AQUIFER STORAGE AND RECOVERY:
A water resources management alternative for Horry County, South Carolina

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INTRODUCTION

Since the beginning of this century, cities in the Coastal Plain area of South Carolina, especially those near the sea, have been relying on ground water as their source of drinking water. By the beginning of the next century many of these cities will have switched to surface water. The change already is evident among the larger coastal cities.

Most utilities and municipalities in Horry County, South Carolina (Fig.1), have abandoned their water wells from aquifers in the Black Creek Formation and have built new surface-water treatment facilities. Two compelling reasons, which could be equally applicable to other counties or cities, have brought about this change. They are the availability and quality of the ground water in this region.

Ground water in these coastal aquifers is often of only marginal quality for drinking. As ground water from recharge areas in the upper and middle sections of the Coastal Plain flows toward discharge areas in the lower Coastal Plain, it becomes more mineralized (Zack, 1977). Concentrations of certain constituents increase above recently revised drinking-water standards. Hence, according to these new rules the ground water would have to be treated before it is used as drinking water. In particular, fluoride, chloride, sodium, and the total-dissolved-solids concentrations would need to be reduced to acceptable levels (Table 1). The treatment of the ground water, for example by reverse osmosis,

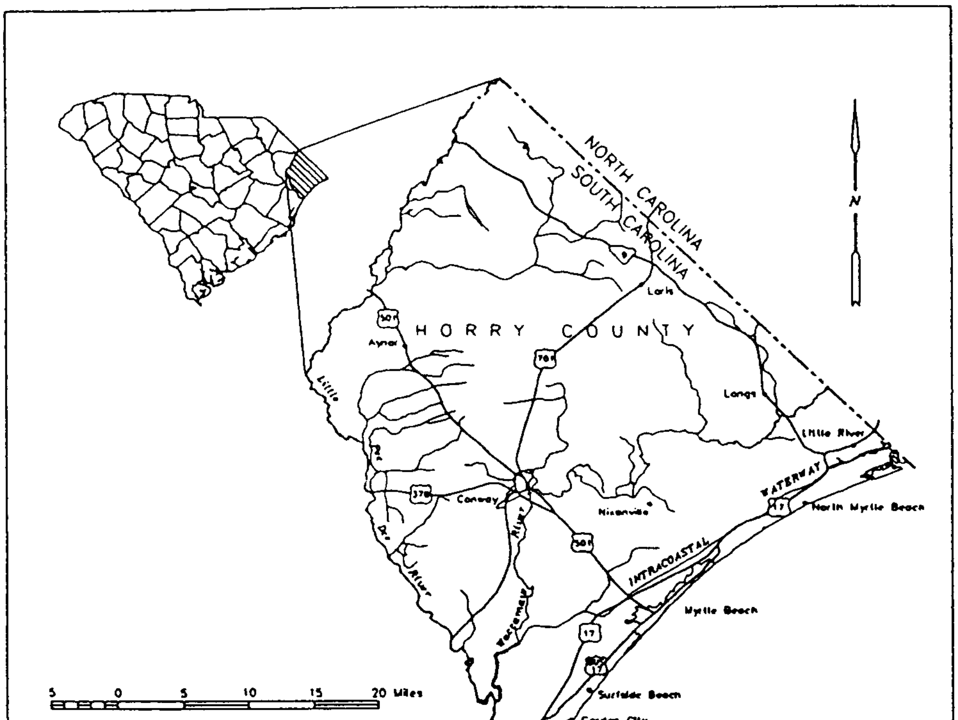

FIGURE 1. Location of the study area.

would substantially increase the production cost of drinking water. The Mount Pleasant Waterworks and Sewer Commission, Charleston County, S.C., uses reverse osmosis for treating ground water at a cost of 1.13 dollars per 1,000 gallons (Clay Duffie, General Manager, written communication). Thus, treated ground water could become as expensive as treated surface water, and therefore a less attractive alternative.

Ground water quantity was also of concern to public suppliers. Extensive development, and often over- pumping of the Black Creek aquifers during the 1980's depressed water levels to near the top of the aquifer. It was not uncommon, during the mid 1980's, to observe declines of 10+ ft per year (Pelletier, 1985). Overpumping threatened the integrity of the formation by increasing the potential for aquifer compaction--loss of storage capacity because of particle rearrangement. Had the excessive pumping continued, the long-term supply of ground water would have been limited to only five more years.

TABLE 1. Characteristics of the Black Creek aquifer exceeding EPA drinking water standards

CHARACTERISTIC	BLACK CREEK AQUIFER (mg/L)		DRINKING WATER STANDARD (mg/L)
	RANGE	AVERAGE	
FLUORIDE	0.89 - 6.9	4.1	2[1]
CHLORIDE	7.2 - 490	140	250[1]
SODIUM	100 - 500	310	20
TOTAL DISSOLVED SOLIDS	265 - 1,390	822	500[1]

[1] Secondary standard

Given the shortcomings of the ground water supply in Horry County, regarding both quality and quantity, water utilities and municipalities had to consider alternative sources for drinking water. Starting in the late 1980's, the city of Myrtle Beach and then the Grand Strand Water and Sewer Authority, the two largest suppliers in the area, abandoned their wells and went to surface water sources for public supplies. The city of Myrtle Beach selected the Atlantic Intracoastal Waterway, which is freshwater, and the Grand Strand Water and Sewer Authority selected Bull Creek. The new sources, although plentiful, brought about new challenges for the public suppliers, among them higher production costs. These higher costs, which pay for dependability and also better quality, are ultimately passed on to consumers.

To combat these cost increases, public suppliers must take advantage of new technologies and better water resources management practices. One such possibility, hereafter referred to as Aquifer Storage and Recovery (ASR), benefits from the abundance of surface water and the exceptional storage capacity of aquifers.

PREVIOUS WORK

Across the nation, most of 70 ASR sites have been inventoried by Pyne (1995). The majority of these sites have been implemented in the last decade only, although there are a few ASR sites (New Jersey) that have been operating for over 30 years. Overseas, Europe, the Middle East, the Far East, and Australia have numerous operational sites (Castro, 1995). The application of artificial recharge is not new nor it has been limited to providing for additional storage of potable water. Artificial recharge has been used for the control of saltwater intrusion in Israel (Bear and Jacobs, 1965); for thermal energy storage (Moltz and others, 1979) and for the disposal of treated effluent (Rebhun and Schwartz; Brown and Silvey, 1977) in the USA; for the melting of street ice and snow in Japan (Abiko and Katsuragi, 1994); and to restore ground water levels by using storm water in Australia (Telfer, 1995). In South Carolina, ASR projects were introduced by the State government in 1988 to provide for the better management of surface water and ground water resources.

METHODOLOGY

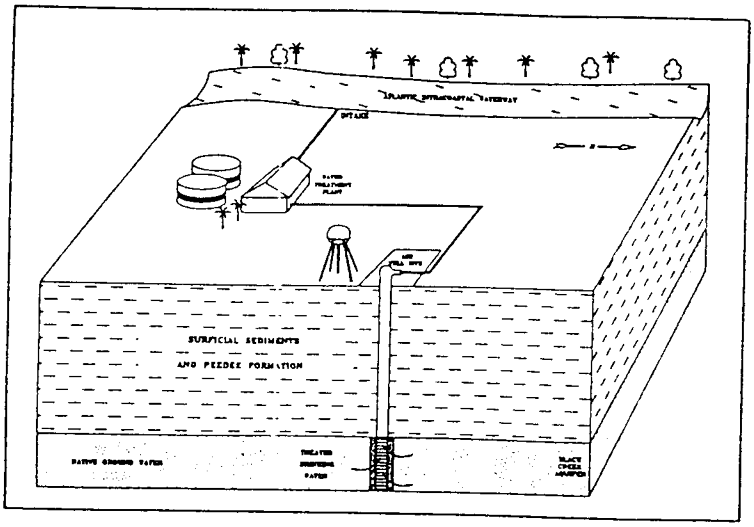

FIGURE 2. The Aqufer Storage and Recovery (ASR) system at Myrtle Beach, S.C.

Definition

ASR is the cyclical storage of treated surface water in a suitable aquifer, when water is available, and the later recovery of the same water to augment flows in a distribution system to meet peak daily and emergency demands. The recovered water, moreover, requires no additional treatment (only disinfection) before it is pumped into a distribution system.

Potable water, produced at any treatment plant, could be routed through a distribution system to a selected injection site (Fig. 2). The water could then be injected into a confined aquifer through the ASR well's riser pipe, using the line pressure of the distribution system, normally 45 to 60 pounds per square inch. The injected water would remain in the aquifer for several days or months, depending on the purpose of the project, before it would be recovered. The stored water could be recovered by pumping the ASR well (same well used during injection) and be directly discharged into the distribution system without any additional treatment. For as long as the degree of mixing between the treated surface water and the native ground water is controlled and minimized, the recovered water will retain its potable characteristics and will meet the state and federal drinking water standards. Disinfection, as required by EPA rules, is always necessary.

Applications

The number and type of ASR applications have significantly increased as more systems have become operational. Pyne (1995) listed 22 ASR applications ranging from increasing storage capacity to improving water quality and to fish hatchery temperature control; Castro (1995) presented additional applications involving improved performance of treatment plants, energy recovery, and conjunctive use of surface water and ground water.

Perhaps the most frequent application of ASR has been to provide additional capacity to store the finished water from a treatment plant. This added storage capacity is normally used to augment flows during peak daily, short-term, long-term, or emergency demands. Alternatively, to meet these often times short-lived peak demands the treatment plant capacity would have be expanded.

The city of Myrtle Beach, S.C., in 1992, had an average demand of 11.5 mgd (million gallons per day) (Fig. 3). The July demand (peak month) was almost three times the December demand; this difference becomes more critical when peak daily demands, rather than average-daily demands, are considered. The July peak daily demand was 8 percent larger than the daily average for the month and 81 percent larger than the daily average for the year. Consequently, in the future the July peak daily demands will be the first to approach the plant capacity; while demands for other months will be well below the capacity of the plant. Then, the plant would have to be expanded to satisfy the relatively short peak demand period.

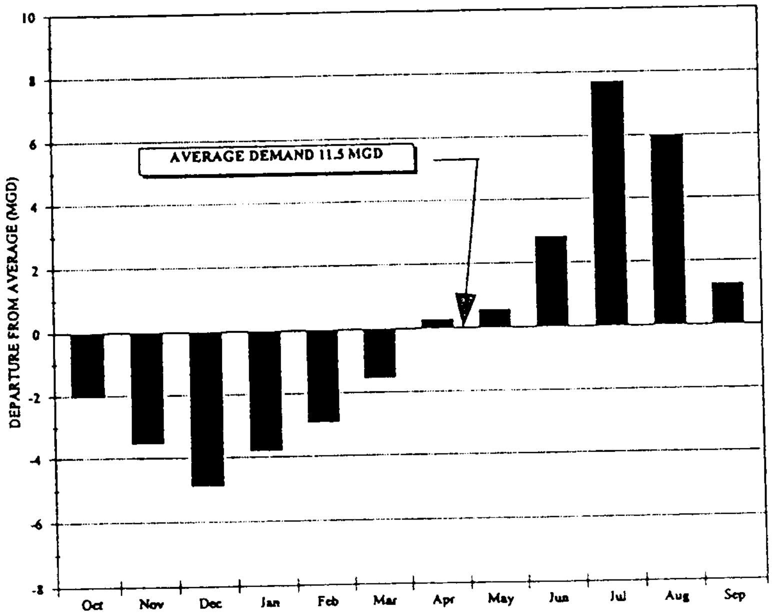

FIGURE 3. Water-use pattern at Myrtle Beach in 1992.

Expansion of the plant capacity, to meet peak daily demands, significantly increases production costs. First, the capital layout for civil work and equipment is substantial, approximately 60 cents per 1,000 gallons per year (Castro, 1995). Second, given that in a year there are 10 percent or fewer days with extremely large peak demands, the added capacity of the plant would be substantially underutilized. This, consequently, would increase the unit cost of expansion, inversely proportional to the number of peak days per year.

The alternative to expansion is an ASR well. The Grand Strand Water and Sewer Authority (GSWSA), one of the two largest utilities in Horry County, has devised an application whose goal is to increase water supply availability during summer weekends when demand is the highest. During the summer of 1995, the Bull Creek Surface Water Treatment Facility had to operate at its peak limit of 18.7 mgd. In contrast, offseason flows average only 11 mgd. Thus, ample unused capacity is available during offseason peak periods for injection. GSWSA is injecting treated water during the summertime weekdays and withdrawing it over the following weekend (Castro and others, 1996). Consequently, the costly expansion of the treatment plant and distribution lines has been postponed until the average demand in the system exceeds the plant capacity.

DISCUSSION

Benefits from an ASR system are both tangible and intangible. While the tangible benefits are susceptible to quantification by comparison with benefits obtained from conventional alternatives, the intangible benefits are not. For example, ASR projects do not require an extensive civil infrastructure, unlike most treatment plant facilities. ASR sites, therefore, can be located almost anywhere in the distribution system with minimal adverse impact on the environment. In an ASR site the actual storage normally is several hundred feet below the land surface, far away from potential surficial-contamination sources and protected from severe natural phenomena, such as earthquakes, tornados, and floodings. These are two examples where the ASR environmental friendliness and reliability may be extremely desirable to a water utility, yet they do not have a quantifiable economic benefit. Another example is observed in systems where the unit cost of water increases stepwise and proportional to the volume used: the larger the usage the higher the unit cost. ASR systems could be used to seasonally store excess water during periods of low demand (low unit cost) and later provide supplemental capacity during periods of high demand (high unit cost). This great operational flexibility could substantially improve the performance of a treatment plant and ease the management of a distribution system.

To evaluate the tangible benefits, a simple unit cost comparison of ASR with more conventional alternatives was made. The facilities used in the analysis were those that provide either additional storage (storage tanks) or additional flow (expansion of treatment plant). Costs were computed as annual cost per 1,000 gallons of water produced and were amortized over 30 years at an interest rate of 7 percent. Most of the data used in the analysis were obtained from the city of Myrtle Beach and the Grand Strand Water and Sewer Authority.

Conventional Alternatives

Storage tanks. Peak daily and emergency water demands might be satisfied by increasing the storage capacity of the distribution system. In a public supply system with varying seasonal demand, surplus water could be accumulated in storage tanks and later used to augment daily flows during periods of high water demand. The most common types of storage facilities are elevated and ground-level storage tanks.

Treatment plant expansion. Another alternative for increasing the production capacity of a plant is to expand the treatment capacity. This would be done by enlarging plant structures and treatment facilities.

Cost analysis

Storage tank alternative. According to information provided by the city of Myrtle Beach in 1992, the construction cost of a 2-million gallon ground tank was 440,000 dollars. The construction of an elevated 0.5-million gallon tank was 610,000 dollars. The annual costs per 1,000 gallons were 31 dollars and 61 dollars, respectively. For a storage alternative these annual unit costs are high. In a distribution system, the storage-capacity importance of tanks is secondary to benefits that tanks provide. For example, the elevated tank aids in regulating pressure conditions on mains and secondary lines. This additional benefit, essential for a public supply system, was not factored in the cost analyses because it does not provide storage benefits to this alternative.

Treatment-plant expansion. On the basis of information provided by the utilities in Horry County, the annual cost per 1,000 gallons for a treatment plant expansion was estimated to be 1.13 dollars, of which 0.59 dollar and 0.54 dollar were for the capital cost and operation-and-maintenance cost, respectively. The amortization period was 30 years and the interest rate 7 percent.

Aquifer storage and recovery (ASR) well. Inasmuch as Horry County has a substantial number of Black Creek aquifer wells that could be converted to ASR wells, the cost analysis (Table 2) considered the upgrading of an existing well and the construction of a new well (Castro, 1995). Cost estimates, therefore, are for a single, dual-purpose, Black Creek well. Computations reflect conditions encountered at the Myrtle Beach test site.

In computing the total annual cost of these alternatives, two important assumptions were made. First, the unit cost for operating and maintaining an ASR well was considered fixed, although it will decrease as the number of wells increases (economy of scales). Second, the volume recovered was assumed to be equal to the volume injected (100-percent recovery).

Table 2. Annual costs, in dollars, for an ASR alternative producing 36 million gallons of water

COST	DESCRIPTION	EXISTING WELL	NEW WELL
UNIT ANNUAL (1,000 GALLONS)	CAPITAL COST	$ 0.06	$ 0.55
	OPERATION AND MAINTENANCE COST	$ 0.42	$ 0.42
	TOTAL ANNUAL COST	$ 0.48	$ 0.97

Costs for other recoveries are shown in Figure 4. It is important to emphasize that the unit cost is inversely related to the production capacity of a well; the more it produces, the lower the unit cost. Therefore, wells delivering twice as much water would have one-half the unit cost.

Annual cost comparison. Figure 5 shows that the cost of both ASR alternatives is less than that of expanding a surface-water treatment plant. The difference lies in the annual capital cost. Whereas the annual capital cost per 1,000 gallons is 0.06 dollar and 0.55 dollar for an upgrade and a new well, respectively, it is 0.59 dollar for the expansion. Even if an upgraded ASR well had a recovery of less than 50 percent, it still would be the most cost-effective alternative.

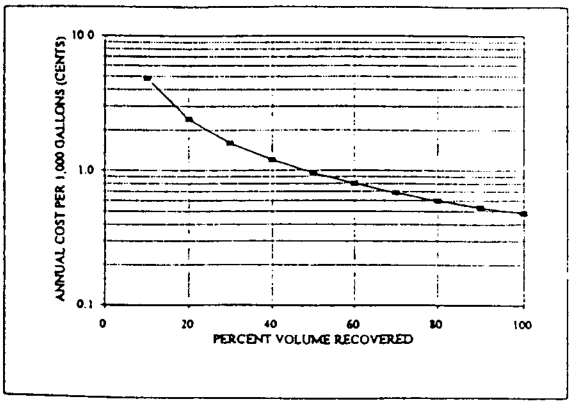

FIGURE 4. ASR costs for various recovery percentages.

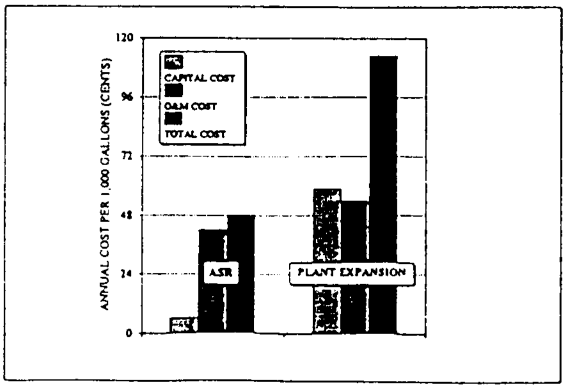

FIGURE 5. Costs for an ASR and a treatment plant expansion.

CONCLUSIONS

Nationwide, aquifer storage and recovery projects are proving to be a feasible water-resources management alternative. Presently, there are more than 70 ASR sites in the USA, with as many as a third of them being operational. Most of these sites were implemented in the last decade.

In South Carolina, ASR was introduced in 1988 by the State government in an effort to curtail rising water costs and to provide for an appropriate management of the severely depleted aquifers. Today, the Grand Strand Water and Sewer Authority has one operational site, and three more are in the process of being permitted by the State. Also the cities of Charleston, Mount Pleasant, and Hilton Head Island are investigating the feasibility of ASR projects.

Aquifer storage and recovery projects, where applicable, are an effective and inexpensive alternative to conventional options for increasing storage and treatment plant capacity. ASR wells can store substantial volumes of treated water and deliver it in quantities higher than those during normal pumping conditions (Castro and others, 1996). The GSWSA, with a single ASR well, can supply more than 8 percent of the peak treatment capacity. This added capacity combined with the ability to recover the stored water at high discharge rates, provides utilities with great flexibility in the operation of a treatment plant.

Considering that ASR wells could be located anywhere in the distribution system, they could conveniently replace the more expensive and limited-storage elevated tanks. The ASR wells could provide enough storage capacity and raise or maintain pressures (by pumping stored water into the distribution system) of mains and secondary lines.

Ground storage tanks (clear wells) could also be replaced by ASR wells. This option is particularly attractive in urban areas where the land is not available or is too expensive. ASR wells could increase the storage capacity of a facility by a factor ranging from 10 to 30 and at a cost 30 times lower.

For the conditions at Myrtle Beach, the annual costs, in dollars per 1,000 gallons, are: 0.48 dollar for an ASR system (upgraded well) versus 1.13 dollars for the expansion and operation of a treatment plant. These include capital and operation-and-maintenance costs. While the operation-and-maintenance costs for both alternatives are similar, the capital costs are not. The ASR alternative has a capital cost of 0.06 dollar per 1,000 gallons, and the treatment plant expansion has a cost of 0.59 dollar per 1,000 gallons.

In summary, ASR systems are simple and easily implemented; they provide substantial storage capacity, which could be located anywhere in the distribution system; and ASR wells are significantly less expensive than conventional alternatives. Thus, ASR systems could become an essential management alternative for water utilities and municipalities.

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