5A.12 Aquifer Storage and Recovery

5A.12.1 Description of Option

Aquifer storage and recovery (ASR) is a process wherein an aquifer is used as a groundwater reservoir for water storage and recovery. Surface water is conveyed, via infiltration basins or injection wells, into subsurface space in an aquifer for storage. The water is pumped back out when needed during periods of drought. The option proposed here is to use the Seymour Aquifer in the Brazos G Region as part of an ASR system that would increase water storage and supply. Analysis of existing records of the Seymour Aquifer in Jones County indicates a large, underground "trough" of unsaturated zone which could potentially offer ample storage capacity to augment surface storage at Fort Phantom Hill Reservoir. This ASR project calls for using a pipeline to convey raw water from Fort Phantom Hill Reservoir during brief periods of wet weather into this trough via infiltration basins in the surface of the aquifer. During brief times of abundance, the raw water would be collected in the basins and allowed to percolate down to recharge the aquifer. During periods of drought, wells would pump the stored water back into the pipeline for return delivery to Fort Phantom Hill Reservoir. Benefits of the option for the Brazos G Region include drought proofing, increasing the water storage and supply, and reducing water lost through evaporation or over the spillway at Fort Phantom Hill Reservoir. The engineering operation is straightforward, and projected environmental impacts are low.

The Seymour Aquifer is a series of disconnected alluvial outcrops comprising unconsolidated clays, silts, sands, and gravels that were deposited in the late Pleistocene era.[1,2] The aquifer was once a continuous geological unit, but it has been dissected into isolated outcrops by recent erosional activity. In the Brazos G Region, the aquifer covers approximately 1,641 square miles (Figure 5A.12-1). The aquifer's two largest water-bearing areas within the Brazos G Region cover about 130 square miles in Jones County and about 624 square miles in Knox and Haskell Counties. The primary source of hydrologic recharge is direct precipitation onto the aquifer surface. No continuous confining layer exists above the water table. Groundwater discharges from the alluvium into the streams dissecting the individual outcrops.

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[1] Ashworth, J.B. and J. Hopkins, "Aquifers of Texas," Texas Water Development Board Report 345, 69 p., 1995.

[2] Price, Robert D., "Occurrence, Quality, and Availability of Ground Water in Jones County, Texas" Texas Water Development Board Report 215, 206 p., 1978.

Currently, groundwater availability from the Seymour Aquifer for all categories is about 7,950 acft/yr in Jones County.

The Seymour Aquifer has characteristics similar to a traditional surface reservoir. It has a definable length, width, and depth, and storage volume exists in the pore spaces between individual grains of sand and gravel. The aquifer's groundwater level is analogous to a surface reservoir's pool level; it fluctuates according to natural discharge into streams and withdrawals from pumping, and with natural recharge through direct precipitation. The depth to the groundwater was investigated as an indicator of potential storage capacity. Areas with a greater depth to water also have a greater depth of unsaturated subsurface that may be viewed as available storage space. An examination of boring logs and of records of wells completed in the aquifer in Jones County indicate that depth to water varies, with a maximum depth of more than 60 feet. Figure 5A.12-2 contains an isopach map with contours of equal depth to water. Based on data from the Texas Water Development Board (TWDB) report,[2] a cross-section of the aquifer was generated. Figure 5A.12-3 depicts a cross-section through this area with elevations of the land surface, unsaturated zone above the water table, groundwater surface, and base of the Seymour Aquifer.

The cross-section reveals a trough of unsaturated zone between two ridges of mounded groundwater. Based on this information, a potential location for the Seymour ASR project was identified (Figure 5A.12-2). As stated previously, this project would enhance recharge by using the available space in the trough by filling it with surface water that would be pumped to infiltration basins on the surface of the aquifer. Once the water level in this subsurface trough were raised to a sufficient level, both the preexisting groundwater storage and the enhanced recharge storage could be drawn upon when needed.

The infrastructure needed to implement this project includes a pump station at the source of raw water, a conveyance pipeline, infiltration basins, and recovery wells. The source of raw water proposed is water that periodically flows unused over the dam spillway at Fort Phantom Hill Reservoir. In addition, to reduce evaporative losses at Fort Phantom Hill Reservoir, it is proposed that the top foot of reservoir storage also be used as a raw water source. Other surface water sources could be used to provide additional supply to enhance aquifer recharge. These sources include Hubbard Creek Reservoir, O.H. Ivie Reservoir, Possum Kingdom Reservoir

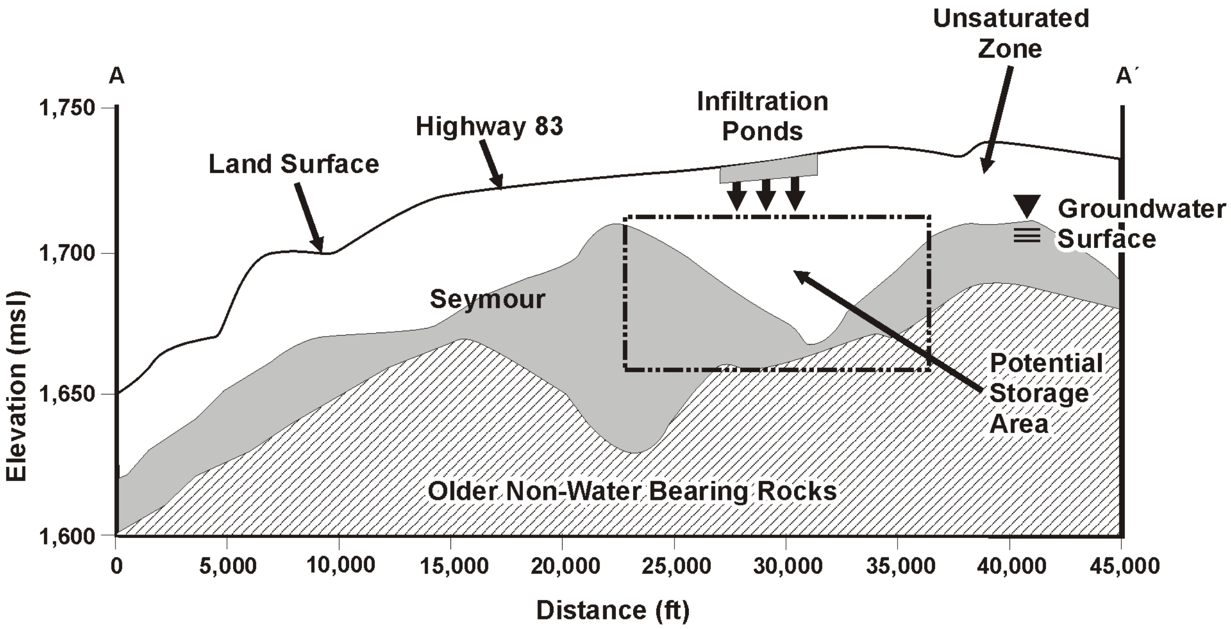

Figure 5A.12-3. Seymour Aquifer Cross-section

through the Oryx/Kerr-McGee pipeline, or diversion of the Clear Fork Brazos River at the Abilene Pump Station. To use water from Fort Phantom Hill, a two-way, 11-mile pipeline would be built to convey the excess water from the reservoir into infiltration basins for percolation into the aquifer's subsurface storage space.

Figure 5A.12-4 demonstrates the hydrologic cycles involved in this ASR project. The top chart trace represents the storage volume of Fort Phantom Hill Reservoir from 1950 to 1960, during which time the drought of record occurred in the region. The bottom chart trace is an idealized representation of aquifer storage volume if an ASR system had been in place during this time period. The chart indicates that during periods when water is being passed over the dam spillway, enhanced recharge to the aquifer could occur, increasing the amount of water in aquifer storage. When the reservoir storage volume dropped below a pre-defined "trigger level," water could be recovered from aquifer storage to complement surface water supplies, and keep the reservoir level from falling below storage elevations that would necessitate emergency drought contingencies. Note that periods of aquifer recharge are much briefer than periods of aquifer storage recovery. Aquifer recharge would occur at high rates during intense episodic precipitation events. Aquifer storage recovery would occur at a much more measured pace to meet daily demands during times of drought.

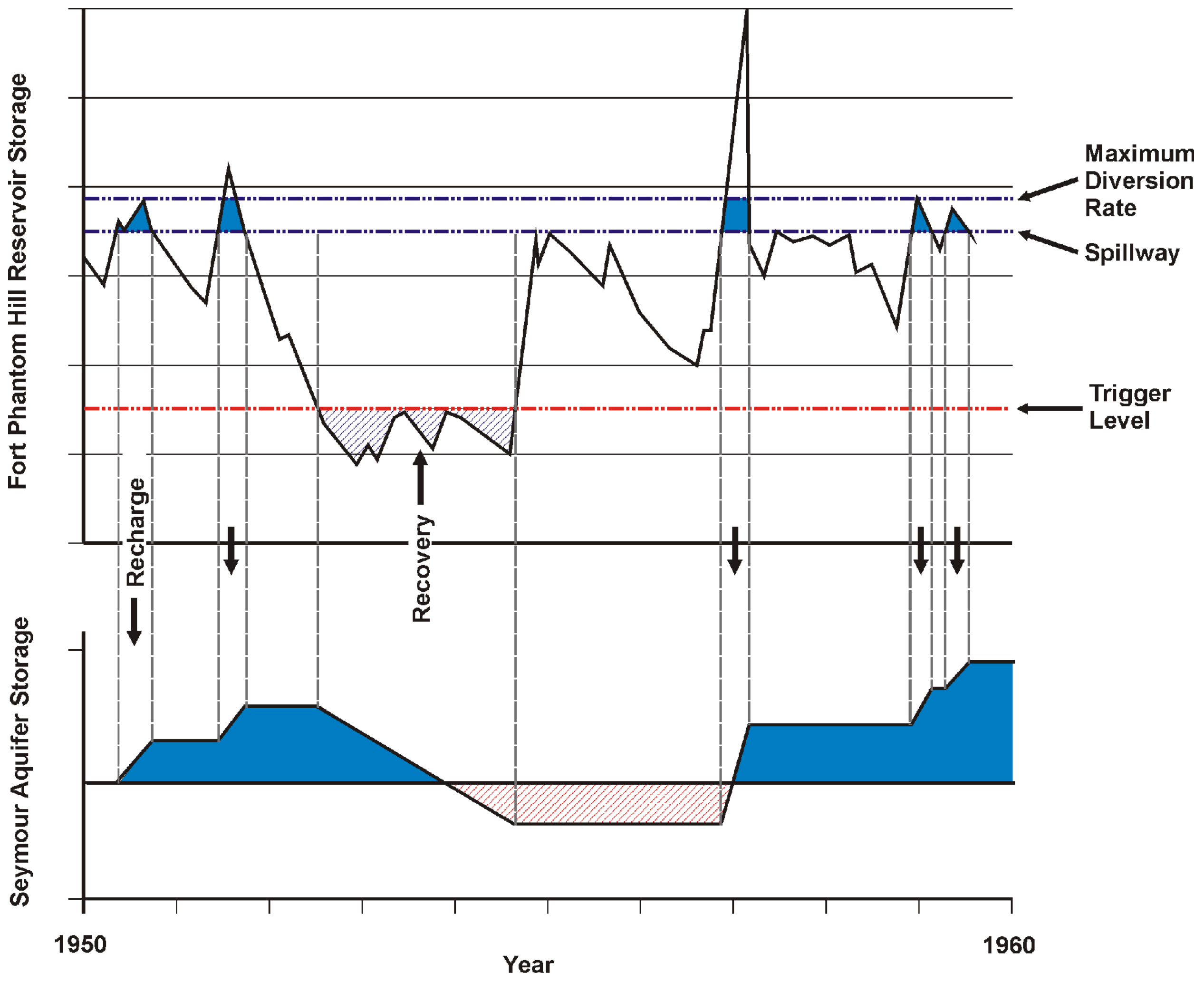

Figure 5A.12-4. Aquifer Storage and Recovery Hydrologic Cycles

For several reasons, infiltration ponds, as opposed to wells, are the proposed means of delivery of water to the aquifer. Unlike water injected into wells, water delivered to infiltration ponds is not required to be treated to drinking-water standards prior to injection. Using ponds would therefore avoid the necessity of treating all of the raw water. Current water treatment plant capacity is not adequate to meet water user demands and treat extra water for delivery to the ASR system. Using wells, therefore, would require construction of treatment facilities of sufficient capacity to treat the high diversion rate from the reservoir during floods when water needs to be conveyed quickly to the aquifer. Ponds require less maintenance and operation than wells, and microbes occurring naturally in the soil treat the water to some extent as it percolates down.

A well field would be installed to pump groundwater back through the pipeline for use at Fort Phantom Hill Reservoir to meet drought demands when surface water sources become depleted.

The Seymour Aquifer can provide abundant storage for water that would normally be passed over the spillway, and which could be recovered for use when needed. The aquifer has a high recharge capacity, and using it as part of a straightforward, low-impact ASR project will increase water storage and supply for the Jones County and the Abilene area, thereby helping to drought-proof the area.

5A.12.2 Available Yield

As stated earlier, the Seymour Aquifer has characteristics similar to a traditional surface reservoir. Therefore, the aquifer may be modeled as a reservoir for the purposes of examining the water budget and for determining available firm yield. To calculate the aquifer's available firm yield, a Fortran computer program named RESSIM was used to model the aquifer system. RESSIM simulates reservoir operations on a monthly basis to determine the firm yield over a given historical period. For this analysis, precipitation data from 1950 to 1999 was used. This period includes the drought of record that occurred during the 1950s. To account for differences between aquifer and reservoir storage, input parameters for the RESSIM files were adjusted. A flow chart (Figure 5A.12-5) depicts the differences in input. The adjustments are explained below.

The EVAP input file simulates evaporative losses from a surface reservoir. Positive values represent such losses. However, negative values can be assigned to the file to represent direct rainfall onto a surface reservoir. As previously mentioned, direct precipitation onto the Seymour Aquifer is its primary source of recharge. For simulation of the ASR system, the EVAP file was used to represent this natural recharge to the aquifer. TWDB Report 215 estimated water reaching the aquifer as natural recharge to be 6.23 percent of precipitation measured at Abilene. Therefore, 6.23 percent of monthly rainfall values from 1950 to 1999 were assigned as recharge, and these were entered as negative.

The INFLOW file represents monthly streamflow into a surface reservoir. To simulate the ASR system, the INFLOW file was used to represent enhanced recharge to the aquifer through the infiltration ponds. Monthly available quantities of enhanced recharge were assigned

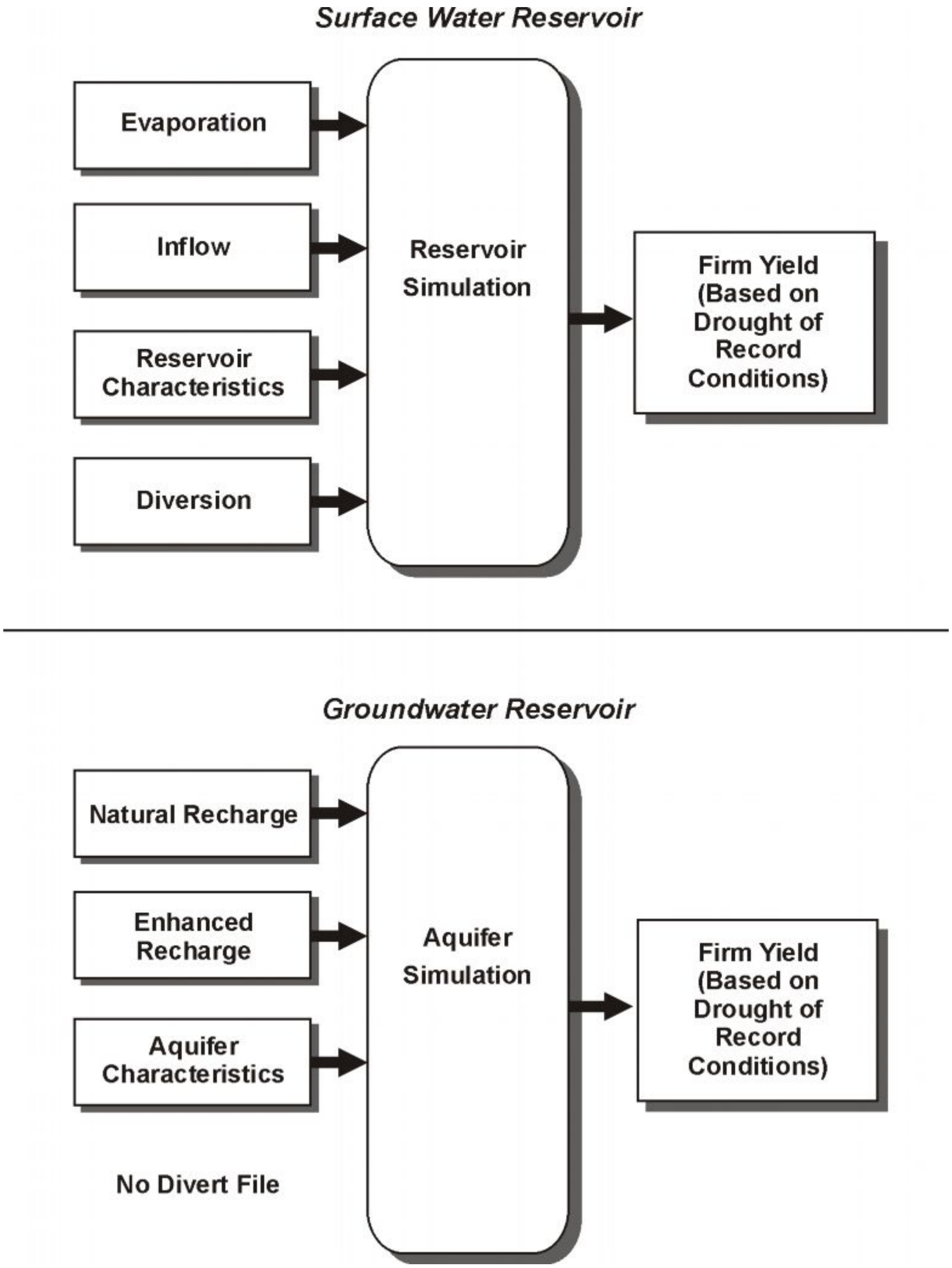

Figure 5A.12-5. RESSIM Model

based on the operational data for Fort Phantom Hill Reservoir from 1950 to 1999. It was determined that pump and pipeline facilities could economically deliver up to 200 acft of raw water per day during episodic periods of wet weather. Measurements of percolation rates in

Jones County range from 0.2 to 20 inches per hour, depending on localized soil conditions. A conservative percolation rate of 0.5 inches per hour (or 1 foot per day) was estimated for enhanced recharge calculations. Given a 200 acft per day water source and a 1-foot per day percolation rate, 200 acres of infiltration ponds would be required. The resulting hydraulic loading rate would to be a total of 200 acft/day. During months in which spills were recorded, it was estimated that a maximum of 200 acft/day, or 6,000 acft/month, of the spill volume could be conveyed to the infiltration ponds. For months in which spills did not occur but in which the operational elevation lay within the top foot of reservoir storage, the volume of this top foot was also represented as being conveyed to the infiltration ponds. These monthly values were then reduced by 10 percent to account for evaporative losses during the operation. If, in a given month, there were neither spills nor storage in the top foot of elevation, no enhanced recharge was assigned to the INFLOW file.

The RESVR file defines the physical dimensions of the surface reservoir in terms of an elevation-area-capacity (EAC) table. The inputs for this file were adjusted in the following ways to represent the aquifer storage system: 1) The aquifer was conceptualized as a reservoir of uniform surface area as delineated in the project area map in Figure 5A.12-2. Thus, for the EAC table, the area value remains constant. 2) The dead storage elevation for the aquifer was input as zero. In reservoir simulations, the value for "dead storage" elevation refers to the pool elevation at which storage is unavailable for practical use (i.e., pool elevation below the outlet elevation). 3) The conservation storage was defined as the storage volume within the saturated thickness of the aquifer. Saturated thickness was limited to a maximum of 20 feet below the ground surface elevation to avoid potential for saturating the root zone of local vegetation. 4) A porosity value was necessary to determine capacity for the EAC table since only pore space within the aquifer's calculated volume is actually available for groundwater storage. TWDB[2] estimated storage capacity of the Seymour Aquifer as 14 percent. Thus, capacity volumes were calculated by multiplying surface area (constant) by groundwater elevation (based on saturated thickness in the groundwater reservoir) by this storage capacity factor.

The DIVERT file represents diversions from the surface water reservoir. Irrigation well pumpage could have been represented using this file, but it was set at zero because data on pumpage in the area of the proposed project was unavailable.

Little information was available on minor inflows and outflows, such as groundwater inflow to the aquifer during floods and groundwater discharge to the streams. For purposes of this analysis, these flows were set approximately equal to each other. Further study is needed to verify whether these flows are indeed equivalent.

The RESSIM model was run using the inputs detailed above. The available firm yield for the natural aquifer in the area modeled with no enhanced recharge is estimated to be about 1,900 acft/yr (this yield is part of the estimated countywide Seymour reliable supply of 7,950 acft). The available firm yield for the aquifer with full ASR utilization was calculated to be about 11,100 acft/yr. This is an increase in firm yield of 9,200 acft/yr. This proposal, however, does not call for the project to be operated on an annual firm yield basis. Rather, it should be operated on an expanded cycle reflecting long-term patterns of precipitation and drought. Water would be moved rapidly to aquifer storage during relatively brief floods and later withdrawn at a considerably slower rate during times of extended drought.

In addition to the primary RESSIM analysis previously described, potential yield due to decreased evaporation losses was examined. Evaporation occurs at the water surface, so evaporation losses in a reservoir are greatest when the reservoir is full, and the surface area of the reservoir is greatest. Evaporative losses in aquifer storage are minimal. The operational data for Fort Phantom Hill Reservoir was examined for the period 1981 to 1992, a relatively wet period during which several spills occurred over the dam. This operational data included evaporation rates, pool elevation, and water surface area. During any period that the pool elevation was within the top foot of the spillway, the volume of water within that top foot of storage was "removed" to the ASR system, and the evaporation rate recorded in the reservoir operational data was applied to the reduced surface area defined by the lowered pool elevation. In this way, water conserved in the ASR system through reduced evaporation could be estimated. In the 11-year period from 1981 to 1992, it was estimated that approximately 4,700 acft would have been conserved due to lower evaporative losses associated with the operation of the ASR project system.

5A.12.3 Environmental Issues

A summary of environmental issues is presented in Table 5A.12-1.

Table 5A.12-1.
Environmental Issues: Aquifer Storage and Recovery*

Environmental Water Needs/ Instream Flows	Possible low to moderate impact below Lake Fort Phantom Hill due to increased diversion
Bays and Estuaries	Negligible impact
Fish and Wildlife Habitat	Possible impact to riparian corridors and upland habitats from pipelines; and possible moderate positive impact from added wetlands
Cultural Resources	Possible low impact
Threatened and Endangered Species	Negligible impact
*Comments: Assumes storage only of raw water for this option.	

Environmental permitting issues are discussed under Section 5A.12.5, Implementation Issues. Mitigation requirements will vary depending on impacts but could include vegetation restoration, wetland creation or enhancement, or additional land acquisition.

5A.12.4 Engineering and Costing

Infrastructure needs for this ASR project include:

- Intake structure and pump station to convey water from Fort Phantom Hill Reservoir
- Ponds to collect water for infiltration into the aquifer
- Wells for recovery of stored water
- Two-way, 11-mile pipeline to carry the water from Fort Phantom Hill reservoir to the infiltration ponds and from the recovery wells back to the reservoir.

The project as proposed would use 200 acres of infiltration ponds. The pump and pipeline would be designed to move water from the reservoir to the infiltration ponds at a rate of 200 acft/day, or approximately 65 million gallons per day (MGD). The well field would be designed deliver water back to Fort Phantom Hill Reservoir at a rate of 30 MGD. This is the amount of daily peak demand for Abilene that is not currently supplied by water purchased from Hubbard Creek Reservoir. This delivery rate could be met with 52 wells each pumping 400 gallons per minute.

The total cost for this project would be approximately $31,895,000, as detailed in Table 5A.12-2. This includes capital for the project infrastructure and engineering,

Table 5A.12-2.
Cost Estimate Summary
Seymour Aquifer Storage and Recovery Project
Second Quarter 1999 Prices

Item	*Estimated Costs for Facilities*
Capital Costs	
Intake and Pump Station	$8,159,000
Transmission Pipeline	5,484,000
Well Field	2,600,000
Infiltration Basins	4,840,000
Total Capital Cost	**$21,083,000**
Engineering, Legal Costs, and Contingencies	$7,105,000
Environmental & Archaeology Studies and Mitigation	538,000
Land Acquisition and Surveying	806,000
Interest During Construction	2,363,000
Total Project Cost	**$31,895,000**
Annual Costs	
Debt Service	$2,317,000
Operation and Maintenance:	
Intake, Pipeline, Pump Station	333,000
Infiltration Basins	75,000
Pumping Energy Costs	198,000
Purchase of Water Easements	46,000
Total Annual Cost	**$2,969,000**
Available Project Yield (acft/yr)	**11,100**
Annual Cost of Water ($ per acft)	**$278**
Annual Cost of Water ($ per 1,000 gallons)	**$0.85**

environmental, and legal costs as estimated per Senate Bill 1 established methodology. These costs were calculated assuming that land purchases will be restricted to land necessary for construction of the infiltration ponds and recovery wells. Annual costs are estimated to be

$2,969,000. This figure includes debt service on the project capital, operation and maintenance of the project infrastructure, and electrical pumping costs.

As shown in Table 5A.12-3, two unit costs were calculated for the project. The first unit cost applies annual cost to all firm yield water available from the project as described, i.e., water delivered via infiltration basins as well as water naturally in storage prior to implementation of the ASR system. Using the Seymour ASR, the total available firm yield of 11,100 acft/yr results in a unit cost of $278 per acft, or $0.85 per 1,000 gallons of water. The second unit cost applies the annual cost only to the *increase* in water available over natural undeveloped conditions, i.e., only the water that is delivered via the infiltration basins. The increase in firm yield 9,200 acft/yr results in a unit cost of $323 per acft, or $0.99 per 1,000 gallons. These are costs for transmission of raw water to and from Fort Phantom Hill Reservoir. Diversion, treatment, and transmission costs must be added for comparison to other specific options for municipal or industrial use.

Table 5A.12-3.
Unit Cost Comparison
Seymour ASR v. Natural Conditions

Project Total Cost	$31,895,000	
Project Annual Cost	$2,969,000	
		Unit Cost
Total Available Firm Yield with ASR	11,100 acft/yr	$278/acft
Increase in Firm Yield under Natural Conditions	9,200 acft/yr	$323/acft

5A.12.5 Implementation Issues

This water supply option has been compared to the plan development criteria, as shown in Table 5A.12-4, and the option meets each criterion.

Table 5A-12-4.
Comparison of Aquifer Storage and Recovery Option to Plan Development Criteria

Impact Category	*Comment(s)*
A. Water Supply:	
1. Quantity	1. Abundant; sufficient to meet demand
2. Reliability	2. High reliability
3. Cost	3. Reasonable
B. Environmental factors	
1. Environmental Water Needs	1. Low to moderate impact
2. Habitat	2. Possible moderate positive impacts accrue from added wetlands; possible low impact due to pipeline construction
3. Cultural Resources	3. Low impact
4. Bays and Estuaries	4. Negligible impact
C. Impact on Other State Water Resources	• No apparent negative impacts on state water resources; no effect on navigation
D. Threats to Agriculture and Natural Resources	• Possible impact to agriculture from conversion of supplies from agriculture to municipal and industrial
E. Equitable Comparison of Strategies Deemed Feasible	• Option is considered to meet municipal and industrial shortages
F. Requirements for Interbasin Transfers	• Not applicable
G. Third Party Social and Economic Impacts from Voluntary Redistribution	•

In order to implement this ASR option, the following issues will need to be addressed.

- **Pilot Project** – Prior to full implementation, a small-scale pilot project should be done in order to determine more accurately the hydraulic loading rates in the project area. Loading rates will vary with site-specific factors such as soil infiltration rates and sediment load of source water. Effective hydraulic loading rates will be used to determine the final area of infiltration ponds necessary to deliver the specified recharge rate. Costs could be affected significantly either up or down dependent on local factors.
- **Land Acquisition** – A sufficient amount of land needs to be acquired within the project area for siting of infiltration ponds and canals.
- **Water Rights Easements** – Negotiations may need to be conducted with landowners in the area of the aquifer. Although groundwater in the aquifer is not currently under heavy irrigation pumpage, easements will need to be purchased in order to use aquifer storage beneath private property, and contracts must be in place limiting groundwater withdrawals by such landowners to historic rates.
- **Surface Water Rights** – A surface water right permit may need to be obtained to collect spill flows from Fort Phantom Hill Reservoir, or an arrangement may be needed with BRA to purchase downstream water at Possum Kingdom Reservoir to mitigate for effect of diversion of water upstream at Fort Phantom Hill.

- **Environmental/Water Quality Issues** – Prior to permitting of the project, TNRCC concerns regarding both the quality of raw water from the Fort Phantom Hill Reservoir and the possible mobilization of contaminants from the unsaturated zone to the aquifer will need to be addressed.
- **Mitigation Funding and Other** – Mitigation requirements would vary depending on impacts, but they could include vegetation restoration, wetland creation or enhancement, or additional land acquisition.

Requirements Specific to Pipelines:

1. Necessary permits:
    a. U.S. Army Corps of Engineers Section 10 and 404 dredge and fill permits for stream crossings.
    b. GLO sand and gravel removal permits.
    c. TPWD sand, gravel, and marl permit for construction in state-owned streambeds.
2. Right-of-way and easement acquisition.
3. Crossings:
    a. Highways and railroads.
    b. Creeks and rivers.
    c. Other utilities.

Requirements Specific to a Well Field:

1. Easements for water well sites and water transmission pipelines.
2. Updated inventory of existing wells.
3. Test drilling and aquifer testing.
4. Chemical analysis.

Requirements Specific to Infiltration Basins:

1. TNRCC permitting.
2. Unsaturated zone environmental characterization.
3. Detailed soil mapping and infiltration testing.
4. NPDES Storm Water Pollution Prevention Plan.