scenario is the cost of tertiary wastewater treatment, making this a relatively expensive option.

The cost estimates are intended only for the purpose of a preliminary evaluation of the ASR option as compared to other water supply options. Many ASR projects are potentially feasible, from small-scale projects that are relatively easy to finance, to large-scale projects that will probably require a combination of funding sources. Much additional study is needed to develop ASR plans more fully, before a complete feasibility analysis can be made for specific projects.

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