ASSESSMENT OF ENVIRONMENTAL EFFECTS ASSOCIATED WITH POTENTIAL AQUIFER STORAGE RECOVERY PROJECTS IN COASTAL GEORGIA

DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION
GEORGIA GEOLOGIC SURVEY

Atlanta

2001

PROJECT REPORT 44

ASSESSMENT OF ENVIRONMENTAL EFFECTS ASSOCIATED WITH POTENTIAL AQUIFER STORAGE RECOVERY PROJECTS IN COASTAL GEORGIA

Performed as part of the Georgia Environmental Protection Division's Interim Strategy to protect coastal Georgia from salt-water intrusion

DEPARTMENT OF NATURAL RESOURCES
Lonice C. Barrett, Commissioner

ENVIRONMENTAL PROTECTION DIVISION
Harold F. Reheis, Director

GEORGIA GEOLOGIC SURVEY
William H. McLemore, State Geologist

Atlanta

2001

PROJECT REPORT 44

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Reply To:
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Atlanta, Georgia 30334
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June 1, 2001

To: Coastal Georgia Ground Water Stakeholders

From: William H. McLemore
State Geologist

Subject: Project Report 44; **ASSESSMENT OF ENVIRONMENTAL EFFECTS ASSOCIATED WITH POTENTIAL AQUIFER STORAGE RECOVERY PROJECTS IN COASTAL GEORGIA**

This Project Report contains two separate reports (Appendices 1 and 2) dealing with the environmental impacts that might be associated with aquifer storage and recovery (ASR) projects in coastal Georgia. In this regard, two separate contractors were given the following identical mission to assess the published and unpublished technical literature regarding the following issues, which have been raised by coastal Georgia stakeholders (i.e., identified as part of a facilitated meeting sponsored by the Georgia Conservancy under contract to EPD and included in this Project Report as Appendix 3):

> *"What happens during aquifer storage and recovery (ASR)? That is, what happens to movement of stored water, quality of stored water and quality of natural water under ASR? What are the effects locally? What is the localized movement? What are the effects across the full sphere of influence? How far does the sphere of influence extend? Others include:*
> - *effects of mixing aerobic and anaerobic waters;*
> - *geochemical effects on the aquifer itself (on the limestone formations);*
> - *effects of prior treatment; and*
> - *mixing effects in general.*

In addition to the above, EPD requested the two contractors to also consider:

> *(1) Potential for the introduction of regulated or radioactive (i.e., tritium) chemicals into the subsurface, and in the event that such chemicals were introduced, the viability of successfully removing such chemicals and preventing them from being introduced into a public drinking water system.*
>
> *(2) Potential impact upon wells belonging to other persons (i.e., loss of water).*
>
> *(3) Other negative impacts."*

The assessment of the above issues, which did not include any field studies or measurements, was to be summarized in a short report that would generally discuss actual and perceived adverse environmental impacts. Any actual environmental impacts would be documented and properly cited.

The above work was contracted to the firms of CH2MHill (Appendix 1) and Golder Associates (Appendix 2). Both CH2MHill's and Golder's reports were peer reviewed by LAW Environmental and Engineering, Inc. and Camp Dresser and McKee, Inc. LAW and Camp Dresser and McKee were further requested to render a technical opinion regarding:

> *Are there any inherent adverse environmental impacts associated with ASR in coastal Georgia that could not be mitigated by competent and reasonable engineering design and thus would preclude the siting and construction of such a facility.*

Before proceeding further, it is important to remember that ASR is regulated as part of Underground Injection Control (UIC), which is a federally delegated program from the United States Environmental Protection Agency (EPA). The legal authority under which UIC rules are promulgated is the Georgia Water Quality Control Act (O.C.G.A. 12-5-20). In the spring of 2001, Georgia's UIC rules were revised to achieve consistency with changes in EPA regulations. The revised rules, which became effective on April 26, 2001 are provided in Appendix 4.

Georgia's UIC rules provide:

> No person shall operate an ASR in a manner that allows the movement of fluid containing any contaminant into any aquifer, if the presence of the contaminant may cause a violation of drinking water standard.
>
> Injected ASR water shall be sited so that both the aquifer and nearby wells are not contaminated. [Note: Georgia's Ground-Water Management Plan further provides that such a siting study shall only be done by a Georgia P.E. or P.G.]
>
> Injected ASR water shall not contain any contaminate that exceeds promulgated drinking water standard (i.e., the injected water must meet drinking water standards).
>
> ASR shall not proceed without the owner first obtaining a permit from EPD; and the permit may contain provisions for monitoring, testing, and reporting.

Both CH2MHill and Golder point out several potential impacts (i.e., reducing conditions in the aquifer, mobilization of metals, disinfection by-products, etc.); however, both firms also point out that such impacts can be mitigated by proper siting, testing, and modifications to design and/or operations.

In their concluding remarks, CH2MHill states:

> *"Experience during the past 17 years with ASR development in other states has shown that initial uncertainties, such as the questions posed in this memorandum* (the CH2MHill Assessment) *are relatively normal.......Full confidence in the applicability of ASR technology in Georgia can only come from having at least one full size ASR well constructed, tested, permitted and placed in operation. Until that time arrives, partial confidence can be achieved through literature reviews, studies, investigations, modeling, and site visits to other nearby operating ASR sites utilizing the upper or lower zones of the Floridan Aquifer as a storage zone."*

Similarly Golder concludes:

> *"In summary, ASR has the potential to be a useful water resource management tool in coastal Georgia. Some concerns have been identified, but no environmental impacts have been identified that could not potentially be mitigated. An active permit program administered by GAEPD could insure that pre-construction investigations, pilot testing, and ASR design, operation, and monitoring are adequate to achieve the water resource management benefits while mitigating environmental impacts."*

Finally, in performing their peer reviews, both LAW and Camp Dresser and McKee could not identify any inherent adverse environmental impacts that would be associated with a properly designed and operated ASR system.

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With the above in mind, EPD recommends that coastal Georgia stakeholders seriously consider ASR as an environmentally sound approach to enhance the water supply options of region.

APPENDIX 1

CH2M HILL
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Gainesville, FL
32608-3928
Mailing address:
P.O. Box 147009
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CH2MHILL

Celebrating 50 Years

April 2, 2001

160843.GG.01

Dr. William H. McLemore, State Geologist
Georgia Geological Survey
19, Martin Luther King Drive, S.W., Room 400
Atlanta, GA 30334

Subject: Aquifer Storage Recovery in Coastal Georgia

Dear Dr. McLemore:

CH2M HILL is pleased to submit our final report entitled "Assessment of Adverse Environmental Impacts Associated with Potential Aquifer Storage Recovery Projects in Coastal Georgia."

We sincerely appreciate the opportunity to work with the Georgia Geological Survey on this project and hope that the report will prove to be helpful in addressing some of the questions that have been raised in recent years regarding this technology. If we can assist further in any way, please let us know.

We would appreciate receiving a copy of the broader report that you mentioned in our last telephone conversation, for which this CH2M HILL report would be a part.

Sincerely,

CH2M HILL

R. David G. Pyne, P.E.

Bryan B. McDonald, P.G.

Assessment of Adverse Environmental Impacts Associated with Potential Aquifer Storage Recovery Projects in Coastal Georgia

Prepared for
Georgia Geological Survey

by

R. David G. Pyne, P.E.
and
Bryan B. McDonald, P.G.

CH2M HILL, Inc.
Gainesville, Florida

April 2, 2001

Assessment of Adverse Environmental Effects Associated with Potential Aquifer Storage Recovery Projects in Coastal Georgia

Prepared for the Environmental Protection Division, Georgia Department of Natural Resources

Prepared by R. David G. Pyne, P.E., and Bryan B. McDonald, P.G.

CH2M HILL, Gainesville, Florida

April 2001

Background

As of April, 2001, at least 39 ASR projects are known to be operational and fully-permitted in the United States. At least 50 more projects are estimated to be in various stages of development, ranging from initial planning to already operational but not yet fully permitted. These 39 projects are located in 14 states. Application of this water management technology has been fairly rapid; as recently as 1983 there were only 3 ASR projects nationally. ASR systems are also operational in Canada, England, Israel and Australia and are under development in several other countries.

Most ASR projects store water in deep, confined aquifers, as has been proposed for coastal Georgia. Storage zone depths range from as shallow as 200 feet to as deep as 2600 feet. Geologic conditions for the storage zones include sand, sandstone, clayey sand, limestone, dolomite, basalt and glacial drift deposits. Projects range from single wells with recovery capacities of under one million gallons per day (MGD), to more than 30 wells with combined recovery capacity exceeding 100 MGD. Storage volumes range from as small as about 10 million gallons (MG) to about 2.7 billion gallons (BG). Most storage zones contain fresh water while some contain brackish water.

ASR wells are different in both design and operation from injection wells or production wells. ASR wells are designed for storage and recovery of high quality water whereas injection wells are designed and operated for either recharge or disposal of water. ASR wells resolve the inherent operational drawbacks of single-purpose injection wells by equipping each well with a pump and operating it in a dual-purpose mode for both recharge and recovery. This approach to aquifer recharge typically overcomes the plugging associated with most injection wells, the hydraulic limitations associated with many surface recharge sites, and the large land area requirements of these sites. ASR wells are typically backflushed for a few minutes every few days to few weeks, to remove accumulated particulates from the well, thereby maintaining long term recharge and recovery rates. Such particulates tend to plug injection wells, which are not usually provided with a pump capable of backflushing particulates to waste. Accordingly, injection wells require either an extremely transmissive injection zone, such as occurs in south Florida, or they require periodic expensive redevelopment, as for the southern California salinity intrusion barriers in Orange and Los Angeles counties during the past 40 years.

ASR systems meet a great variety of needs. Most common is the storage of water to meet seasonal, emergency or long-term needs during drought-flood cycles. Others include water quality improvement during storage, reduction or elimination of withdrawals from surface water sources during dry weather periods, salt water intrusion control, reducing water facility expansion costs, maintaining water distribution system flows or pressures, and about 20 other applications. Most ASR systems store treated drinking water. However in recent years a growing number of ASR systems are storing high quality reclaimed water; partially-treated, high quality surface water; or groundwater from overlying or underlying aquifers, or from the same aquifer at a different location.

Typically the same volume of water stored in an ASR well can be recovered. In some situations it may be possible to recover a greater volume than the amount recharged, relying upon mixing between the stored water and the surrounding native water in the aquifer to provide a blend of acceptable quality. In other situations, leaving a small percentage of the stored water in the ground may be desirable to restore depleted groundwater reserves; to address concerns regarding potential geochemical plugging; to form or maintain a buffer zone between stored water and surrounding brackish or poor quality native water; or to build up a reserve for future recovery during droughts, emergencies, or anticipated times of higher demand.

ASR recovered water usually requires no retreatment following recovery, other than disinfection for potable uses. In a few situations, pH adjustment of the recovered water or blending with high quality water may also be needed.

The Floridan Aquifer underlies Florida and portions of Georgia and South Carolina. Within this area, nine ASR projects are operational and at least 30 more are in development. Of these nine operational projects, four are in locations where the native groundwater in the aquifer is fresh while the remainder are in locations where it is brackish. The closest ASR site to coastal Georgia is at Beaufort Jasper Water and Sewer Authority in South Carolina, immediately north of Savannah. This site has been in operation for over a year and is being expanded to include two additional wells.

ASR Proposed Application in Coastal Georgia

During the past few years, ASR has been proposed for application in coastal Georgia, to meet public water supply needs and also to help reverse salt water intrusion. As shown in Figure 1, groundwater levels in the upper Floridan aquifer in coastal Georgia have experienced significant declines during the past few decades, reflecting primarily industrial and urban water supply withdrawals in the

Savannah area and urban water supply withdrawals in the Brunswick area. Similar to many other areas along the Eastern Seaboard, salt water intrusion is occurring in the upper Floridan aquifer in coastal Georgia and adjacent portions of South Carolina. The occurrence of a large, regional "bowl" in the potentiometric surface of the upper Floridan aquifer, as shown on Figure 1, presents a good opportunity for aquifer recharge with seasonally available water supplies from various potential sources. Any water recharged would be unlikely to leave the region due to the configuration of the potentiometric surface.

ASR was originally proposed for storage in the upper Floridan aquifer in coastal Georgia, reflecting regional water management needs and opportunities, and the minimal amount of information available regarding hydraulic characteristics and water quality of the lower Floridan aquifer in this area. Subsequently attention has also focused on the potential for ASR storage in the lower Floridan aquifer. Field investigations are underway or planned that would provide further information to support a careful assessment of which storage zone may be preferable.

Several questions have been raised regarding these ASR proposals. Following are the key questions, as summarized by the Georgia Geological Survey, and answers to each.

(1) What happens during aquifer storage and recovery (ASR)? That is, what happens to movement of stored water and quality of natural water under ASR? What are the effects locally? What is the localized movement? What are the effects across the full sphere of influence? How far does the sphere of influence extend? Others include:

- ***effects of mixing aerobic and anaerobic waters?***
- ***Geochemical effects upon the aquifer itself (on the limestone formations)***
- ***Effects of prior treatment, and***
- ***Mixing effects in general.***

Aquifer storage recovery is defined as the "storage of water in a suitable aquifer through a well during times when it is most available, or when water quality is most suitable, and recovery from the same well when the water is needed, or when water quality from other sources is unacceptable. During storage of water in an ASR well, a large bubble of stored water is created, displacing water in the aquifer around the well. Typically the bubble of stored water is sufficient in volume to meet a planned recovery duration, such as 90 days, at the rate available from that well, such as 2 million gallons per day (2 MGD) while meeting water quality criteria established for that well during recovery. This is called the "stored water volume." It is perhaps helpful to envision this process as shown in Figure 2, which is a somewhat simplified version of the expected conditions underground during ASR operations. Figure 2 shows a typical ASR well in a confined artesian aquifer, as may be expected in coastal Georgia.

Surrounding the stored water volume is a buffer zone, which contains a mix of stored water and native groundwater. The volume required in the buffer zone depends upon several factors such as aquifer thickness, porosity, permeability, degree of confinement, regional hydraulic gradient, native water quality and recovery water quality criteria. If there is no real difference between recharge water quality and native groundwater quality, there may be no buffer zone volume required. Most ASR sites, however, require a buffer zone volume due to the presence of one or more water quality constituents that would otherwise require treatment of the recovered water in order to meet drinking water quality standards.

The sum of the stored water volume and the buffer zone volume is called the "Target Storage Volume," or TSV. Experience at several operational ASR sites suggests that, once the TSV is reached, subsequent ASR operations usually achieve full recovery of the water stored after that time. Prior to achieving the TSV, less than full recovery may occur. The radial distance from the ASR well to the edge of the TSV depends upon the thickness and bulk porosity of the aquifer, and the volume of water stored. However typical radial distances are a few hundred feet around each ASR well. Within the TSV, water quality will change during recharge and recovery. Figure 2 shows the stored water volume, buffer zone volume, and the Target Storage Volume.

Outside the TSV, native groundwater quality is theoretically unchanged. The water may move slightly in one direction during recharge and the opposite direction during recovery, however the quality of that water would not be changed as a result of ASR operations. During a typical recharge and recovery cycle, such as one year, the net movement of the native water surrounding an ASR well would be no different than if the ASR well did not exist, unless the ASR well is operated purposefully to leave water underground, such as for a salinity barrier, or to recover more water than is recharged, such as for a wellfield.

Although water quality changes occur fairly close to an ASR well, pressure changes extend much further, creating a "sphere of influence" for ASR wells. Water level in adjacent wells may rise during recharge and decline during recovery at distances of up to a few thousand feet from an ASR well. Table 1 indicates approximate changes in water levels in wells at distances of 100, 1000 and 10,000 feet from an ASR well recharging at an assumed rate of 2 MGD in the upper Floridan aquifer near Savannah. Assumed transmissivity is 30,000 ft^2/day, which is perhaps representative of the Savannah area. Actual transmissivities in coastal Georgia vary over a wide range, from less than 10,000 to more than 200,000 ft^2/day, so the drawdown estimates shown in Table 1 are approximate. Water level impacts associated with ASR wellfields, instead of single wells, will be proportionately greater.

Table 1 Distance Drawdown Impacts

Radial Distance (ft)	100	1000	10,000
Change in Water Level (ft)	2.4	0.1	—

During a typical annual cycle of ASR operations, the net change in water level in adjacent wells will be about zero, unless the ASR well is used for multiple purposes, including salinity control. With salinity control operation, water levels would increase during recharge and decline during recovery, however recharge volume would exceed recovery volume, and therefore annual average change in regional water level would be positive.

As described above and as shown in Figure 1, ASR operations proposed in coastal Georgia would superimpose any water level changes in adjacent wells upon an aquifer that has already experienced significant historic water level declines. An important criterion for engineering design and operation of ASR systems will be the appropriate selection of the well location and storage zone to be utilized, considering the high gradient occurring historically in the upper Floridan aquifer and the consequent potentially high rate of lateral movement of stored water around an ASR well between the time of recharge and the time of recovery. Where the water quality difference between the stored water and the native groundwater is insignificant, any lateral movement of the storage bubble should also be insignificant. In the Savannah area, in particular, the configuration of the "bowl" in the potentiometric surface is such that no recharged water will flow out of the regional system, except by pumping from other wells.

As described above, Figure 2 is a somewhat simplistic version of what actually happens underground around an ASR well. In reality, the boundaries between the storage volume, the buffer zone volume and the surrounding native water in the aquifer are not that well defined, representing a gradation from one quality to the next. In fine-grained aquifers, such as sand or sandstone, this proposed "model" of the TSV is probably fairly accurate, whereas for karst limestone aquifers, the boundaries are more diffuse. For most purposes, however, this model is sufficient since it leads to workable initial estimates of the TSV required for new ASR sites. These initial estimates are then adjusted during initial operations, as needed to achieve ASR objectives at each site.

The general framework described above is applicable for most ASR sites, particularly those storing treated drinking water in limestone aquifers, as proposed for coastal Georgia. It is most appropriate for conservative water quality constituents, such as chloride and total dissolved solids. It is less appropriate for non-conservative constituents, for which concentrations may change during ASR storage due to reaction processes other than simple mixing, dilution, diffusion and dispersion. Such non-conservative processes typically include geochemical and microbiological processes. ASR experience since 1983 in the United States has shown that ASR storage of treated drinking water is successful, such that non-conservative underground reactions are insignificant in most, but not all sites. Drinking water is disinfected so bacterial reactions underground tend to be limited. Furthermore, drinking water tends to be relative stable from a geochemical perspective, so subsurface geochemical reactions are usually minor , transitional and insignificant. When treated drinking water is stored in an ASR well, it usually meets drinking water standards during recovery, although disinfection is provided after recovery before the water is sent to the distribution system in order to meet regulatory public health requirements. At a few sites, pH adjustment of the recharge water or the recovered water is provided, in order to control potential reaction processes.

Effects of Mixing Aerobic and Anaerobic Waters

Native water in aquifers used for ASR storage is usually, but not always, devoid of oxygen, reflecting bacterial and geochemical processes naturally occurring underground during movement from the location of recharge at an outcrop area to locations of discharge, such as production wells or natural discharge into the Atlantic Ocean. Typical travel times for this movement range from hundreds to thousands of years, or longer, during which oxygen in the recharge water is consumed and eventually converted to minerals in the aquifer, such as carbonate.

When this water quality equilibrium is disturbed, such as through recharge in an ASR well, the composition of minerals and clays in the aquifer may tend to change, moving toward a new equilibrium through a variety of natural processes such as ion exchange, adsorption, desorption, solution and precipitation. These various processes have been the subject of extensive geochemical research to define the reaction pathways, reaction times, and end products. Models are now available, with varying degrees of complexity, to provide a reasonable basis for estimation of geochemical changes expected underground during ASR storage, the rate at which these changes occur, and the reactions that occur along this pathway. The models usually indicate the tendency of mixed waters, in the presence of certain minerals, to dissolve or precipitate clays or other minerals, depending upon the pH and the Eh of the various waters. Oxidation reduction ("Redox") potential, or ORP, are other terms for Eh that are commonly used, depending upon the equipment used for measurement.

Somewhat less well-defined are the bacterial changes occurring underground. Bacteria are naturally present in ASR storage zones, even at great depths. Addition of water containing oxygen, carbon, nutrients, or with other constituents different than native groundwater, can cause a change in bacterial metabolic activity that can raise or lower pH values in the stored water, thereby potentially triggering geochemical reactions. Similarly, geochemical changes can cause a shift in pH, affecting microbial activity.

Fine-grained ASR storage zones such as sands, sandstones and clayey sands tend to be more reactive than limestone, dolomite or basalt aquifers, which sometimes have greater pore space. ASR experience during the past 17 years in the United States has demonstrated the need for extensive coring and geochemical analysis to support successful development of ASR wells in new areas utilizing such fine-grained aquifers. Redox reactions in such aquifers can cause the precipitation of iron and the dissolution of manganese, if minerals containing these elements are present in the storage zone and if these reactions are allowed to occur in ASR wells. Successful experience has shown that such reactions can be controlled, such as through pH adjustment of the recharge water, so that recovered water does not contain iron or manganese at unacceptable concentrations, even from storage zones where iron and manganese are abundant.

On the other hand, substantial experience in limestone aquifers has shown them to be relatively non-reactive. Other than water quality changes due to mixing and dispersion, recovery water quality has typically been similar to recharge water quality. Accordingly, ASR systems in limestone aquifers have received significantly less attention to changes in water quality associated with storing water from surface and groundwater sources that may or may not contain oxygen, in aquifers that do not contain oxygen.

Recent experience has shown that limestone aquifers can be more reactive than previously understood. During the past two years, detailed investigations at two ASR sites under development in Florida, utilizing limestone aquifers for storage of treated drinking water, have shown that minerals occurring in the storage zone can release arsenic into the recovered water at elevated concentrations compared to either the recharge water or the native groundwater. Based upon these investigations, the following preliminary conclusions have been drawn:

1. The occurrence of arsenic in the recovered water from ASR wells is a transitional phenomenon, most likely to occur at new ASR sites during cycle testing and initial operations. Through natural attenuation processes occurring in the aquifer, arsenic concentrations diminish with time, approaching background concentrations after four to eight operational cycles.

Concentrations also appear to diminish with distance from the ASR well and are probably contained within the stored water volume and certainly within the target storage volume surrounding an ASR well. Arsenic is absent in the recovered waters from long-term operating ASR systems at several Florida and South Carolina sites that have been checked to date.

2. ASR systems utilizing groundwater sources are less likely to have a problem with arsenic in the recovered water during cycle testing and initial operations. ASR systems utilizing surface water sources are more likely to experience arsenic in the recovered water during cycle testing and initial operations, however such occurrence will attenuate with continuing operations.

3. If arsenic is initially present in the recovered water from an ASR site at unacceptable concentrations, that geochemical process can be controlled quickly and relatively inexpensively through a chemical feed into the recharge water. The arsenic naturally present in the aquifer will stay in the aquifer and will not be dissolved out through successive storage and recovery operations so long as the chemical feed continues.

4. It is possible to accelerate the process by which arsenic concentrations decline in the recovered water from an ASR well, through initial control of pH and oxidation processes. At some sites this approach for managing As concentrations during the transition period may be worthwhile if options are available for blending and/or treatment of the recovered water in early cycles.

5. Arsenic is present naturally in Floridan aquifer limestones and in natural groundwaters in the upper Floridan aquifer. It is one of the most common elements globally present in the environment. It is often associated with the presence of pyrite minerals and the occurrence of iron and manganese in natural groundwaters. For 17 years of ASR operations, and at eight operating sites to date in the Floridan aquifer, arsenic has not been a problem. However until recently it has not been studied intensively during initial cycle testing programs. Typically these programs have demonstrated that natural groundwater, recharge water and recovered water at the end of the cycle testing programs, have complied with drinking water standards. Expensive coring and geochemical analyses in limestone ASR systems has typically not been implemented since there appeared to be no need. In other states with finer-grained aquifer systems, such coring and geochemical analysis is routine. As a result there is little information on differences in pyrite concentrations, and other minerals that may contain arsenic, at different ASR locations in the Floridan aquifer. In the absence of such information, the potential for arsenic formation should be assumed to be roughly the same at different locations where the aquifer is present.

6. Where it occurs, the generation of As appears to be primarily due to an oxidation-reduction reaction, reinforced by natural bacterial activity underground. Groundwaters and other water sources with low Redox potential are less likely to dissolve arsenic from aquifer minerals that may be present. Surface waters tend to have higher dissolved oxygen concentrations and also higher concentrations of natural organics that can drive bacterial reactions underground, potentially altering pH and releasing any arsenic that may be present in the aquifer. As described above, such reactions are believed to be transitional and their rate and duration can be controlled, as needed to meet regulatory constraints.

Geochemical Effects on the Aquifer Itself (on the limestone formation)

No significant geochemical effects on the aquifer have been noted at operating ASR sites to date.

At the first ASR site, in Manatee County, Florida, dissolution of the limestone was noted in the immediate vicinity of the well during initial cycle testing conducted prior to 1983. This manifested as a steady rise in the specific capacity of the well during both recharge and recovery of the initial test cycles. Specific capacity is a measure of the rate of water movement into or out of the well (gallons per minute), divided by the increase or decrease in water level at the well (feet). Once the mechanism was understood and quantified, the source of water for recharge was changed so that the recharge water would be treated drinking water, which is geochemically stable, rather than a more convenient piping location at the original ASR site, which was at the water treatment plant, that yielded water from an intermediate point in the process flow stream that was not geochemically stable. The Manatee ASR site is now expanding for the third time, which reflects satisfactory ASR performance at that site.

Temporary well plugging has been noted at most ASR sites, however this is a normal part of the operation and is usually resolved by periodic backflushing of the well to remove accumulated particulates in the well bore or the screen and gravel pack. Permanent plugging of the aquifer around the well, such as might occur from precipitation of calcium carbonate or ferric hydroxide, has been a source of concern at a few ASR sites where the potential for this to occur was evident, however to the best of our knowledge no such plugging has been noted. Aquifer performance tests have been conducted at a few sites, to compare aquifer hydraulic data before and after ASR operations. However such comparisons have not noted any significant differences. Plugging potential in limestone aquifers, such as those present in coastal Georgia, is less likely to be significant. Plugging potential is greater in ASR systems using fine-grained aquifers, which often require more frequent backflushing of ASR wells during normal operation.

Effects of Prior Treatment

Water proposed for recharge into coastal Georgia ASR wells would meet state and federal drinking water standards. Treatment prior to recharge would depend upon the water source, however if it is assumed that this is a river such as the Savannah, Ogeechee or Altamaha rivers, then treatment might include a range of processes such as disinfection, chemical coagulation, precipitation and filtration. Other water sources, such as brackish aquifers, might include membrane treatment such as reverse osmosis. Microfiltration or ultrafiltration processes may also be used to render the water suitable for drinking purposes or for ASR storage.

To enhance the likelihood of ASR success, water treatment process design, ASR system design, and the design of connecting piping should be integrated into a single project so that the quality of water for recharge, and the quality of water produced during recovery, are compatible with water distribution system needs and opportunities while also being compatible with aquifer mineralogy and native water quality. Where there is inadequate integration or coordination of treatment, transmission and recharge components, a higher risk exists that the ultimate plan may not work properly.

In some situations, the quality of drinking water leaving the water treatment plant is not compatible with the materials of construction for the piping in the transmission or distribution system, creating corrosion problems. Corrosion reaction products then can plug ASR wells during recharge in addition to arousing customer complaints regarding "red water" conditions. In other situations, treatment processes may continue in the piping system, creating aluminum hydroxide flocs or microbial masses, either of which can cause well plugging. Also, the geochemical and other constraints imposed by the aquifer mineralogy in the ASR storage zone may not be compatible with the quality of water available for recharge. These are not common problems, however they occur sufficiently often that they need to be considered at each ASR site. In such situations, further pretreatment of the recharge water may be required, in addition to, or instead of, more frequent backflushing of the ASR well. This may typically include filtration, sand separation or pH adjustment.

As posed in the question above, "prior treatment" is assumed to include those supplemental processes that may be required in addition to treatment to meet drinking water standards. Prior treatment may therefore include supplemental filtration, sand separation or pH adjustment. Supplemental filtration has never been required for recharge of ASR wells in the Floridan aquifer storing treated drinking water. This reflects the high quality of the water source and the high permeability of the storage zone typically utilized for ASR storage.

Sand separation is sometimes required in areas utilizing sand and sandstone aquifers for production purposes, or for ASR storage, since sand may accumulate in distribution systems even though it is not present at significant concentrations in the water leaving the water treatment plant. During ASR recharge, flow direction in nearby portions of the water distribution system may reverse direction, flushing sand deposits into the ASR well and contributing to well plugging. This is also not a problem for ASR systems utilizing the Floridan aquifer.

pH adjustment of the recharge water is uncommon in drinking water ASR systems, occurring where needed to control mobilization of manganese and arsenic, or precipitation of ferric oxyhydroxide during ASR storage. pH adjustment tends to condition a portion of the aquifer in a short radial distance around an ASR well so that undesirable reactions are either controlled or do not occur. Such reactions include control of iron precipitation as ferric oxyhydroxide, manganese solution, and also solution of arsenic. At the edge of this treatment zone, no change in pH would be anticipated.

In a few states, laws or regulations have been implemented or are under consideration that call this short radial distance a "Zone of Discharge (ZOD)" or an "ASR Management Zone (AMZ)," within which natural subsurface treatment is allowed to occur. In the Netherlands, this practice has been utilized for over 50 years to treat the water supply for the City of Amsterdam. It is also practiced in Australia, to improve the quality of recharge water being stored in aquifers containing brackish water. In the United States such practice is probably consistent with federal law (1974 Safe Drinking Water Act) but may be inconsistent with the current interpretation of EPA regulations promulgated in 1981 pursuant to that law.

Mixing Effects in General

As described above, mixing effects occur within the target storage volume for an ASR well, which is usually within a radius of a few hundred feet. For very thin aquifers and large storage volumes, the TSV may extend to perhaps as far as 1000 to 2000 ft radius, however that would be unusual.

Mixing effects would include primarily dispersion but also diffusion. Dispersion would be advective, including movement downgradient away from the ASR well due to the slope of the potentiometric surface in the upper Floridan aquifer, as shown in Figure 1. Lateral dispersion would also occur around an ASR well, due to mixing between stored water and native groundwater during recharge and recovery operations. To put these into perspective, the diameter of a typical stored water bubble might be 1000 ft. During a typical six month period between the middle of recharge and the middle of recovery, this bubble might move downgradient about 100 ft due to the steep gradient of the potentiometric surface in the Savannah area. If the same volume of water stored is recovered, the quality of the water at the end of recovery would represent a blend of recharge water and native groundwater in the aquifer. Fortunately in the Savannnah area, the two water qualities are probably similar so there would be no practical adverse effects due to mixing. However in other areas where the Floridan aquifer is brackish, this level of mixing may impact ASR operations by creating a situation where some of the stored water is lost every year. Where the value of stored water is high, this could be a substantial annual cost, perhaps necessitating selection of a different site in the same aquifer, or a different aquifer for storage. Fortunately such situations are rare for ASR wells.

Diffusion would also occur, between the solution channels within the limestone, and the adjacent pores within the limestone. However, this "dual porosity" aspect of Floridan aquifer limestones is believed to be a relatively insignificant mechanism affecting quality of the recovered water during initial ASR testing and operations.

(2) Potential for introduction of regulated or radioactive (ie: tritium) chemicals into the subsurface, and in the event that if such chemicals are introduced, the viability of successfully removing such chemicals and preventing them from being introduced into a public drinking water distribution system.

Water proposed for recharge into ASR wells in coastal Georgia would probably be from a public drinking water distribution system. Monitoring programs are already in place, or would be required, to protect public health and water quality. If any regulated or radioactive chemicals are in the drinking water, their introduction into ASR wells may be considered a much smaller threat to public health than their direct consumption for public supply purposes. Many regulatory procedures are in place to ensure the high quality and reliability of water provided to the public for drinking purposes in Georgia. Since the continued availability of this valuable resource is threatened by salt water intrusion in some areas, ASR is a water management tool under consideration to enhance water supply reliability by helping to control salt water intrusion.

Many barriers are available to protect public health and drinking water quality. In the event of contamination of any surface water source, such as due to an accidental spill of contaminants, the water treatment plant intake could be shut down until the contaminants have passed by. Monitoring systems are in place on the Savannah River for this purpose, and others could be added if other rivers are developed for water supply purposes. A second barrier to protect public health is the water treatment plant, to the extent that treatment processes are capable of treating the contaminants of concern. A third barrier is that ASR recharge would probably only occur during high flow months of the year, so any source water contamination occurring at other times of the year would not lead to aquifer recharge of those contaminants able to pass through the water treatment plant. A fourth barrier is that contaminants able to pass through the water treatment plant processes would tend to be non-reactive, traveling easily with the water. As a result they should be removable from an ASR well by pumping to waste a sufficient volume of water from the well so that concentrations of the contaminant are reduced to acceptable levels. Typically this might include pumping 1.5 to 2 times the volume of contaminated water introduced into the well. Assuming that any contaminant spill is detected within one day, recovery of at least 4 MG of stored water should resolve the problem. This would require about two days. A fifth barrier is that any portion of the contaminant remaining underground in the ASR well despite each of the first four barriers, would be subject to natural attenuation due to mixing, geochemical and bacterial processes in the aquifer during storage, prior to recovery. The ASR well could be operated in more of a production well mode for a limited time period, such as recovering 120 percent of the recharge volume each year, thereby controlling movement of the contaminant toward adjacent wells and ensuring that all stored water is recovered from the ASR well. This water would not be sent into the public distribution system until testing indicates that it meets applicable water quality standards.

The presence of tritium in water from the Savannah River is widely known. The Beaufort Jasper Water and Sewer Authority obtains its water supply from this river, and has maintained records of tritium levels for many years. Tritium has a half-life of 13.4 years, so activity levels are declining. Typical tritium activity levels at the water treatment plant intake location on the Savannah River from July 1987 to June 1998 ranged from a maximum of 4460 picoCuries/litre (pCi/L) in January 1989 to a minimum of 111 pCi/L in April 1993. The drinking water standard for tritium is 20,000 pCi/L, so at no time did the activity level exceeded 25 percent of the standard during this monitoring period. Furthermore, a clear declining trend in tritium concentrations is evident in the data from this period of record.

Recharge water containing any tritium and entering an ASR well will probably be recovered for direct potable use within a few months of storage. However any portion of the water remaining underground will tend to move toward a point of discharge, such as an adjacent well. Assuming subsurface movement of between 35 and 350 feet per year in coastal Georgia, due to the gradient of the potentiometric surface, the distance to an adjacent water supply well that would achieve a further half-life reduction of tritium activity would be 470 to 4,700 feet. This is provided only as a point of reference, since all such activity levels are consistent with drinking water standards.

(3) Potential impact upon wells belonging to other persons (ie: loss of water)

Potential impacts may include changes in water levels or changes in water quality, both of which have been discussed above. Careful siting of any ASR facility will ensure that no adverse effects result from ASR operations.

Changes in water levels will depend upon the intended use of an ASR system. If it is used only for seasonal water storage, water levels in adjacent wells will be unchanged on an annual average basis, however they will rise during recharge periods and fall during recovery periods. The amount of rise and fall will need to be determined on a site-specific basis, however Table 1 provides a preliminary estimate based upon representative data for the Savannah area. If the ASR system is intended for multiple uses, such as seasonal storage and also salt water intrusion control, then average water levels will tend to rise, offsetting the substantial decline that has occurred during the last few decades of heavy groundwater production. This would tend to reduce pumping costs for adjacent well owners.

Changes in water quality are not expected outside the radius associated with the target storage volume for an ASR well. As described above, for a typical ASR well in the upper Floridan aquifer in the Savannah area, the radius of the TSV is estimated at approximately 2000 feet or less, associated with seasonal water storage operations. Adjacent wells located outside this radius would be unlikely to experience any change in water quality associated with seasonal storage operations. If much greater volumes are stored, or if storage durations are such that considerable advective transport of the stored water occurs, it is possible that adjacent wells located downgradient of the ASR well might experience a slight change in water quality, associated with blending treated drinking water with the fresh water naturally occurring in the aquifer.

(4) Other negative impacts

We are aware of no other negative impacts upon groundwater quality, public health or the environment, associated with ASR operations at 39 sites around the United States. The principal driver for implementation at these sites has been the relatively low cost of meeting urban and ecosystem water needs with ASR technology, compared to other conventional options. Typically ASR can meet these needs at less than half the capital cost of other options.

A very important secondary driver has been the perceived environmental benefits of ASR compared to other water storage technologies. In particular, ASR has been supported by many water management and regulatory agencies as a desirable approach that provides sustainable water supplies, reducing or eliminating the need for diverting water from rivers and lakes during dry periods, maintaining minimum flows and levels, and reducing or eliminating the need for construction and operation of surface storage reservoirs.

Opposition to ASR has occurred at two locations that we are aware of. The first was in Kerrville, Texas, about five to eight years ago when whitewater kayaking recreational interests intervened legally to block efforts by the Upper Guadalupe River Authority to operate an ASR system that they had already constructed and tested. Their opposition was based upon concern regarding diverting water from the river at high flow periods. After three court decisions in three years, that legal challenge was ended and the Kerrville ASR system is now in satisfactory operation, with expansion underway. The second area of legal opposition has been in coastal Georgia, which has been the subject of this brief report.

Other technical and regulatory issues have arisen on virtually all of the operating ASR sites, and have been successfully resolved. Typically the first ASR system in each new state requires a lot of effort to resolve issues and questions that are raised. Once the first system is constructed and placed into operation, other systems usually follow rapidly to capitalize on the benefits and cost-savings of ASR.

Some more common water quantity issues have included whether or not water can be stored in wet periods and recovered in dry periods, as intended, or whether recharge and recovery should be constrained to occur within a calendar year or a water year, regardless of whether or not that year is relatively wet or dry. Ownership or permitted rights to the stored water is also an issue in some areas, although the direction of legal and regulatory decisions is to sustain permitted rights to recover the stored water from an ASR well, rather than requiring separate permits for recharge and for recovery. Mitigation of any significant adverse effects upon water levels in wells of adjacent well owners has sometimes arisen as a site-specific issue. And the definition of ambient groundwater quality in a proposed storage zone has been the subject of recent discussion in Florida, whether to evaluate this based upon pumping a well for a few hours or days until water quality reaches an equilibrium, or to define it after sampling three casing volumes immediately after well construction, regardless of whether water quality equilibrium has been reached.

A high profile, current ASR water quantity issue that is now the subject of much discussion is the planned Comprehensive Everglades Restoration Program in south Florida. That plan includes over 300 ASR wells capable of recharging and recovering water at combined rates up to two billion gallons per day. Concern has been expressed that such high rates may hydrofracture the Hawthorn confining layer over the upper Floridan aquifer, which is proposed as the storage zone. The confining layer is about 600 feet thick and is composed of stiff clays, low permeability limestones and clayey sands. A series of ASR Demonstration Sites are planned to gather the information needed to properly address this issue. Preliminary modeling conducted by CH2M HILL suggests that this should not be a problem. It is significant, perhaps, to the proposed regional ASR applications in coastal Georgia since this Florida project is the first planned large-scale regional application of ASR technology.

Some water quality issues of concern at different sites have included the need for control of iron, manganese, fluoride, hydrogen sulfide, chloride, total dissolved solids, sulfate, arsenic, radium (224, 226, 228), radon, gross alpha radioactivity, disinfection byproducts, coliform bacteria, protozoa, viruses, nitrate, nitrite, ammonia, phosphorus, mercury, dissolved gases, and other natural constituents sometimes found in native groundwaters or in aquifer minerals. For some of these issues, the effort required to achieve resolution has been time consuming, however in each case to date a satisfactory resolution has been found, enabling these projects to move forward.

Conclusion

Experience during the past 17 years with ASR development in other states has shown that initial uncertainties, such as the questions posed in this memorandum, are relatively normal. It is hoped that the responses that have been offered will prove helpful in guiding future ASR development in coastal Georgia and other parts of the state, providing one more proven water management tool to those charged with managing regional water resources and providing urban, domestic, agricultural and industrial water supplies.

Full confidence in the applicability of ASR technology in Georgia can only come from having at least one full size ASR well constructed, tested, permitted and placed into operation. Until that time arrives, partial confidence can be achieved through literature reviews, studies, investigations, modeling, and site visits to other nearby operating ASR sites utilizing the upper or lower zones of the Floridan aquifer as a storage zone. In South Carolina, such sites are located at Beaufort Jasper Water and Sewer Authority, Mt Pleasant Waterworks, and Grand Strand Water and Sewer Authority, while an additional site is approaching completion of testing at Kiawah Island. In Florida, the nearest operational ASR sites are at the City of Cocoa, Town of Palm Bay, City of Tampa, Manatee County, Peace River/Manasota Regional Water Supply Authority and City of Boynton Beach.

To assist in this process, pertinent references regarding ASR are included at the end of this report. Several web sites have also been developed for ASR, including www.asrforum.com, which has links to some of the other web sites.

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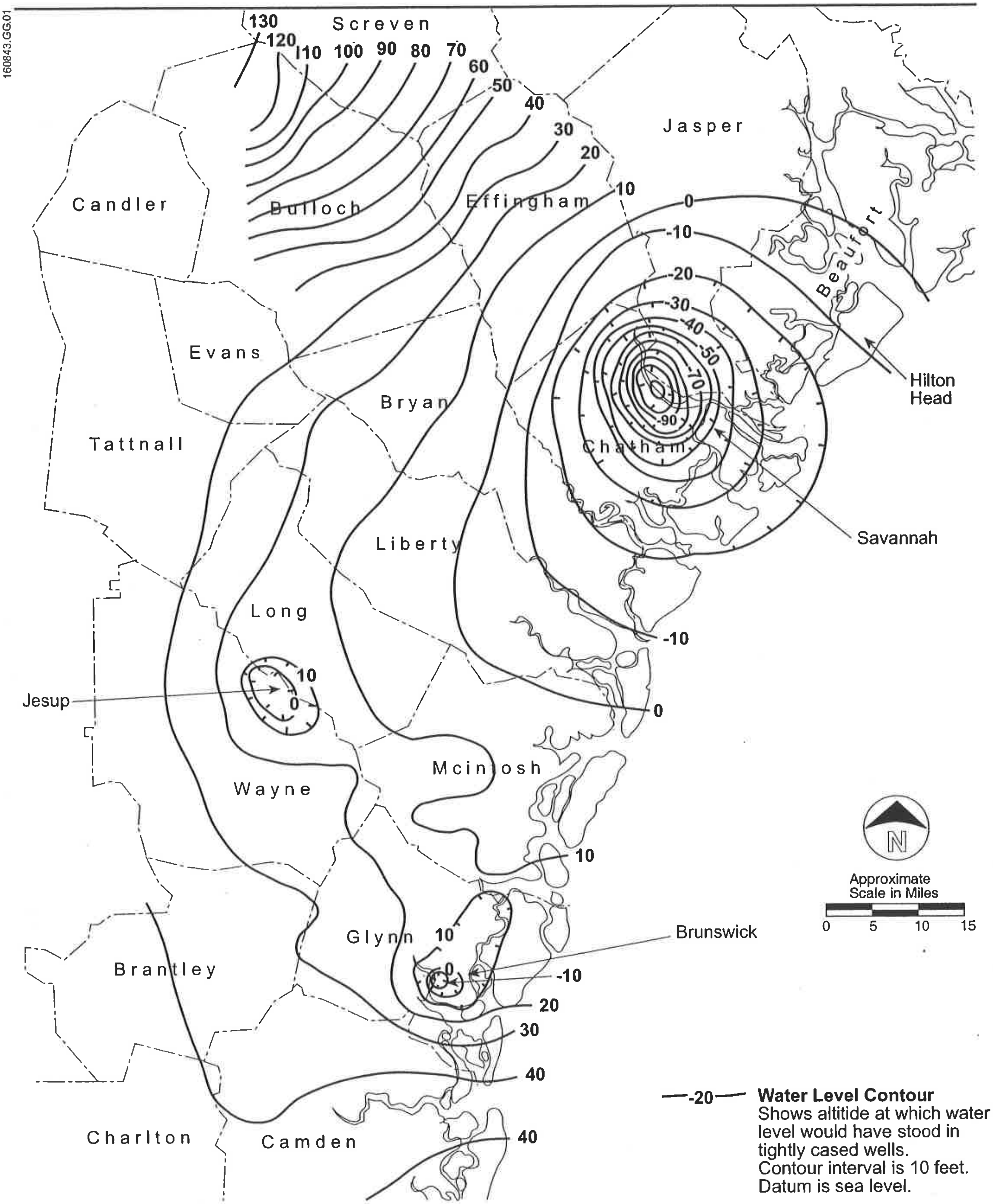

(U.S. Geological Survey, 1996)

Figure 1. Upper Floridan Aquifer Potentiometric Surface, May 1988.

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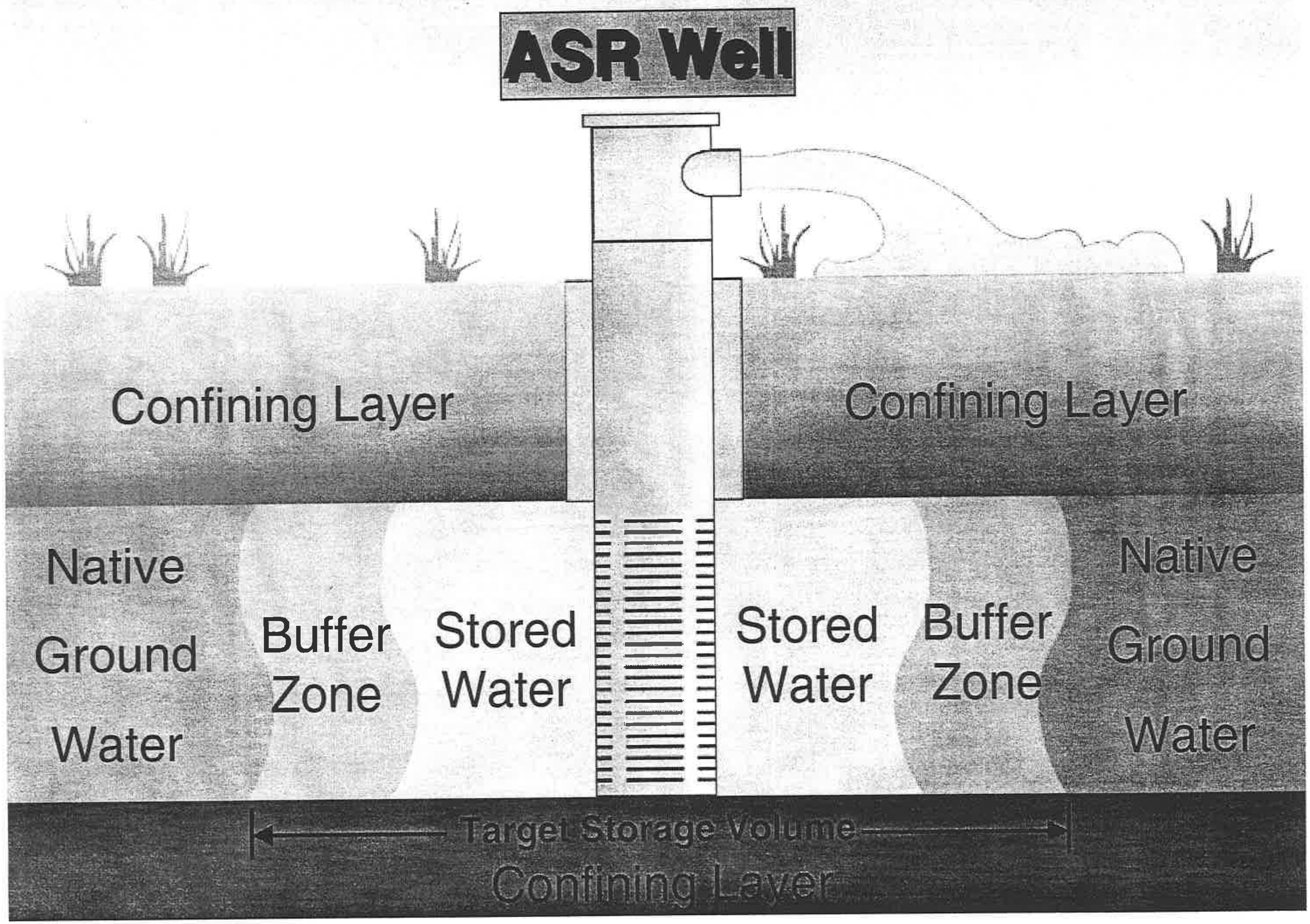

Figure 2. Aquifer Storage Recovery Diagram.

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APPENDIX 2

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Golder Associates

TRANSMITTAL LETTER

TO: Georgia Geologic Survey
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DATE: April 27, 2001
Project No.:003-3019.002

ATTN: Dr. William McLemone
State Geologist

Sent by: Jim Renner

- ☐ Mail
- ☐ Air Freight
- ☐ Hand Carried
- ☐ Under Separate Cover
- ☐ Enclosed
- ☒ Federal Express

QUANTITY	ITEM	DESCRIPTION
3	Reports	Report on Environmental Review of Aquifer Storage and Recovery in the Floridian Aquifer of Coastal Georgia
Remarks:		

Per:

Golder Associates Inc.

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Golder Associates

REPORT ON ENVIRONMENTAL REVIEW OF AQUIFER STORAGE AND RECOVERY IN THE FLORIDAN AQUIFER OF COASTAL GEORGIA

Submitted to:

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April 2001 003-3019.002

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EXECUTIVE SUMMARY

The Georgia Environmental Protection Division Geologic Survey Branch (GAEPD) requested that Golder Associates Inc. identify environmental impacts that might arise from construction and operation of an aquifer storage and recovery (ASR) system in the Floridan Aquifer of coastal Georgia. This review included an examination of the following issues identified by GAEPD as being of significance to coastal Georgia stakeholders:

- Movement and distribution of water recharged to the aquifer;
- Pressure effects resulting from injection, including ground stability or water level impacts on wells adjacent to the ASR well field;
- Alteration of the quality of the water recharged to the aquifer (including the likely effects of chemical reaction between the recharged water and the Floridan Aquifer limestones);
- Alteration of the quality of any in situ groundwater affected by ASR operations (including general mixing effects and the effect of mixing aerobic and anaerobic water);
- Potential for the introduction of regulated or radioactive substances (e.g. tritium) to the Floridan Aquifer; and
- Likelihood that contamination can be successfully remediated.

Golder Associates performed a limited review and assessment of the published and unpublished technical literature on ASR and considered the physical and hydrochemical processes of ASR in light of the characteristics of the Upper and Lower Floridan Aquifers. No instances where aquifers have become polluted as a consequence of ASR have been reported by EPA. In addition, no literature was reviewed that identified physical impacts resulting from an operating ASR. However, physical and hydrochemical processes of ASR could result in environmental impacts depending on the design and operation of a specific ASR system, the characteristics of the storage aquifer and confining or interconnected units, and the utilization of other production wells. Potential impacts of ASR in the Floridan Aquifer of coastal Georgia might include:

Lower Floridan Aquifer

- Generation of suspended iron and manganese oxi-hydroxide sediment due to dissolved oxygen in the injected water;
- Generation of Disinfection by Products (DBP's) as a consequence of organic matter oxidation by disinfection chemicals present in the injected water;
- Increased solute concentrations in the Upper Floridan Aquifer as a consequence of the ASR-induced displacement of poor quality water from the Lower Floridan.

Upper Floridan Aquifer

- Uncontrolled discharge from improperly abandoned wells, loss of yield in nearby production wells, and ground destabilization effects linked to water level changes during injection and recovery;
- Suspended sediment and DBP generation similar to that described for the Lower Floridan Aquifer;
- Increased concentration of dissolved uranium due to oxidation of uranium-bearing minerals by dissolved oxygen in the injected water;
- Increased sulfate and metal concentrations and decreased pH as a consequence of pyrite oxidation in the Upper Confining Unit due to ASR-induced dewatering of the unit;
- Lateral migration of poor quality water to other production wells due to flow in large diameter conduits in the southern coastal area and steep hydraulic gradients in the northern coastal area;
- Diffusion of exchange of solutes between the injected water and the aquifer matrix.

In each case, the probability of the impact being realized, the severity of the impact, and the need for and design of impact mitigation measures could be assessed by site-specific investigations for a proposed ASR. Such investigations would:

- Describe the local geology, hydrogeology, and hydrochemistry;
- Model the behavior of the aquifer and associated units during alternative injection and recovery scenarios;
- Define source-pathway-receptor relationships (e.g. the influence of the proposed ASR on other production wells or sensitive hydrologic systems).

Following the initial assessment, pilot testing would be an effective means of validating models, making direct observations of physical and hydrochemical processes, and comparing alternative ASR designs and operating schedules. Finally, monitoring water quality, aquifer characteristics, and ground conditions in potentially sensitive areas during ASR operation would alert operators to possible concerns. Such a monitoring program implies effective facility maintenance, staffing, and operator training as a necessary requirement of ASR operation.

In summary, ASR has the potential to be a useful water resource management tool in coastal Georgia. Some concerns have been identified, but no environmental impacts have been identified that could not potentially be mitigated. An active permit program administered by GAEPD could insure that pre-construction investigations, pilot testing, and ASR design, operation, and monitoring are adequate to achieve the water resource management benefits while mitigating environmental impacts.

1.0 INTRODUCTION

1.1 Background

Aquifer storage and recovery (ASR) is a water resources management technique in which treated water is stored by injection into permeable geologic formations. Common ASR applications include:

- Meeting demand during periods when the available reserves of raw water are depleted (during droughts, for example);
- Meeting demands which exceed the available treatment capacity (peak demand management);
- Managing groundwater levels for the purpose of maintaining well-field yields or controlling salt-water intrusion.

During typical ASR operations, treated water from a surface source or supply aquifer is injected into an alternate aquifer when surplus water resources are available, demand is low, and surplus treatment capacity exists (Figure 1). The duration of the subsequent storage period is usually a function of seasonal influences on resource availability and demand. A combination of demand, available yield and the total volume of treated water in storage determine the rate and duration of recovery.

Operational ASR facilities are found in Europe, Africa, Australia and the United States. Systems in the United States have been in operation or in pilot studies for about thirty years, including approximately 34 facilities in Florida, several of which utilize the Floridan Aquifer. Typically, these facilities utilize either treated surface water or treated ground water as their supply source. However, Florida has recently issued two construction permits, received another construction application and held two pre-application meetings with several utilities interested in using reclaimed wastewater as an ASR source water. Raw ground water injection and raw surface water injection are also proposed (ASRIT, 1999).

In South Carolina, three ASR systems are operating and one system has been under study for 6 years (Campbell, 2000):

- The Beaufort-Jasper Water and Sewer Authority injects treated Savannah River water into the Upper Floridan Aquifer to supply peak demands during summer months, thereby avoiding the need to build an additional treatment plant. The ASR system has operated for one year. Last year 140 million gallons were injected and 120 million gallons were withdrawn at a rate of about 2.5 mgd. The withdrawn water is treated lightly (slight disinfection) and mixed with treated surface water. Plans call for increasing capacity to 500 million gallons (Saxon, personal communication).

- The Mt. Pleasant Waterworks uses reverse osmosis to treat approximately 400 to 500 gal/min (less than 1 mgd) of water withdrawn from the Cretaceous Middendorf Aquifer. Excess water is injected into the Santee Limestone, a Lower Floridan equivalent, allowing the reverse osmosis system to operate at a constant rate.
- The Grand Strand Water Authority serves the seasonal peak demand of Myrtle Beach by injecting treated surface water into the Cretaceous Black Creek Aquifer.
- The U.S. Geological Survey has been testing an emergency ASR system for the City of Charleston to provide water during severe weather when the old distribution system typically experiences problems. This system is somewhat unusual in that it will rely on one time injection of treated surface water into the Santee Limestone.

In Georgia, the state legislature has instituted a moratorium on ASR permitting in order to allow the Georgia Environmental Protection Division (GAEPD) to consider the benefits and consequences of ASR in the coastal area. Additionally, the GAEPD is interested in the utility of ASR in managing salt water intrusion in the vicinity of Savannah and Brunswick.

1.2 Report Objective and Approach

The purpose of this report is to identify environmental impacts that might arise from ASR operations in the Floridan Aquifer of coastal Georgia and to identify possible means by which impacts could be mitigated or managed. For this report, environmental impacts are taken to be any situation or circumstance that has the potential to cause harm or damage to human health or the environment, including:

- Physical impacts such as flooding, loss of well yield, and ground destabilization effects (such as ground heave, subsidence, or hydraulic fracturing);
- Water quality impacts, such as concentrations of chemicals or micro-biological organisms that are in excess of those currently permitted in drinking water.

To identify potential impacts and mitigation measures, Golder Associates Inc. (Golder) reviewed literature describing the hydrogeology and hydrogeochemistry of the Floridan Aquifer of coastal Georgia and assessed critical features of the aquifer system relative to ASR. Floridan Aquifer characteristics were then compared to theoretical and actual descriptions of ASR processes, as documented in peer-reviewed journals, conference proceedings, published and unpublished reports and on the internet. Owing to marked differences in Floridan Aquifer hydrogeology, the potential for ASR-related environmental impacts is discussed in terms of the northern (Savannah) and southern (Brunswick) coastal areas.

In identifying ASR impacts and mitigation measures, Golder made several assumptions, as directed by GAEPD:

- Any ASR system will require a permit from GAEPD;
- ASR permit applicants will have to perform site specific investigations under the direction of qualified geologists, hydrogeologists, and engineers to address the potential for adverse environmental impacts;
- Only entities with sufficient capital to invest in appropriate operational facilities, staffing, and operator training will be permitted to develop ASR;
- Any water injected into the Floridan Aquifer will meet State drinking water standards.
- Water may be injected into the Upper or Lower Floridan Aquifers, but not the Fernandina Permeable Zone.

For purposes of this report, impacts resulting from operator error (e.g. accidental injection of improperly treated water) are not emphasized since operator error is possible with any water treatment or distribution system and is not unique to ASR.

2.0 ASR PHYSICAL AND HYDROCHEMICAL PROCESSES

ASR operations initiate physical and hydrochemical processes in the storage aquifer. Physical processes include deformation of the aquifer host rock and movement of the injected or native ground water. Ground water pressure changes are often associated with physical processes. Hydrochemical processes include alteration of the chemical characteristics of the recharged water (including changes due to chemical reaction with the aquifer host rock) and alteration of the in-situ ground water quality.

2.1 Physical Processes

No literature was reviewed that identified physical impacts directly related to an operating ASR system. Nonetheless, ASR physical processes could provide an opportunity for environmental impacts, depending on the characteristics of the aquifer, the design and operation of the ASR system, and the presence of nearby sensitive receptors (other production wells).

The treated drinking water used for ASR is typically recharged using large-diameter purposefully designed injection wells or modified production wells. These wells allow the water to enter the well via the pump column, sized drop-pipes, drop pipes with flow control valves or direct injection into the annular space between the casing and the pump rising main. Recharge rates are maintained either by gravity flow or pressure in the distribution system; the choice being dependent upon the rest water level in the well and the water level rise or pressure ("head") increase which occurs in response to injection. The head build-up in the well is a function of both the hydraulic properties of the aquifer and the well efficiency; the head build-up in the aquifer is a function of the aquifer properties alone. Similar effects determine the water level response to recovery.

Storage of recharged water in confined aquifers occurs principally by elastic deformation of the aquifer matrix. However, ASR storage processes are evident as both a head level increase associated with elastic deformation and a displacement of the in situ groundwater by the injected water. Typically, the pressure effects are transmitted over larger areas than the change in water quality that is associated with displacement of the in-situ groundwater.

The shape and properties of the region of increased pressure or water level rise and the recharged water mass is a function of:

- Recharge rate and duration (total stored volume);
- Distribution of aquifer properties (vertically and horizontally);
- Presence of aquifer boundary conditions;
- Properties of the in situ groundwater (pressure, temperature, salinity);
- Pre-existing hydraulic gradients.

For a given aquifer geometry, in situ groundwater quality, and well efficiency, ASR operations in higher transmissivity/lower storativity systems produce smaller head changes and more rapid stabilization of head build-up and draw-down than equivalent operations in lower transmissivity/higher storativity systems. In all cases, transmissivity effects dominate over storativity effects.

Simultaneous ASR operations in closely spaced wells typically produce head build-ups or draw-downs that are greater than would be anticipated on the basis of the performance of each individual well. This effect arises as a consequence of the superposition of the head changes associated with each well (termed "well interference").

2.2 Water Quality Processes

The U.S. Environmental Protection Agency reported that there have been no instances where aquifers have become polluted as a consequence of ASR (EPA, 1999a). However, ASR-related changes in water quality can be observed within the stored water, in the mixing zone between the stored and in situ water, and at locations removed from the ASR aquifer and the stored water mass. Physical and chemical processes that may be responsible for such changes include:

Within the Stored Water	• Reactions between constituents in the injected water and the aquifer matrix minerals; • On-going reactions between constituents in the injected water; • Diffusion of constituents in the injected water into the matrix-held groundwater and vice-versa (in dual porosity aquifers)
In the Mixing Zone	• Reaction between dissolved constituents in the injected water and the in situ groundwater; • Hydrodynamic-dispersion of the injected water, including mechanical dispersion and diffusion

At Off-site Locations	•	Pressure displacement of in situ groundwater and migration into adjacent aquifers or surface waters.

3.0 IMPACTS AND IMPACT MITIGATION - LOWER FLORIDAN AQUIFER

3.1 Physical Effects

No adverse physical environmental impacts are anticipated from ASR operations in the Lower Floridan Aquifer due to:

- Large thickness of overlying strata (750 ft to 1500 ft).
- The postulated high permeability of the Lower Floridan Aquifer in the southern coastal area. Therefore, the pressure effects arising from injection or recovery are likely to be both small and spread over a large area.
- The absence of production wells that penetrate the Lower Floridan Aquifer.

Consequently, there is little potential for ASR-related ground destabilization, flooding, reduced yield in other wells, or other physiographic or hydrologic impacts.

3.2 Water Quality Effects

3.2.1 Suspended Sediment Formation

No data describing the redox conditions in the Lower Floridan Aquifer were available. However, given the widespread occurrence of reducing conditions in the Upper Floridan Aquifer and the origin of freshwater in the Lower Floridan Aquifer as recharge from the Upper Floridan Aquifer, it is considered likely that reducing conditions prevail in the Lower Floridan Aquifer.

When treated water containing dissolved oxygen is injected into reducing groundwaters that contain iron or manganese, oxidation of these constituents will result in the formation of oxide and oxy-hydroxide precipitates. In the conduit flow systems of the southern coastal region, these precipitates may remain suspended in solution under the influence of high groundwater velocities or turbulent flow. Such suspended material may then adversely impact the quality of groundwater that is withdrawn from affected portions of the aquifer.

The affected portion of the aquifer is likely to be restricted to the mixing zone between the injected and in-situ water in areas where (a) the mixing zone is penetrated by water supply wells and (b) the in-situ ground water contains dissolved iron and manganese. Given the limited development of the Lower Floridan Aquifer for water supply purposes and the likely presence of sulfide in the in-situ groundwater, the potential for adverse impact is small. Additionally, impacts could be effectively managed by a combination of the following measures:

- Identification of production wells in the vicinity of the mixing zone between the injected and in-situ water;
- Site specific assessment of the redox conditions and dissolved constituents in the in-situ ground water;
- Water quality monitoring during ASR pilot testing;
- Modification of the ASR location, size, and/or operations schedule (injection rate, storage duration, recovery rate, etc.);
- Relocation of potentially affected production wells if impacts are observed or predicted;
- Treatment of withdrawn water to remove suspended sediment.

3.2.2 Disinfection By-products

In ASR operation, raw water from a surface source or alternative aquifer is treated to drinking water standards prior to injection into the storage aquifer. Residual disinfectant compounds may be present in the injected water, and oxidation of organic matter in the storage aquifer may produce disinfection by-products (DBPs). Some DBPs are believed to adversely affect human health (e.g. trihalomethanes). Under circumstances in which DBPs are generated and accumulate, stored water quality may be adversely affected. ASR provides an opportunity for generation of DBPs beyond that encountered in traditional water supply operations due to the introduction of treated water after disinfection into a medium (the storage aquifer) that may contain organic matter.

The potential for forming DBPs is a function of the disinfectant (chlorine compounds are of particular concern), disinfection method (concentration, contact time, etc.), the types of organic matter present in the storage aquifer, water temperature, pH, and the concentration of bromide in the in-situ ground water. It is likely that impacts associated with DBP formation can be effectively managed by:

- Characterization of the injected and in-situ water quality and the organic matter content of the ASR aquifer matrix material;
- Modeling and assessment of the potential for DBP formation;
- ASR pilot testing and monitoring of injected, in-situ, and extracted water;
- Modification of the disinfection method of the injected water;
- Injection into a stratum with lower potential for DBP formation;
- Managing the ASR injection and extraction schedule to promote natural attenuation of the DBPs;
- Additional treatment of water extracted from the storage aquifer prior to distribution.

3.2.3 Solute Transport Effects

In localized areas of both the northern and southern coastal regions, the Lower Floridan Aquifer is thought to be in hydraulic continuity with the Upper Floridan Aquifer. In the north this is reflected in the hydraulic response of both aquifers to pumping from the Upper Floridan Aquifer. In the south it is suggested by the pattern of saline upconing in Brunswick.

If injection into the Lower Floridan Aquifer results in an increase in the head gradient across the Middle Confining Unit, upward flow from the Lower to the Upper Floridan Aquifer may be increased. In such cases, the quality of Upper Floridan Aquifer water may be adversely affected if the quality of water migrating upward from the Lower Floridan Aquifer is poor. The potential for adverse impacts to production wells in the Upper Floridan Aquifer will be a function of the in-situ water quality, local permeability distribution, the size of the proposed ASR system, and the proximity of the system to production wells in the Upper Floridan Aquifer. This suggests that the potential for any adverse impacts are likely to be local and so may be effectively managed by:

- Characterization of the groundwater quality of the Lower Floridan Aquifer;
- Assessment of the existing and predicted hydraulic gradients and the permeability of the Middle Confining Unit;
- Modeling of ground water migration under different operation conditions;
- ASR pilot testing and monitoring in the Upper and Lower Floridan Aquifers;
- Identification of local Upper Floridan Aquifer production wells, and monitoring during ASR operation;
- Alteration of the ASR operation schedule to reduce the potential for upward migration (possibly including relocation to an area where the confining unit is least permeable).

4.0 IMPACTS AND IMPACT MITIGATION - UPPER FLORIDAN AQUIFER

4.1 Physical Effects

It seems unlikely that substantial physical impacts will derive from ASR in the Upper Floridan Aquifer of the southern coastal region, principally due to a combination of the significant thickness of the overlying Upper Confining Unit and extremely high values of aquifer transmissivity. Under such circumstances, ASR-induced head changes are likely to be small and distributed over a large area, so that ground effects or interference with nearby production well yields are likely to be minimal.

By contrast, the lower transmissivity of the Upper Floridan Aquifer in the northern coastal region, combined with the reduced thickness or local absence of the Upper Confining Unit, means that there is a greater potential for ASR-related physical effects. Such effects would arise from the larger head responses that may occur in response to injection or recovery and could include:

- Uncontrolled overflow from poorly sealed or capped wells or very localized flooding by upward leakage through the Upper Confining Unit;
- Loss of yield in nearby wells;
- De-stabilization of deep foundations as a consequence of re-saturation of near surface sediments and an associated loss of mechanical strength;
- Ground heave or subsidence caused by changing pore-water pressures in near surface sediments;
- Hydraulic fracturing of confining strata.

Cooper-Jacob scoping calculations indicate that the risks are only likely to be significant in areas close to the ASR site, where the resultant potentiometric surface is at or near ground level and where exceptionally large volumes of water are recharged and recovered through networks of closely spaced wells. This suggests that the potential for any associated impact is likely to be localized and so may be effectively managed by:

- Site-specific characterization of the geology and hydrogeology at the test site;
- Hydrologic modeling to determine the magnitude of the head level changes that are likely to result from ASR operations;
- Reducing the amount of injected or recovered water;
- Modifying the ASR well-field layout so as to increase the distance between adjacent wells.
- Monitoring foundation movement and ground elevation in the immediate vicinity of injection and recovery wells during pilot testing and operation;
- Capping and/or properly abandoning unused Floridan Aquifer wells.

4.2 Water Quality Effects

4.2.1 Suspended Sediment and Disinfection By-products

The potential for formation of suspended iron and manganese oxi-hydroxide sediment and DBPs impacts in the Upper Floridan Aquifer and the opportunity for mitigating these impact is similar to the Lower Floridan Aquifer.

4.2.2 Uranium Mobilization and Introduction of Tritium

Eocene and Miocene rocks in Georgia frequently contain strata of clay, organic material, phosphates, or dolomites which contain uranium minerals. In particular, concentrations of the element are found in the phosphate bearing minerals that are distributed throughout the Upper Confining Unit.

Given the reducing conditions in the Upper Floridan Aquifer, any uranium that is present is likely to be in the form of the low solubility mineral uraninite. Under circumstances in which the uraninite comes into contact with injected water containing dissolved oxygen, however, oxidation may result in dissolution of the mineral and mobilization of the associated uranium. Where concentrations of the element accumulate, an adverse impact on the stored water quality may potentially occur.

Given that phosphate-bearing minerals are relatively uncommon, except in the Upper Confining Unit, the associated risk is likely to be localized and so may be effectively managed by:

- Characterizing the mineral assemblages present in the aquifer host rocks and the confining units, with particular emphasis on identification of uranium bearing minerals in the strata targeted for ASR development;
- Examine the accessibility of the uranium-bearing minerals to the injected water containing dissolved oxygen and predict dissolution and resultant concentrations of dissolved uranium ions;
- If necessary, identify alternate locations for the ASR system where uranium minerals are not abundant or case off individual uranium-bearing strata;
- Operate the ASR system to extend storage time to promote natural reduction of dissolved uranium.
- Monitor for dissolved uranium during ASR pilot testing and operation.

Tritium is a constituent of concern in Savannah River water due to the Savannah River Site nuclear facility upstream. Reported levels of radionuclides in Savannah River water are well below regulatory guidelines, so the likelihood of introducing tritium into an ASR system that made use of Savannah River water would appear to be low. In addition, the City of Savannah and other entities already use the Savannah River as a raw water supply. Therefore, the risk of utilizing Savannah River water for ASR does not seem to be substantially different than the risk now accepted by existing water users, except that the processes of diffusion exchange and advective transport described below could influence the transport of tritium introduced into the aquifer.

4.2.3 Pyrite Oxidation

Although not detected during visual inspection of cores and washed samples (USGS, personal communication), pyrite may be locally present in the clays, silts and sandy clays of the Upper Confining Unit. If groundwater withdrawal from the Upper Floridan Aquifer dewaters the Upper Confining Unit, pyrite may be oxidized, possibly causing adverse sulfate, pH, iron or alkali metal impacts on the quality of the recovered water. The magnitude of the impact will be a function of the amount of pyrite present, the permeability of the Upper Floridan Aquifer and the Upper Confining Unit, and the extent to which withdrawals induce dewatering of the Upper Confining Unit. Special attention should be paid to pyrite oxidation in areas where the Upper Confining Unit has already been dewatered by extensive pumping. Impacts from pyrite oxidation may be effectively managed by:

- Quantify the pyrite content of the Upper Confining Unit strata likely to be affected by the proposed ASR operations;
- Predict the draw-down likely to be experienced during the extraction of the stored water;
- If necessary, relocate the ASR system to a more favorable location;
- Reduce the amount of stored water that is recovered in an individual well;
- Increase the spacing between extraction wells to minimize exaggerated drawdown caused by well interference;
- Monitor water quality during ASR pilot testing and operation;

4.2.4 Advective Transport

Poor quality water generated by any of the mechanisms previously described could laterally migrate within the Upper Floridan Aquifer due to:

- The concentration of flow in large-diameter conduits such as cavities and solution channels in the southern coastal region;
- The occurrence of steep hydraulic gradients in areas close to Savannah in the northern coastal region;

- The presence of a large number of public and private water supply wells in both the northern and southern coastal regions.

The potential for extensive lateral migration of poor quality water could be effectively reduced by:

- Employing previously described measures to limit the opportunity to generate poor quality water;
- Controlling the ASR injection and extraction schedule and well locations to avoid substantial steepening of hydraulic gradients;
- Monitoring water quality in nearby production wells.

4.2.5 Diffusion Exchange of Solutes

Where groundwater flow in the Upper Floridan Aquifer of the northern coastal region occurs through fractures, the moderate hydraulic conductivity of the unit suggests that these may include a significant number of relatively small-scale features. A group of small-scale fractures has greater surface area relative to the amount of void space versus a large fracture. If the fractured matrix also possesses significant porosity, solute species flux between the fractures and the matrix via the process of diffusion exchange. Under these circumstances, poor quality water that enters the system may partition between the water in the fractures and the matrix-held pore water. Therefore, if ASR introduces or generates poor quality ground water, the poor quality water and/or undesirable constituents may be retained longer than would be predicted for ground water flow in large scale fractures.

The options for mitigating the impact of solute exchange and extended retention of poor quality water are the same as those for managing other water quality concerns. In addition, if an acute water quality problem were identified (e.g. accidental injection of poor quality water) it might be prudent to monitor the recovered water for constituents of concern for an extended period.

While the process of diffusion exchange could also occur in the Upper Floridan Aquifer of the southern coastal region, the associated impact is likely to be mitigated by the concentration of flow in this system in large-diameter conduits.

5.0 SUMMARY

No instances where aquifers have become polluted as a consequence of ASR have been reported by EPA. In addition, no literature was reviewed that identified physical impacts resulting from an operating ASR. However, physical and hydrochemical processes of ASR can result in environmental impacts depending on the design and operation of the ASR system, the characteristics of the storage aquifer and confining or interconnected units, and the utilization of other production wells. Potential impacts of ASR in the Floridan Aquifer of coastal Georgia could include:

Lower Floridan Aquifer

- Generation of suspended iron and manganese oxi-hydroxide sediment due to dissolved oxygen in the injected water;
- Generation of DBP's as a consequence of organic matter oxidation by disinfection chemicals present in the injected water;
- Increased solute concentrations in the Upper Floridan Aquifer as a consequence of the ASR-induced displacement of poor quality water from the Lower Floridan.

Upper Floridan Aquifer

- Uncontrolled discharge from improperly abandoned wells, loss of yield in nearby production wells, and ground destabilization effects linked to water level changes during injection and recovery;
- Suspended sediment and DBP generation similar to that described for the Lower Floridan Aquifer;
- Increased concentration of dissolved uranium due to oxidation of uranium-bearing minerals by dissolved oxygen in the injected water;
- Increased sulfate and metal concentrations and decreased pH as a consequence of pyrite oxidation in the Upper Confining Unit due to ASR-induced dewatering of the unit;
- Lateral migration of poor quality water to other production wells due to flow in large diameter conduits in the southern coastal area and steep hydraulic gradients in the northern coastal area;
- Diffusion of exchange of solutes between the injected water and the aquifer matrix.

In each case, the probability of the impact being realized, the severity of the impact, and the need for and design of impact mitigation measures may be assessed by site-specific investigations for a proposed ASR (Table 1, Table 2). Such investigations would:

- Describe the local geology, hydrogeology, and hydrochemistry;

- Model the behavior of the aquifer and associated units during alternative injection and recovery scenarios;
- Define source-pathway-receptor relationships (e.g. the influence of the proposed ASR on other production wells or sensitive hydrologic systems).

Following the initial assessment, pilot testing would be an effective means of validating models, making direct observations of physical and hydrochemical processes, and comparing alternative ASR designs and operating schedules. Finally, monitoring water quality, aquifer characteristics, and ground conditions in potentially sensitive areas during ASR operation would alert operators to possible concerns. Such a monitoring program implies effective facility maintenance, staffing, and operator training as a necessary requirement of ASR operation.

In summary, ASR has the potential to be a useful water resource management tool in coastal Georgia. Some concerns have been identified but no environmental impacts have been identified that could not potentially be mitigated. An active permit program administered by GAEPD could insure that pre-construction investigations, pilot testing, and ASR design, operation, and monitoring are adequate to achieve the water resource management benefits while mitigating environmental impacts.

TABLE 1 (1 of 2)
Potential Impacts Associated with ASR Operations in the Lower Floridian Aquifer

Potential Environmental Impact	Responsible Process(es)	Region Where Impact Most Likely to be Experienced	Mitigation or Management Strategy
Increasing solute concentrations in the Upper Floridan	Pressurization of the Lower Floridan as a consequence of injection and upward migration of poor quality groundwater under the influence of increasing vertical head gradients	Areas where the treated water is injected into poor quality in-situ groundwater, where upward vertical head gradients are likely to develop as a consequence of injection and where there exists a pathway between the Upper and Lower Floridan	• Characterization of the groundwater quality of the Lower Floridan Aquifer; • Assessment of the existing and predicted hydraulic gradients and the permeability of the Middle Confining Unit; • Modeling of ground water migration under different operating conditions; • ASR pilot testing and monitoring in the Upper and Lower Floridan Aquifers; • Identification of local Upper Floridan Aquifer production wells, and monitoring during ASR operation; • Alteration of the ASR operation schedule to reduce the potential for upward migration (possibly including relocation to an area where the confining unit is least permeable).
Increasing concentrations of disinfection by-products (DBP's)	Oxidation of organic matter by (disinfection) chemicals present in the injected water	Stored water in areas where the potential for in-situ formation of DBP's is high	• Characterization of the injected and in-situ water quality and the organic matter content of the ASR aquifer matrix material; • Modeling and assessment of the potential for DBP formation; • ASR pilot testing and monitoring of injected, in-situ, and extracted water; • Modification the disinfection method of the injected water; • Injection into a stratum with lower potential for DBP formation; • Managing the ASR injection and extraction schedule to promote natural attenuation of the DBPs; • Additional treatment of water extracted from the storage aquifer prior to distribution.

TABLE 1 (continued 2 of 2)

Generation of suspended sediment and increasing turbidity	Oxidation of any dissolved iron or manganese that is present in the in-situ groundwater	The mixing zone between the stored water and in-situ groundwater in areas where the in-situ groundwater contains dissolved iron or manganese.	• Site specific assessment of the redox conditions and dissolved constituents in the in-situ ground water; • Identification of production wells in the vicinity of the mixing zone between the injected and in-situ water; • Water quality monitoring during ASR pilot testing; • Modification of the ASR location, size, and/or operations schedule (injection rate, storage duration, recovery rate, etc.); • Relocation of potentially affected production wells if impacts are observed or predicted; • Treatment of withdrawn water to remove suspended sediment.

TABLE 2 (1 of 3)
Potential Impacts Associated with ASR Operations in the Upper Floridian Aquifer

Potential Environmental Impact	Responsible Process(es)	Region Where Impact Most Likely to be Experienced	Mitigation or Management Strategy
Flooding, loss of yield and ground destabilization	Water level changes associated with injection and recovery	Regions close to the ASR well(s) in areas where either the permeability of the Upper Floridan aquifer is relatively low, large quantities of treated water are injected and recovered or where the Upper Confining Unit is thin or absent.	• Site-specific characterization of the geology and hydrogeology at the test site; • Hydraulic modeling to determine the magnitude of the head level changes that are likely to result from ASR operations; • Reducing the amount of injected or recovered water; • Modifying the ASR well-field layout so as to increase the distance between adjacent wells. • Monitoring foundation movement and ground elevation in the immediate vicinity of injection and recovery wells during pilot testing and operation; • Capping and/or properly abandoning unused Floridan Aquifer wells.
Increasing solute concentrations	Lateral migration of any poor quality groundwater that enters the Upper Floridan from the Lower	Wells with capture zones that intersect pathways between the Upper and Lower Floridan through which poor quality groundwater could migrate from the underlying Lower Floridan.	• Employing measures described in Table 1 to limit the opportunity to generate poor quality water; • Controlling the ASR injection and extraction schedule and well locations to avoid substantial steepening of hydraulic gradients; • Monitoring water quality in nearby production wells. • Extended monitoring if diffusion exchange is a concern.

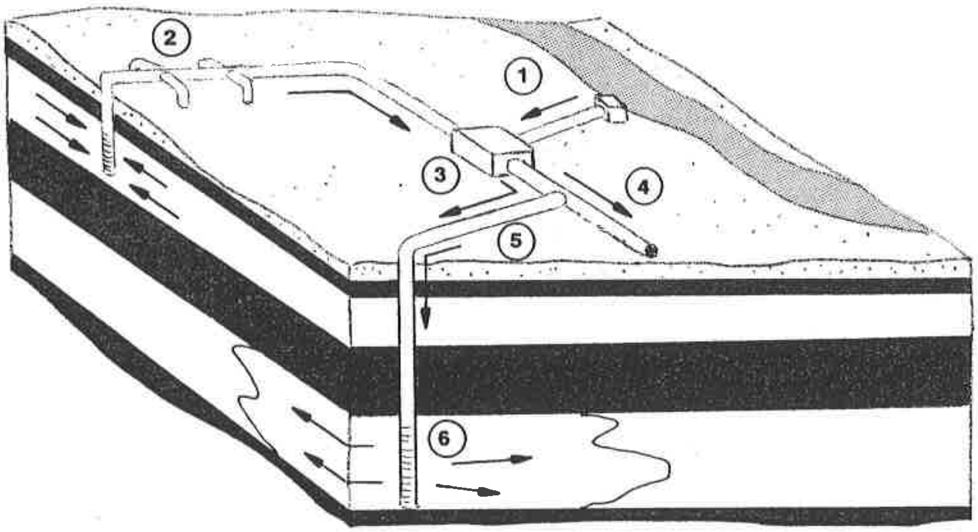
TABLE 2 (continued 2 of 3)

Increasing concentrations of disinfection by-products (DBP's)	Oxidation of organic matter by (disinfection) chemicals present in the injected water	Stored water in areas where the potential for in-situ formation of DBP's is high	• Characterization of the injected and in-situ water quality and the organic matter content of the ASR aquifer matrix material; • Modeling and assessment of the potential for DBP formation; • ASR pilot testing and monitoring of injected, in-situ, and extracted water; • Modification the disinfection method of the injected water; • Injection into a stratum with lower potential for DBP formation; • Managing the ASR injection and extraction schedule to promote natural attenuation of the DBPs; • Additional treatment of water extracted from the storage aquifer prior to distribution.
Introduction of tritium and increasing concentrations of uranium	Oxidative dissolution of uranite	Stored water in regions where dissolved oxygen is likely to come into contact with uranite, including by migration into the base of the Upper Confining Unit.	• Characterizing the mineral assemblages present in the aquifer host rocks and the confining units, with particular emphasis on identification of uranium bearing minerals in the strata targeted for ASR development; • Examine the accessibility of the uranium-bearing minerals to the injected water containing dissolved oxygen and predict dissolution and resultant concentrations of dissolved uranium ions; • If necessary, identify alternate locations for the ASR system where uranium minerals are not abundant or case off individual uranium-bearing strata; • Operate the ASR system to extend storage time to promote natural reduction of dissolved uranium. • Monitor for tritium and dissolved uranium during ASR pilot testing and operation.

TABLE 2 (continued 3 of 3)

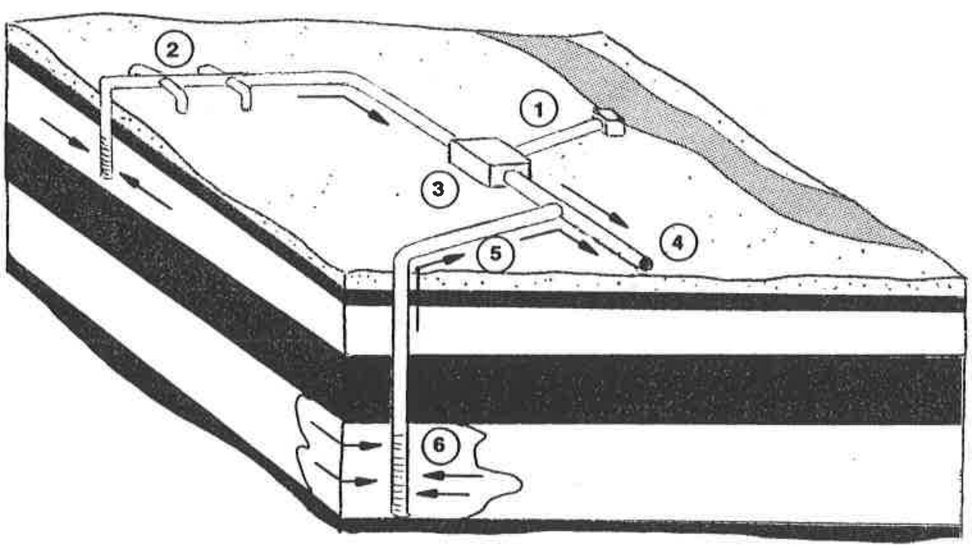
Increasing sulphate and trace metal concentrations and decreasing pH	Dewatering of Upper Confining Unit strata during recovery of the stored water and oxidation of pyrite or mobilization of historical pyrite oxidation products	Recovered water where recovery results in dewatering of the Upper Confining Unit or stored water where injection raises the water level in the Upper Floridan into previously dewatered Upper Confining Unit strata that originally contained pyrite.	• Quantify the pyrite content of the Upper Floridan Aquifer and Upper Confining Unit strata likely to be affected by the proposed ASR operations; • Predict the draw-down likely to be experienced during the extraction of the stored water; • If necessary, relocate the ASR system to a more favorable location; • Reduce the amount of stored water that is recovered in an individual well; • Increase the spacing between extraction wells to minimize exaggerated drawdown caused by well interference; • Monitor water quality during ASR pilot testing and operation;

FIGURES



1. RAW WATER WITHDRAWAL FROM RIVER
2. RAW OR POTABLE WATER WITHDRAWAL FROM ALTERNATIVE SUPPLY AQUIFER
3. WATER TREATMENT PLANT
4. TREATED WATER TO USERS
5. TREATED WATER TO RECHARGE WELL
6. TREATED WATER INJECTED INTO STORAGE AQUIFER

RECHARGE DURING LOW DEMAND PERIOD OR WET SEASON



1. NO OR REDUCED WITHDRAWAL FROM RIVER
2. NO OR REDUCED WITHDRAWAL FROM ALTERNATIVE AQUIFER
3. WATER TREATMENT PLANT
4. TREATED WATER TO USERS (INCLUDING RECOVERED WATER)
5. RECOVERED WATER ADDED TO DISTRIBUTION SYSTEM WITH MINOR TREATMENT (e.g., DISINFECTION)
6. STORED TREATED WATER RECOVERED FROM AQUIFER

WITHDRAWAL DURING PEAK DEMAND PERIOD OR DRY SEASON

Golder Associates Atlanta, Georgia

TITLE: CONCEPTUAL ASR OPERATION

CLIENT/PROJECT: GAEPD/ASR/GA

DRAWN RJS	DATE 12/00	JOB NO. 003-3019
CHECKED	SCALE N.T.S.	DWG NO. / REV. NO.
REVIEWED	FILE NO. 003-3019	SUBTITLE / FIGURE NO. 1

APPENDICES

APPENDIX A

Summary of Documented Environmental Impacts of ASR Operation

APPENDIX A

Summary of Documented Environmental Impacts of ASR Operation

A.1 Physical Impacts

Physical impacts associated with ASR operations theoretically include flooding, interference with nearby production wells, and ground stability effects. No examples of any such effects could be found in the literature, although routine assessment of the associated risks was apparent.

A.2 Water Quality Impacts

Hydrogeochemical processes that have the potential to impact ASR water quality include reduction-oxidation reactions, dissolution, and ion exchange. These processes may act singly or in combination, with the associated water quality changes being observed in either the stored water mass or the mixing zone between the stored water and the in situ groundwater. Solute transport processes that may subsequently act to influence the movement and distribution of ASR-related poor quality water include advection, mechanical dispersion, and diffusion.

Examples of ASR facilities where there has been an observable (but not necessarily critical) hydrogeochemical impact on the quality of either the recovered water or in situ groundwater include:

- Tri-halomethane (THM) impacts on the quality of water recovered from an ASR scheme in the basin sediments of Las Vegas, NV (Thomas et al, 2000 and Landmeyer et al, 2000);
- Nickel and arsenic concentration impacts on the quality of water recharged to a series of sandy aquifers in the Netherlands (Stuyfzand, 1998a);
- Iron concentration and low pH impacts on the quality of water recharged to the Magothy aquifer of Long Island, NY (Ragone and Vecchioli, 1975);
- Sulfate, magnesium, potassium and total hardness impacts on the quality of water recovered from an ASR scheme in the London Basin Chalk (Flavin and Joseph, 1981);
- Sodium, potassium and ammonium concentration impacts on the quality of water injected into marginal quality groundwater in the London Basin Chalk (Moncaster and Cook, 1999);
- Recovery of water contaminated with excessive quantities of manganese from an ASR scheme in Chesapeake, Virginia (Ibison et al, 1995);
- Dissolution driven suspended sediment contamination of water recovered from an ASR scheme in Australia (Rattray et al 1986).

APPENDIX B

Floridian Aquifer Hydrogeology

APPENDIX B

Floridan Aquifer Hydrogeology

B.1 GENERAL

The Floridan Aquifer comprises a "vertically continuous sequence of carbonate rocks of generally high permeability that are of Tertiary age, hydraulically connected in varying degrees, and whose permeability is generally several orders of magnitude greater than that of the rocks that bound the system above and below" (Miller, 1986).

The system underlies all of Florida, southeast Georgia and adjacent parts of Alabama and South Carolina. In Georgia, the Floridan Aquifer strata outcrop parallel to the fall line and dip to the south and southeast. The thickness of the sequence increases from less than 100 ft at outcrop to more than 2,000 ft at the (Atlantic) coast. In the coastal areas, the aquifer is divided into two permeable sub-units, the Upper and Lower Floridan Aquifer. These sub-units are separated by a confining unit of variable hydraulic properties.

Groundwater recharge to the coastal Georgia system occurs as a combination of groundwater inflow from updip or adjacent units of the Floridan Aquifer and natural or induced leakage through the upper confining unit. The predominant direction of flow is from west to east in the south and from north-west to south-east in the north, in both cases from topographically high regions inland towards pumping centers located at the coast. Groundwater discharge occurs both as withdrawal at the coastal pumping centers and, in areas to the south and east, via upward leakage into the upper confining layer. All of the withdrawal in coastal Georgia is understood to be from wells that penetrate the Upper Floridan Aquifer. However, the yield from these wells is sustained in part by upward leakage from the Lower Floridan Aquifer. This occurs as a consequence of both natural and induced head gradients and is locally facilitated by the presence of high permeability flow-paths associated with a series of high-angle faults. Groundwater development and use in coastal Georgia has resulted in a regional decline in the potentiometric surface and pronounced cones of depression at major pumping centers, notably around Savannah and Brunswick.

Water quality in the Floridan Aquifer system varies from a calcium bicarbonate type inland to a calcium magnesium bicarbonate or calcium magnesium bicarbonate sulfate at the coast. In addition, high levels of withdrawal in some parts of the region have resulted in saline intrusion to the aquifer. Consequently, concentrations of chloride are locally excessive. The intrusion occurs both laterally and vertically, with poorer quality water entering the Upper Floridan Aquifer from the areas offshore and from deeper sections of the aquifer, respectively.

A brief description of the lithology and hydraulic properties of each of the components of the Floridan Aquifer system is given below. This is largely derived from Krause and Randolph (1989).

B.2 UPPER CONFINING UNIT

The Upper Confining Unit comprises an interbedded sequence of sand, silt, clay and sandy clay of low permeability. The unit achieves a maximum thickness of 600 ft in the vicinity of Brunswick and thins northwards to less than 100 ft in the vicinity of Savannah. Locally, in the area of Savannah and Hilton Head Island, the unit has been breached by the effects of erosion with the result that the underlying Floridan Aquifer is exposed.

Measured values of the vertical hydraulic conductivity of the Upper Confining Unit vary between 8E-07 ft/d and 1.1 ft/d, while values estimated from the results of regional aquifer modeling vary between 1E-05 ft/d and 1E-03 ft/d. Leakance estimates systematically increase from less than 1E-06 ft/d/ft in the south to greater than 1E-04 ft/d/ft in the north. This trend reflects the decreasing thickness of the unit towards the north and the relatively narrow range of composite or average vertical hydraulic conductivities.

B.3 UPPER FLORIDAN AQUIFER

In the study area the Upper Floridan Aquifer comprises Oligocene and Late Eocene units including the Suwannee and Ocala Limestone. The former is composed of limestones which vary from soft, chalky and fossiliferous to dense, calcitized, saccharoidal and unfossiliferous. The latter is a white to gray, fossilferous, recrystalized, porous limestone containing large solution cavities.

Wells in the Brunswick area penetrate two permeable zones in the Upper Floridan Aquifer which are both within the Ocala limestone. The upper zone is between 75 ft and 150 ft thick and contributes up to 70% of the available yield. The lower zone, which locally includes part of the Middle Eocene Avon Park Formation, is between 15 ft and 110 ft thick and contributes the remainder. In the Savannah area, wells also penetrate two permeable zones in the Upper Floridan Aquifer. The upper of these is less than 50 ft thick and lies within basal Suwannee and Upper Ocala strata; the lower is between 25 ft and 75 ft thick and is entirely within middle Ocala strata. These two zones contribute 70% of the available yield.

Estimates of the transmissivity of the Upper Floridan Aquifer derived from aquifer testing vary between 30,000 ft^2/d and 280,000 ft^2/d, while estimates derived from regional aquifer modeling range between 50,000 ft^2/d and 250,000 ft^2/d. In both cases values decrease to the south and north of Camden County, with extremely high values occurring in the vicinity of Brunswick. Associated estimates of the hydraulic conductivity vary between 80 ft/d and 670 ft/d. Estimates of the storativity, where these are available, are of the order of 0.0004 to 0.0006.

The extremely high values of aquifer transmissivity reflect flow through cavities, cavernous zones and solution channels in the limestone. The majority of these are orientated in the horizontal plane, enhancing lateral permeabilities, although vertical features associated with high-angle fault zones are also present.

B.4 THE LOWER FLORIDAN AQUIFER AND MIDDLE CONFINING UNIT

In the study area the Lower Floridan Aquifer comprises strata of the Lower and Middle Eocene including the Avon Park, Oldsmar, and Cedar Keys formations and the Gosport equivalent. The hydraulic properties of the unit have not been determined, although transmissivity is thought to vary between 2000 ft^2/d and 400,000 ft^2/d and to be less than 100,000 ft^2/d in areas outside of extreme southeast Georgia.

In the vicinity of Brunswick, the lower two-thirds of the Avon Park formation and the upper portion of the Oldsmar formation comprise an interbedded sequence of limestone and dolomite in which significant secondary permeability has developed as a consequence of solution activity along bedding planes. By contrast, upper Avon Park strata is composed of a dense, low-permeability recrystalized carbonate. This sub-unit acts to confine groundwater in the Lower Floridan Aquifer, separating it from groundwater in the Upper Floridan Aquifer except in areas where faulting allows flow between the two. The vertical hydraulic conductivity of intact Middle

Confining Unit strata is estimated from cores recovered in the Brunswick area to vary between 4E-06 ft/d and 5E-05 ft/d. Water level differences across the unit vary between 2 ft and 20 ft but are generally thought to be less than 5 ft.

The base of the Lower Floridan Aquifer in the Brunswick area contains an additional semi-confining unit and an underlying cavernous limestone known as the Fernandina Permeable Zone. The hydraulic properties of each of these sub-units are unknown, although the scale of the caverns in the limestone are such that the transmissivity of the unit is thought to be of the order of 1E06 ft^2/d.

In the Savannah area, the Gosport equivalent is composed of a calcareous sand or very sandy limestone. The unit responds to pumping in the Upper Floridan Aquifer and is thus thought to be in hydraulic continuity with the Upper Floridan Aquifer. Properties for the Lower Floridan Aquifer and middle confining unit in this area are unknown.

APPENDIX C

Bibliography

APPENDIX C

Bibliography

The following references are pertinent to a description of ASR environmental impacts and were reviewed in preparing this report. Included in this list are specific literature citations from this report, as well as references of general use.

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APPENDIX 3

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MEMORANDUM

To: Groundwater Stakeholder Meeting Participants

From: Patty McIntosh, Coastal Programs Director
The Georgia Conservancy

Date: June 16, 2000

Subject: Meeting Summaries

Enclosed are summaries of both groundwater stakeholder meetings. The February meeting summary was revised based on corrections and comments received from participants. The May meeting summary contains the stakeholder recommendations that will be forwarded to the Georgia Environmental Protection Division, the US Geological Survey, and the Upper Floridan Aquifer Technical Advisory Committee.

We anticipate hosting additional stakeholder meetings as the Sound Science Initiative proceeds and groundwater management policies are formulated. We hope you will continue to participate in these important sessions. Your input is invaluable to developing a sound strategy that will ensure a safe, adequate water supply for coastal Georgia. We will notify you of future meetings as they are scheduled.

Please contact me at (912) 447-5910 or tgccoast@bellsouth.net if you have any comments or questions about the enclosed meeting summaries. Thank you.

Groundwater Stakeholder Meeting

Hosted by The Georgia Conservancy
Wednesday, February 23, 2000 ◆◆ 1:00-4:00 PM
Midway, Georgia

Meeting One Summary

urpose

he meeting was held as one of the tasks outlined in the Georgia Environmental Protection ivision's (EPD) Sound Science Initiative to address saltwater intrusion into the Upper Floridan quifer. EPD contracted with The Georgia Conservancy to plan, arrange and host the meeting. takeholders representing industry, local government, agriculture, recreation and non-profit rganizations were asked to identify groundwater management questions they would like EPD's roundwater models and technical investigations to answer. Stakeholder input will be used by PD and the United States Geological Survey (USGS) in developing the next generation of roundwater models for use in the Sound Science Initiative.

ttendance

resenters:
r. Bill McLemore, Georgia EPD
hn Clarke, USGS
orothy Payne, USGS

Facilitator:
Gail Cowie
Carl Vinson Institute of Government
University of Georgia

anel Participants:

ack Amason
ea Garden Seafood

en Brewton
oastal Environmental
rganization and Bryan
ounty

ichard Douglas
oastal Georgia Regional
evelopment Center

illy Edwards
ity of Hinesville

l Elfer
ekyll Island Authority

ary Elfner
oastal Georgia Land Trust

ill Foster, Jr.
epresenting Sea Island
ompany

Wes Harris
Bulloch County Extension
Service

Dan Hawthorne
McIntosh County Soil
Conservation Commission

Glen Hoffman
Hercules, Inc.

John Karrh
Effingham County

Lamar Keller
Savannah Electric

Jack Lantz
The Landing Golf Courses

Dave Kyler
Coastal Georgia Center for
Sustainable Development

Michelle Liotta
Fort James Corporation

Dean Moss
Beaufort-Jasper Water and
Sewer Authority

Milton Peterman
Representing Glynn County

Pete Peterson
Effingham County Chamber
of Commerce

Dave Rutherford
City of Port Wentworth

Doug Shaw
The Nature Conservancy
Altamaha Bioreserve

Deborah Sheppard
McIntosh County Chamber of
Commerce

Others in attendance:

John C. Baird
Jekyll Island Authority

Sid Beauchamp
The Landings

Michael Dale
South Carolina Department of Natural Resources

Robert G. DeWitt
R&R Seafood Company

Kenny Dumas
City of Savannah

Tony Foyle
Georgia Southern University

Jeri Gale
The Georgia Conservancy

Amy Horton
Brunswick News

Rick Krause
USGS, Retired

Jackie Jackson
Fort Stewart

Elliott Jones
USGS

Harry Jue
City of Savannah

Gail Krueger
Savannah Morning News

Christi Lambert
The Nature Conservancy

Tom Matyok
Coastal Georgia Center for Sustainable Development

Patty McIntosh
The Georgia Conservancy

York Phillips
Coastal Georgia Regional Development Center

Allan Pulaski
The Landings

Camille Ransom
SC DHEC

Constance Riggins
McIntosh County Chamber of Commerce

Roy Rountree
Georgia EPD

Steve Royer
Georgia-Pacific Corporation

Gary Sharpe
Gilman Paper Company

Don Smith
South Atlantic Utilities

Jon Sprague
TSG Water Resources

Welby L. Stayton
USGS

Katherine Zitsch
Camp Dresser & McKee

Opening Remarks

Patty McIntosh, Director of Coastal Programs for The Georgia Conservancy, welcomed panel participants and others in attendance, discussed the purpose of the meeting, and introduced the presenters and the facilitator. Dr. Bill McLemore, State Geologist, discussed the use of models in the Sound Science Initiative, efforts and costs to date, and how the stakeholder meeting fits into the Sound Science Initiative and Interim Strategy for Addressing Saltwater Intrusion into the Upper Floridan Aquifer.

USGS Overview of Modeling Effort

John Clarke, USGS Project Manager of the Sound Science Initiative, made a presentation explaining what the groundwater models can and cannot do. He also gave a historical overview of the movement of saltwater into the Upper Floridan Aquifer, relating that movement to the drop in artesian pressure due to pumping over the years to support development.

USGS modeler Dorothy Payne gave a presentation about flow and solute transport models, modeling objectives and modeling limitations. She defined a model as a quantified educated guess and said the models are complex because the hydrologic system is complex. She explained how the groundwater flow system is conceptualized, how the models are constructed and calibrated, how management scenarios can be applied, and how the models can be verified. She also explained the differences in capability between he current models and the next generation of models USGS will use in the aquifer study. The next generation of models will update the previous models, focusing on confined aquifers.

Based on input from the Groundwater Stakeholder meeting, USGS will look at how to orient the models to address areas of interest and specific boundaries. The problems and issues highlighted in today's meeting will affect the size and location of the model boundaries. This process encourages stakeholders to think of issues not addressed by the previous models. The new generation of models may or may not be able to answer all of the questions posed.

USGS also noted the potential that the proposed Savannah Harbor deepening may cause more saltwater intrusion into the aquifer. The new models could be used to show the vertical flux of the water table system and may provide more information about the potential for downward movement of saltwater over time.

Questions/concerns posed to EPD and USGS by panel participants:
Jack Amason asked about the Snapper Hole.
Concern was expressed about the lack of knowledge regarding agricultural pumpage. Dr. McLemore replied that DNR has contract with the Agricultural Extension Service to calculate pumpage over a five-year period by sampling a subset of irrigation systems. The study began in July 1998.
Does agricultural use of groundwater require a permit? EPD responded yes.

Facilitated Discussion

Gail Cowie, with the University of Georgia's Carl Vinson Institute of Government, introduced herself as the facilitator. She stated that her role was to help the group focus on information needs. She also stated that a second meeting may be needed and that when the information is compiled, results would be sent to EPD and shared with the Upper Floridan Aquifer Technical Advisory Committee.

After an opening exercise in which panel participants indicated their expectations for the next generation of models, the facilitator asked each participant to think of questions for the groundwater models in the following terms:

What would happen to (object) if (action) takes place in this location (boundary)?

The panel participants were asked to break into small groups and discuss groundwater management questions in the suggested format, keeping in mind what would make significant changes to life in coastal Georgia. The group then reconvened and the facilitator recorded the scenarios each group felt should be addressed by the EPD's models and technical investigations.

The following scenarios were posed by participants and recorded by the facilitator:

1. What would happen to the Miocene aquifer(s) if it/they were developed? What would happen to the surficial aquifer and surface water bodies, wetlands, etc., if the Miocene aquifer(s) were developed?
2. What would happen to river base flow and freshwater inflow to the estuary and freshwater wetlands if there were increased development of the Miocene and surficial aquifers? What would happen to river base flow and freshwater to the estuary and freshwater wetlands for any alternative use scenario? More generally, what would be the ecological impacts of each scenario?
3. What would be the geological impacts of pumping from the Miocene aquifer?

4. What would happen if groundwater use were reduced by 50% and surface water used instead? Are surface water sources sufficient to provide this amount? What would be the ecological effects of such a scenario?

5. What would happen to the saltwater interface if specific water conservation actions were implemented (e.g., retrofits)? How much water (mgd) could be saved? What would be the impact of specific reductions in use (e.g., 10%, 20%, 30%) on the saltwater interface?

6. What would happen to saltwater intrusion and groundwater quantity if certain wells closest to the coast and to the cone of depression were abandoned and withdrawals were relocated to the west where the aquifer is deeper? Similarly, what would happen to saltwater intrusion and groundwater quantity if these wells were abandoned and use shifted to surface water sources at the coast?

7. What would be the effect on existing inland wells (water level, particularly) if use were moved inland? Scenarios include shifting pumpage from downtown Brunswick to western Glynn County; from Glynn County to Camden, Wayne, or McIntosh County; and Chatham County to Effingham County.

8. What would happen to saltwater movement into Hilton Head if 5 mgd of freshwater were injected as a barrier on the north end of Hilton Head Island?

9. How much water can be pumped out of existing wells in Glynn County and still have the Floridan aquifer reach a steady state (steady state in terms of groundwater level and salt concentration)? Similarly, how much can be pumped from existing wells in Chatham County with the Floridan reaching a steady state? Moreover, are the conditions at that steady state acceptable?

10. What would be the quantity and quality effects in Chatham and the surrounding areas from unchanged withdrawals in a) Chatham County or b) the study region?

11. What would be the effects on biological functions of unchanged withdrawals region-wide?

12. What is the local effect on saltwater movement due to wells in southern Bryan, southern Effingham, and all counties in the study area? That is, was the cap on withdrawal put in place because of contributions to localized saltwater impacts or because of contributions to impacts elsewhere?

13. What are the potential impacts of existing open-bore wells along the Georgia coast?

14. What happens during aquifer storage and recovery (ASR)? That is, what happens to movement of stored water, quality of stored water and quality of natural water under ASR? What are the effects locally? What is the localized movement? What are the effects across the full sphere of influence? How far does the sphere of influence extend? Other include:
    -effects of mixing aerobic and anaerobic waters
    -geochemical effects on the aquifer itself (on the limestone formations);
    -effects of prior treatment; and
    -mixing effects in general.

15. What would be the flow scenarios (short-term and long-term) under major drought conditions?

16. What would happen to groundwater and surface water quality and quantity with continued alteration of wetlands (i.e., drain and fill) across the region?

17. What would happen to the saltwater intrusion due to sea-level rise?

Other questions/comments posed by participants:

A few related questions arose during discussion at the meeting and some participants submitted additional scenarios in writing at the close of the session. These questions and comments are listed below:

- What would be the relative cost/benefit of investment in water conservation equipment for major industrial users versus the development of other water sources?
- What happened to the money allocated in 1995 for offshore wells to be drilled? *[Dr. McLemore answered that: money was allocated for Tybee and St. Mary's, but not for offshore drilling.]*
- Concern was expressed about the effects of saltwater intrusion in the aquifer on freshwater in the estuaries and the refusal of DNR's Coastal Resources Division to see the connection.
- Does ground water pressure or absence of same affect the quantity of fresh water in coastal estuaries? The answer to that question should be transferred to the legislature, the Coastal Resources Division or Environmental Protection Division of Georgia DNR, and South Carolina DNR.
- What can the new models tell us about the potential of downward saltwater leakage caused by harbor deepening?
- What is the long-term potential for saltwater intrusion impacting the Skidaway wells based on current regional withdrawal rates?
- If the shallow aquifer on Skidaway is utilized to reduce demand on the Floridan Aquifer, will the potential for saltwater intrusion be increased?
- How susceptible is the shallow aquifer to saltwater intrusion?
- What would the "head pressure" become for the Floridan Aquifer (knowing what pre-well days were)? Would the pressure be reversed enough to reduce or eliminate the flow of saltwater intrusion if a policy dictates an MGD reduction? If not, what is the purpose of continuing the model building process other than for monitoring if in fact we are not solving what seems to be a futuristic problem?

Conclusion/Adjournment

At the close of the meeting, participants agreed that it would be useful to meet a second time to review the scenarios listed above and discuss priorities in the face of limited resources. At that meeting, EPD and USGS will provide feedback on the scenarios and their suitability for model application. If possible, information from the USGS report on previous modeling efforts, currently being finalized, will be provided to the panel before the next meeting, which will be held late spring.

The meeting was adjourned promptly at 4:00 PM.

Groundwater Stakeholder Meeting

Hosted by The Georgia Conservancy
Wednesday, May 17, 2000 ◆ 1:00-4:00 PM
Midway. Georgia

Meeting Two Summary

'urpose

he meeting was held to conclude the work of stakeholders in identifying groundwater management uestions and modeling scenarios for input into groundwater models and other technical investigations eing conducted under EPD's Sound Science Initiative. The initial meeting was held on ebruary 23, 2000.

ıttendance

'resenters:

ɔhn Clarke, USGS
ıorothy Payne, USGS

Facilitator:

Gail Cowie, University of Georgia,
Carl Vinson Institute of Government

'anel Participants:

ıck Amason
ea Garden Seafood

ob Benson
ilynn County

en Brewton
'oastal Environmental
rganization and
ryan County

ichard Douglas
ong County

l Elfer
ekyll Island Authority

ary Elfner
'oastal Georgia Land Trust

Kelly Ferda
South Island Utilities
HHI, SC

Wes Harris
Bulloch County
Extension Service

Richard Johnston
Glynn County

Lamar Keller
Savannah Electric

David Kyler
Coastal Georgia Center for
Sustainable Development

Jack Lantz
The Landing Golf Courses

Michelle Liotta
Fort James Corporation

Dean Moss
Beaufort-Jasper Water and
Sewer Authority

Pete Peterson
Effingham County
Chamber of Commerce

David Rutherford
City of Port Wentworth

Deborah Sheppard
McIntosh County
Chamber of Commerce

)thers in attendance:

aurie K. Abbott
'oastal Water & Sewerage

'ony Abbott
'onsolidated Utilities

am Arora
lydrovision

John C. Baird
Jekyll Island Authority

Deatre Denion
Chatham-Savannah MPC

Kenny Dumas
City of Savannah

Fred Falls
US Geological Survey,
Columbia, SC

Dieter Franz
Camp, Dresser & McKee

Jeri Gale
The Georgia Conservancy

Christine Griffiths
The Nature Conservancy

Phyllis Isley
Georgia Southern University

Alice Miller Keyes
The Georgia Conservancy

Rick Krause
Hydrovision

Gail Krueger
Savannah Morning News

Judy Jennings
Sierra Club

Jean McDowell
Chatham-Savannah MPC

Patty McIntosh
The Georgia Conservancy

Andy Ninnemann
Landings Club

Jimmy Otto
McIntosh County
Development Authority

Camille Ransom
SC DHEC

Roy Rountree
Georgia EPD

Steve Royer
Georgia-Pacific Corporation

Gary Sharpe
Gilman Paper Company

Cardwell Smith
Army Corps of Engineers

Jon Sprague
TSG Water Resources

Steve Walker
Georgia Geological Survey

James White
SC DHEC

Opening Remarks

USGS staff discussed their model scenario report and provided feedback on the 17 scenarios posed by stakeholders at the February 23rd meeting (see list of scenarios and USGS responses attached to this summary). Bill McLemore (GAEPD) and Dieter Franz (Camp, Dresser, & McKee) reviewed the surface water assessments underway as part of the Sound Science Initiative. Under contract with GAEPD, a consultant (Camp, Dresser & McKee) is looking at surface water supplies and storage needs. Their studies will address reclaimed water, off-mainstream impoundments, conjunctive surface-groundwater use, and water conservation opportunities.

Meeting participants stressed the importance of protecting minimum flows in the large rivers. The consultant is evaluating ways to provide water supply during minimum flow periods (e.g., conjunctive surface-groundwater use). Participants suggested that GAEPD and their consultants look at water supply in an environmentally sound manner, including protection of riverine habitat with provision of water supply (a concern for the Ogeechee River, in particular).

Facilitated Discussion

Participants broke into five small groups to review the modeling scenarios developed at the February 23rd meeting. Each group was asked to select up to five scenarios they felt would provide information critical to the future of the region. The following items were selected:

Selected by four groups

a) What would happen to river base flow and freshwater inflow to the estuary and freshwater wetlands if there were increased development of the Miocene and surficial aquifers? What would happen to river base flow and freshwater to the estuary and freshwater wetlands for any alternative use scenario? More generally, what would be the ecological impacts of each scenario?

   Suggested revision: Ecological concepts should be defined and considered up-front in developing scenarios to be studied. For example, what minimum in-stream flow and seasonal fluctuations are necessary to maintain ecological functions of subject streams?

   Facilitator's note: This item is closely related to item g, which was selected by two of the groups.

b) What would happen to saltwater intrusion and groundwater quantity if certain wells closest to the coast and to the cone of depression were abandoned and withdrawals were relocated to the west where the aquifer is deeper? Similarly, what would happen to saltwater intrusion and groundwater quantity if these wells were abandoned and use shifted to surface water sources at the coast?

Facilitator's note: Item j includes a related question.

Selected by three groups

c) What would happen if groundwater use were reduced by various amounts (e.g., 50%) and surface water used instead? Are surface water sources sufficient to provide this amount? What would be the ecological effects of such a scenario?

d) What would happen to the saltwater interface if specific water conservation actions were implemented (e.g., retrofits)? How much water (mgd) could be saved? What would be the impact of specific reductions in use (e.g., 10%, 20%, 30%) on the saltwater interface?

e) How much water can be pumped out of existing wells in Glynn County and still have the Floridan aquifer reach a steady state (steady state in terms of groundwater level and salt concentration)? Similarly, how much can be pumped from existing wells in Chatham County with the Floridan reaching a steady state? Moreover, are the conditions at that steady state acceptable?

Selected by two groups

f) What would happen to the Miocene and Lower Floridan aquifer(s) if developed as an alternative to the Upper Floridan Aquifer? What would happen to the surficial aquifer and surface water bodies, wetlands, etc. if the Miocene aquifer were developed?

g) What would be the biologial and ecological effects of all scenarios evaluated? EPD must accept that there is a relationship between groundwater and surface water and a compound effect on the coastal ecology and estuaries. All water decisions need to be considered as they affect the coastal ecology.

h) What is the local effect on saltwater movement due to wells in southern Bryan, southern Effingham, and all counties in the study area? That is, was the cap on withdrawal put in place because of contributions to localized saltwater impacts or because of contributions to impacts elsewhere?

i) What happens during aquifer storage and recovery (ASR)? That is, what happens to movement of stored water, quality of stored water, and quality of natural water under ASR? What are the effects locally? What is the localized movement? What are the effects across the full sphere of influence? How far does the sphere of influence extend?

Related issues: effects of mixing aerobic and anaerobic waters; geochemical effects on the aquifer itself (on the limestone formations); effects of prior treatment; and mixing effects in general.

Selected by one group

j) What would be the effect on existing inland wells (water level, particularly) if use were moved inland? Scenarios include shifting pumpage from downtown Brunswick to western Glynn County or from Glynn and Chatham counties to Bryan and Effingham counties, respectively.

Facilitator's note: Related questions are listed on item b above.

k) What would be the quantity and quality effects in Chatham and the surrounding areas from unchanged withdrawals in a) Chatham County or b) the study region?

n summary, participants recommended the following:

. Assess the ecological effects of all use scenarios, particularly effects on river base flow, on wetlands, and on freshwater inflow to estuaries (see items a, c and g above).
!. Model specific use scenarios listed above (see items b, c, d, f, i and j).
. Assess conditions at steady state groundwater levels and chloride concentrations (see item e).
. Specify impacts of current and unchanged withdrawals (see items h and k).

Conclusion/Adjournment

The facilitator reiterated that the purpose of the two stakeholder meetings was to solicit input specifically for the groundwater models and technical investigations. Some questions can be answered through these mechanisms, but others are beyond the scope and will have to be addressed by EPD in another manner. The result of the facilitated sessions will be forwarded to EPD, the Upper Floridan Aquifer Technical Advisory Committee, and meeting participants.

Upon an offer from EPD, stakeholders expressed interest in participating in additional meetings to provide input as the Sound Science Initiative studies progress and management policies are formulated. The Georgia Conservancy agreed to host the meetings and will notify interested parties as they are scheduled.

The meeting was adjourned at 4:00 PM.

USGS Feedback on Stakeholder Modeling Scenarios

The following scenarios were posed by stakeholders at the February 23rd meeting. USGS reviewed the scenarios to determine their suitability for model application. Their responses appear in italics.

1. What would happen to the Miocene aquifer(s) if it/they were developed?
   What would happen to the surficial aquifer and surface water bodies, wetlands, etc., if the Miocene aquifer(s) were developed?

   This question may be addressed by scenario testing with the models, and is within the scope of the proposed modeling.

2. What would happen to river base flow and freshwater inflow to the estuary and freshwater wetlands if there were increased development of the Miocene and surficial aquifers? What would happen to river base flow and freshwater to the estuary and freshwater wetlands for any alternative use scenario? More generally, what would be the ecological impacts of each scenario?

   This question may be partially addressed by the models. Differences in groundwater discharge to the surface-water body resulting from changes in pumpage can be simulated. Ecological impacts that result from these changes cannot be addressed directly by the model. To simulate the particular processes occurring in the estuaries, a more specific model of the surficial aquifer would be required. The time scale and the length scale are much shorter in the surficial aquifer than in the confined aquifer system, and the unsaturated zone behaves differently than the saturated zone. These conditions should be considered and incorporated into a more detailed surficial aquifer model. However, this is not compatible with the proposed modeling scope. The modeling results may subsequently highlight or provide a framework from which to build a proper, more accurate surficial model.

3. What would be the geological impacts of pumping from the Miocene aquifer?

   Subsidence and aquifer compaction are not addressable by the type of modeling proposed, nor are they understood to be part of the scope.

4. What would happen if groundwater use were reduced by 50% and surface water used instead? Are surface water sources sufficient to provide this amount? What would be the ecological effects of such a scenario?

   A detailed surface water model is not proposed, but impacts on surface water can be addressed in a general manner as described in point #2 above. Ecological effects may be inferred from the modeling, but are not directly addressed. Impacts of pumpage reductions on ground water conditions can be simulated by the models.

5. What would happen to the saltwater interface if specific water conservation actions were implemented (e.g., retrofits)? How much water (mgd) could be saved? What would be the impact of specific reductions in use (e.g., 10%, 20%, 30%) on the saltwater interface?

   Scenario testing using the saltwater transport model will address questions such as these, for specific locations. Similar scenarios have been tested using existing ground water models in coastal Georgia (see scenarios A-2, A-3 in USGS report).

6. What would happen to saltwater intrusion and groundwater quantity if certain wells closest to the coast and to the cone of depression were abandoned and withdrawals were relocated to the west where the aquifer is deeper? Similarly, what would happen to saltwater intrusion and groundwater quantity if these wells were abandoned and use shifted to surface water sources at the coast?

   Scenario testing using the saltwater transport model will address questions such as these, for specific locations; the model will address surface water effects in a general way. Similar scenarios have been tested using existing ground water models in coastal Georgia.

7. What would be the effect on existing inland wells (water level, particularly) if use were moved inland? Scenarios include shifting pumpage from downtown Brunswick to western Glynn County; from Glynn County to Camden, Wayne, or McIntosh County; and Chatham County to Effingham County.

   The regional flow model will address these questions through scenario testing. Similar scenarios have been tested using existing ground water models in coastal Georgia.

8. What would happen to saltwater movement into Hilton Head if 5 mgd of freshwater were injected as a barrier on the north end of Hilton Head Island?

   The saltwater transport model could address this through scenario testing.

9. How much water can be pumped out of existing wells in Glynn County and still have the Floridan aquifer reach a steady state (steady state in terms of groundwater level and salt concentration)? Similarly, how much can be pumped from existing wells in Chatham County with the Floridan reaching a steady state? Moreover, are the conditions at that steady state acceptable?

   These questions can be addressed using transient simulations of ground water flow and solute transport. Whether these conditions are acceptable or not can then be evaluated by water managers.

10. What would be the quantity and quality effects in Chatham and the surrounding areas from unchanged withdrawals in a) Chatham County or b) the study region?

    These will be addressed by the scenario testing of the models.

11. What would be the effects on biological functions of unchanged withdrawals region-wide?

    The models will not be able to address this directly, but the results may be useful for other studies regarding this question.

12. What is the local effect on saltwater movement due to wells in southern Bryan, southern Effingham, and all counties in the study area? That is, was the cap on withdrawal put in place because of contributions to localized saltwater impacts or because of contributions to impacts elsewhere?

    This question can be addressed by ground water flow and solute transport modeling.

13. What are the potential impacts of existing open-bore wells along the Georgia coast?

    This is a site-specific problem that could be addressed with very high resolution modeling, but is probably beyond the scope of the planned models.

14. What happens during aquifer storage and recovery (ASR)? That is, what happens to movement of stored water, quality of stored water and quality of natural water under ASR? What are the effects locally? What is the localized movement? What are the effects across the full sphere of influence? How far does the sphere of influence extend? Other include:
-effects of mixing aerobic and anaerobic waters
-geochemical effects on the aquifer itself (on the limestone formations);
-effects of prior treatment; and
-mixing effects in general.

Although the models are capable of evaluating the impact of aquifer storage and recovery on ground water levels and saltwater intrusion, they are not capable of evaluating water-quality impacts of injected waters. Such questions can be addressed using geochemical speciation and reaction-transport modeling, which are not part of the planned models.

15. What would be the flow scenarios (short-term and long-term) under major drought conditions?

This can be addressed through scenario testing of both the flow and solute transport models by varying the amounts of surficial recharge.

16. What would happen to groundwater and surface water quality and quantity with continued alteration of wetlands (i.e., drain and fill) across the region?

This is a specific question that is probably better addressed by smaller scale modeling of surficial aquifers that can account for changes that occur in engineered situations: changes in surface topography, sediment compaction, etc.

17. What would happen to the saltwater intrusion due to sea-level rise?

It is possible to address the effect of sea level change on the movement of the saltwater-freshwater interface, but the time scale of a sea level change of sufficient magnitude to affect the interface (thousands of years) is likely to be many times greater than the time scale of interest to management problems (one hundred years).

USGS response to summary of stakeholder recommendations

July 27, 2000

The summary of stakeholder recommendations is concise and specific and provides recommendations that are generally achievable by, and are appropriate to the scope of the modeling study. Our response to the four recommendations follows:

(1) Assess the ecological effects of all use scenarios, particularly effects on river base flow, on wetlands and on freshwater inflow to estuaries: The models cannot address ecological effects directly, but they can be made to address at least in a general way the interaction between the surface water and ground water. The regional flow model and subregional solute-transport models will each simulate flow in the surficial aquifer, and can thus simulate interactions with between the ground water and surface-water systems, with some limitations:

- The regional flow model will include major rivers and streams as part of the upper model boundary. The surficial aquifer will be actively modeled and will be allowed to interact with the surface water and the underlying confined and semi-confined aquifers. Data used to characterize this part of the model will be taken, in part, from a stream-baseflow analysis, yet to be performed. The results of this model will not be able to simulate, in detail, individual wetland or estuarine systems because the time and areal scale of the model will be of too coarse a resolution. Despite these limitations, simulations may indicate specific areas appropriate for more-detailed modeling of surface water/groundwater interactions.
- For the Savannah-Hilton Head Island solute-transport model, it is particularly important to characterize the surficial aquifer and interactions between surface water bodies and the confined aquifers. A leading hypothesis for saltwater contamination of the Upper Floridan aquifer in this area is thinning or breaching of the surfical aquifer, both off-shore, and landward of the barrier islands (intra-coastal areas). The areal scale of this model will also be more conducive to characterizing the local estuarine systems.

- For the Brunswick solute-transport model, the primary area of concern is upward migration of hypersaline water at depth (Fernandina permeable zone). Interactions between the surface water bodies and the confined aquifers are not likely to be very important, as the aquifers are deeply buried and the overlying confining unit is extremely thick. Nonetheless, the surficial aquifer can be modeled actively, and interaction between the surface water and confined aquifers will be considered.

(2) Model specific use scenarios: The scenarios discussed at the meetings included unchanged (or increased) withdrawals, conservation actions, use of surface water in place of ground water, redistribution of pumping locations, and redistribution of pumping to other usable aquifers. Interest was expressed in the resulting effects of these scenarios on surface-water bodies (as discussed above), on ground-water levels of the various aquifers, and on saltwater movement. The calibrated models will be capable of evaluating each of these impacts to varying degrees. It should be noted that these ground-water flow and solute-transport models will not be able to specifically address the surficial water resources, but, as indicated previously, the effect of changing surface-water flow on the surficial and underlying aquifer flow systems can be examined.

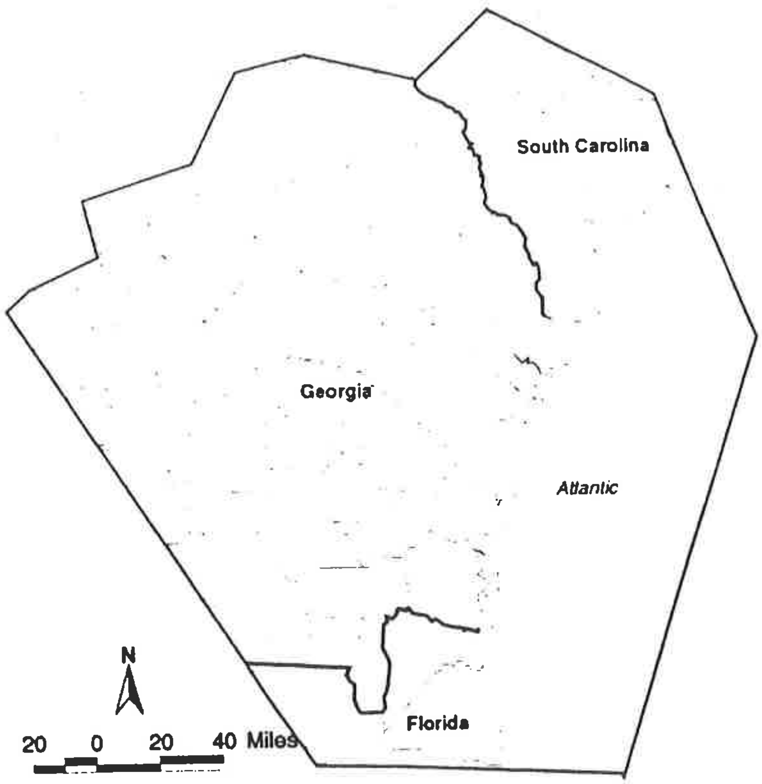
(3) Assess ground-water levels and chloride concentrations under steady-state conditions: Transient model simulations will be used to evaluate the maximum quantity of ground water that can be removed before the system can no longer sustain a steady-state condition. For the ground-water flow model, the flow system will be stressed to the point of assumed unrecoverable loss of aquifer head (incomplete saturation of the confined aquifers). For the solute-transport models, steady state is achieved when the saltwater front (transition zone) is stationary; which may occur under entirely different conditions than steady state for the ground-water flow model. These models may be used to assess the time it takes for a steady state flow system to achieve steady state chloride distribution, and the geometry of that distribution. Each of these scenarios will help assess the water-supply potential of the various aquifers.

(4) Specify impacts of current and unchanged withdrawals: This is essentially a specific use scenario as described under "Model-specific use scenarios". This will be addressed as part of model calibration to current conditions.

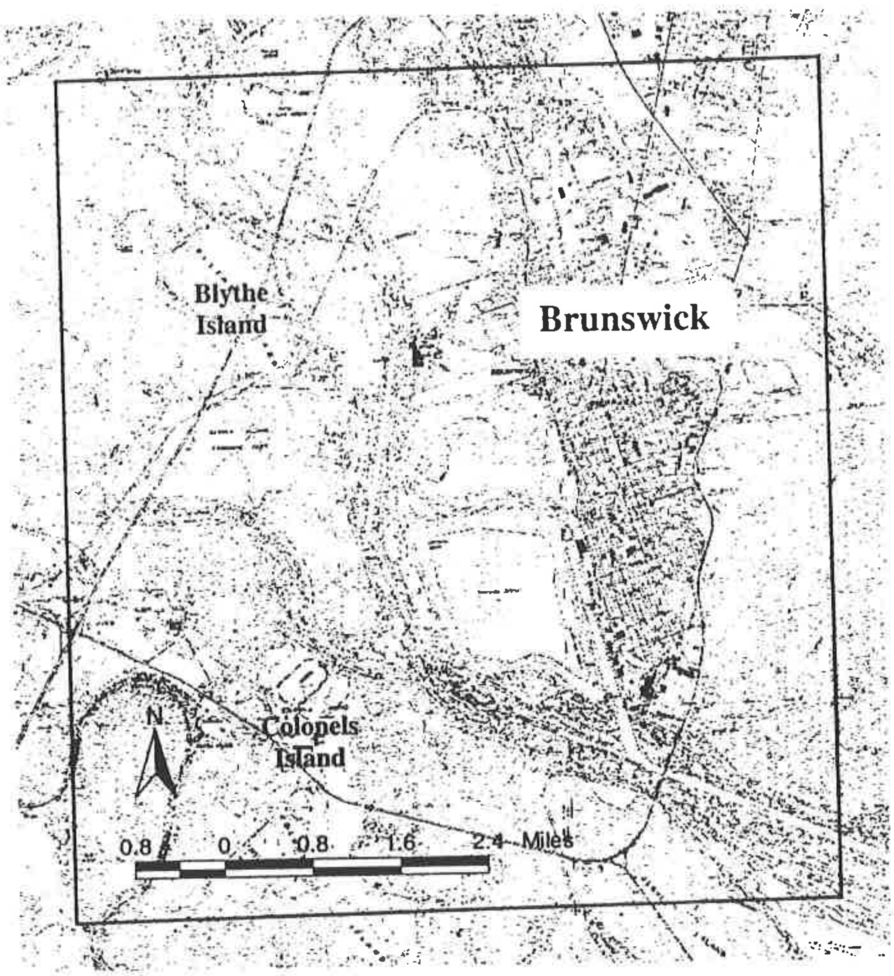
Model Boundaries

To facilitate development of specific model scenarios, we offer the following maps that show the anticipated boundaries for the flow and solute-transport models. These are subject to change with additional information, directives, or preliminary modeling results. All model boundaries are shown in red.

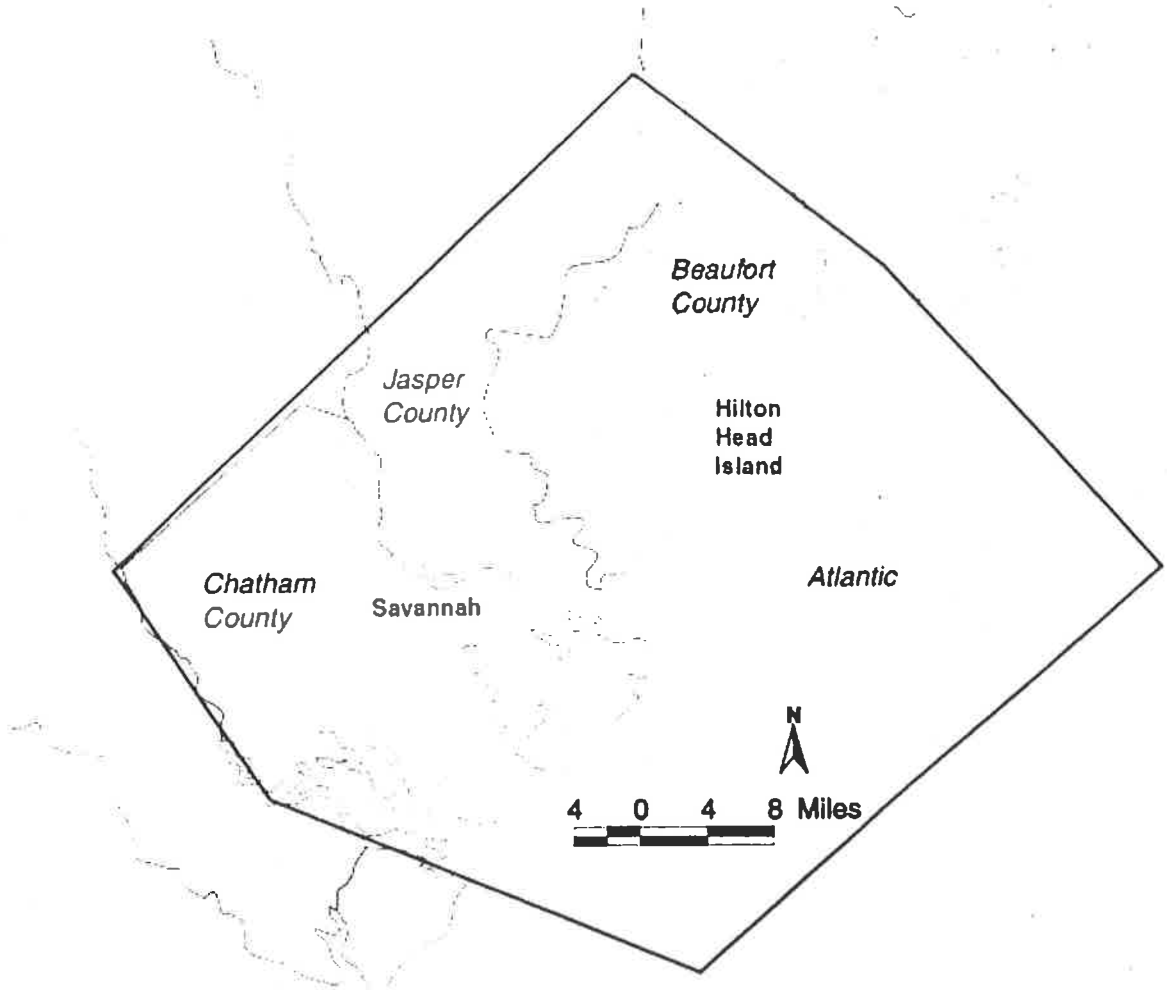
Regional Flow Model Boundary



Brunswick Solute Transport Model



Savannah-Hilton Head Island Solute Transport Model



Georgia Department of Natural Resources

205 Butler Street, S.E., East Floyd Tower, Atlanta, Georgia 30334

Lonice Barrett, Commissioner
Harold F. Reheis, Director
Environmental Protection Division

October 13, 1999

John Sibley
President
The Georgia Conservancy
1776 Peachtree Street, NW
Ste. 400 South
Atlanta, GA 30309

Dear Mr. Sibley:

This letter follows up on discussions between Dr. William McLemore, the State Geologist, and Mrs. Patricia McIntosh of the Conservancy's Savannah Office. This letter also is an Agreement between the Environmental Protection Division (EPD) and the Georgia Conservancy, Inc. for the purposes of the Conservancy facilitating a meeting on "Ground-Water Modeling Needs for Coastal Georgia" sometime in the Winter/Spring of 1999-2000. This meeting represents Task #1 of Project Three-Scenario Development (a photocopy of the narrative description of this task taken from the Recommendations of the Upper Floridan Technical Advisory Committee is attached and is made part of this Agreement.) A copy of the Recommendations report has been provided separately to Mrs. McIntosh.

The primary objective of the facilitated meeting would be for the convened stakeholders to identify those ground-water management questions that they expect EPD's technical investigations and ground-water modeling to answer. For illustrative purposes, examples of the questions might include:

(1) What would happen if Upper Floridan pumpage in Chatham County is reduced by x million gallons per day?

(2) What would happen if x million gallons of pumpage in Brunswick, Glynn County were moved westward to the vicinity of Mt. Pleasant in Wayne County?

In this regard, it does need to be remembered that modeling is useful in making predictions of changes in chloride concentrations over time. Thus the answer to Question #1 might be that the chloride front would take an additional y years to reach Savannah, or the upward plume at Brunswick would shrink in areal extent by z percent. Modeling will not tell whether the scenario is good or bad; it will only give estimates of changes in salt-water intrusion.

With the above in mind, the Conservancy shall:

(A) Secure a meeting site in either Savannah or Brunswick for the purposes of the meeting. The meeting shall last between ½-1 days; and the Conservancy shall provide coffee, tea, and other refreshments to meeting participants.

(B) Provide a meeting facilitator to keep the meeting focused on the specific goal of modeling needs. The Conservancy shall further provide a court reporter, who will transcribe meeting notes and panel comments.

(C) Invite and secure confirmations of approximately two dozen panel participants. The Conservancy shall further invite the members of the Technical Advisory Committee and the USGS, whom will not be panel participants. The Conservancy shall also permit a maximum of six of EPD's contractors or employees to attend, strictly for educational purposes.

(D) Insure that the panel is approximately equally divided between industry (large and small), local governments (large and small), agriculture and recreation, and non-profit organizations (chambers of commerce, environmental advocacy organizations, political advocacy organizations, etc,). The Conservancy shall attempt to insure that the panel generally reflects the water users of coastal Georgia.

(E) Summarize meeting results/recommendations in a short report (six copies, which EPD will reproduce, as needed). The Conservancy shall also provide one copy of the court reporter's transcript. The report and transcript shall be provided to EPD within 90 days of the meeting.

(F) All work shall be completed by September 30, 2000.

The Conservancy's fee for the above services shall be for a fixed fee of $7,000, which be paid upon receipt of an invoice upon completion of activities (A through E, above). If the above terms and conditions are acceptable, please sign in the space below and return four originals to myself.

Sincerely:

Harold F. Reheis
Director

Accepted:
The Georgia Conservancy, Inc.

Name: ______________________ Title: President

Date: 10/25/99

cc: Bertha Turner
William McLemore
Carolyn Cardin
USGS

Engineering and Environmental Services, different models based on different computer codes may be needed at Savannah-Hilton Head and at Brunswick. Law recommends and EPD supports that the solute-transport codes selected be chosen after a comprehensive analysis of the major programs and available case studies. In this regard, it is recognized that national experts, including the USGS and private companies, be convened, utilizing a facilitator, to analyze the technical issues and make a recommendation regarding the model or models to be used. The experts should attempt to define the expected capability of the model and the expected calibration/validation/documentation. The only limitation on the model recommendation would be that the code is documented and it is acceptable to the USGS, which is the agency that provides modeling expertise to the States of Georgia, Florida, and South Carolina as well as local governmental agencies through a variety of joint funding agreement. The general minutes of the convened experts as well as their recommendations should be described in a report.

<u>Task #4</u> Develop three-dimensional, density dependent, transient solute-transport models for both the Savannah-Hilton Head area and the Glynn County area. The models should be based on the computer codes recommended in Project Two-Task #4 above. Both models also should be integrated and compatible with the recalibrated flow model including the revised estimates of agricultural pumpage and reconfigured potentiometric surface at Savannah reflecting the three offshore monitoring wells. The Savannah-Hilton Head model should be capable of estimating travel times for an encroaching salt water wedge (i.e., 250 ppm, 500 ppm, and 1000 ppm) to reach certain water supply wells on Hilton Head and at Savannah from known or suspected entrance points. The Brunswick model should be capable of estimating the salt water flux from the Fernadina Permeable Zone to the Lower Floridan and from the Lower Floridan to the Upper Floridan as well as the change in size of current "T" shaped plume. Both models should be capable of considering diffusion, advection, and mechanical/hydrodynamic dispersion. The results of the modeling and the assumptions upon which the modeling is based should be described in two reports (one for Savannah-Hilton Head and one for Brunswick). The model also should be made available to stakeholders in digital format so that they may independently perform their own scenarios.

Project Three-Scenario Development:
Scenario development involves modeling actual and hypothetical changes in recharge and withdrawals to assess the impact of salt water intrusion. Basically the scenario development attempts to answer a variety of "what would happen if" questions.

<u>Task #1</u> Obtain a general consensus on the needed modeling scenarios. The effectiveness of scenario development is dependent on a general consensus that the scenarios being modeled are reasonable and appropriate; therefore, it is recommended that

appropriate stakeholders be convened and querried, utilizing a facilitator, regarding needed scenarios. The general minutes of the convened stakeholders and their recommendations should be described in a report.

Task #2 Model varying pumping and ground-water management scenarios. Depending on the recommendations of the aforementioned convened stakeholders, scenarios would be modeled and the results would be presented in map and narrative format. Information that should be provided for each scenario should include: a potentiometric map, salt water travel times to key wells for the Savannah-Hilton Head area, changes in flux and changes in size of the plume in the Brunswick area, and narrative describing modeling assumptions and impacts (i.e., the Hilton Head wedge would reach a certain well in approximately a certain number of years or the "T" shaped plume at Brunswick would increase in size by a certain percentage). While the exact number of modeling scenarios is not predictable at this time, for estimating purposes it is anticipated that the total number will be on the order of 200. It is further recommended that upon completion of all modeling scenarios, that the results be summarized in a report or a series of reports.[5]

Project Four-Impact Analysis:

Task #1 Validate hydrogeologic rationale for separating the Northern and Central Subareas. Ground-water flow modeling by the USGS (Professional Paper 1403-D) indicates that Upper Floridan withdrawals north of the Gulf Trough[6] have little impact on water levels south of the Gulf Trough. While the Gulf Trough is reasonably well-defined southwest of Statesboro, its existence northeast of Statesboro is not well documented. Extension of the Gulf Trough from Statesboro to the Savannah River would be reasonable justification for maintaining the integrity of the Northern Subarea and less restrictive water use regulations. On the other hand, if the Trough does not extend northeast of Statesboro, then it may be appropriate to include portions of Bulloch and Screven counties in the Central Subarea. Validation of the northeast extension of the Gulf Trough should be assessed by performing two seismic-reflection profiles, generally perpendicular to the axis of the Trough, and coring three deep borings, utilizing EPD's wire-line coring equipment, along one or near one of the seismic profiles, through the confining units and into the carbonate portion of the aquifer for about 100-200 feet. The seismic profiles would define the existence or nonexistence of any northeastward

[5] Much of the Final Strategy will be dependent on the modeling scenarios that are developed. Many of these may be analyzed between July 1, 2005 when EPD initiates preparation of the Final Strategy and December 31, 2005 when EPD is scheduled to finalize the Final Strategy. In all likihood, the report describing the scenarios would not be initiated until after January 1, 2006.

[6] The Gulf Trough is a subsurface geologic feature that separates the Northern Subarea from the Central Subarea.

APPENDIX 4

RULES
OF
GEORGIA DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION

CHAPTER 391-3-6

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391-3-6-.13 Underground Injection Control

(1) **Purpose.** The purpose of this rule, 391-3-6-.13 is to establish classes of injection wells, prohibitions, criteria and standards applicable to injection wells.

(2) **Definitions. Amended.** All terms used in this rule shall be interpreted in accordance with the definitions as set forth in the Act, unless otherwise defined in this Paragraph or in any other Paragraph of this Chapter. All federal regulations adopted by reference are those in effect as of January 1, 2000.

(a) "Abandoned well" means a well whose use has been permanently discontinued or which is in a state of disrepair such that it cannot be used for its intended purpose or for observation purposes.

(b) "Aquifer" means a geological formation, group of formations, or part of a formation that is capable of yielding water to a well or spring.

(c) "Area of review" means the area surrounding an injection well or field where migration of the injection and/or formation fluid into an underground source of drinking water may occur.

(d) "Casing" means a pipe or tubing of appropriate material of varying diameter and weight, lowered into a borehole during or after drilling in order to support the sides of the hole and thus prevent the walls from caving, to prevent loss of drilling mud into porous ground or to prevent water, gas or other fluid from entering or leaving the hole.

(e) "Catastrophic collapse" means the sudden and utter failure of overlying strata caused by the removal of underlying materials.

(f) "Cementing" means the operation whereby a cement slurry is pumped into a drilled hole and/or forced behind the casing.

(g) "Cesspool" means a "drywell" that receives untreated sanitary waste containing human excreta, and which sometimes has an open bottom and/or perforated sides.

(h) "Class V septic system" means a "septic system" that handles sanitary and/or other wastes and has the capacity to serve 20 or more persons a day.

(i) "Confining bed" means a body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

(j) "Confining zone" means a geological formation, group of formations, or part of a formation that is capable of limiting fluid movement above or below an injection zone.
(k) "Contaminant" means any physical, chemical, biological or radiological substance or matter in water.
(l) "Conventional mine" means an open pit or underground excavation for the production of minerals.
(m) "Disposal well" means a well used for the disposal of waste into a subsurface stratum.
(n) "Drainage well" means a well used to drain surface water into a shallow aquifer. An induced recharge well which drains ground water from a shallow aquifer into a deeper aquifer is not a drainage well.
(o) "Drywell" means a well, other than an improved sinkhole or subsurface fluid distribution system, completed above the water table so that its bottom and sides are typically dry except when receiving fluids.
(p) "Exempted aquifer" means an aquifer or its portion that meets the criteria in the definition of underground source of drinking water but which has been exempted according to the procedures in Rule 391-3-6-.13(4) of this Chapter.
(q) "Facility, operation or activity" means any injection well or system.
(r) "Fluid" means any material or substance which flows or moves whether in a semisolid, liquid, sludge, gas, or any other form or state.
(s) "Formation" means a body of consolidated or unconsolidated rock characterized by a degree of lithologic homogeneity which is prevailingly, but not necessarily, tabular and is mappable on the earth's surface or traceable in the subsurface.
(t) "Formation fluid" means fluid present in a formation under natural conditions as opposed to introduced fluids, such as drilling mud.
(u) "Generator" means any person, by site location, whose act or process produces hazardous waste identified or listed in Federal Regulations, 40 C.F.R. Part 261.
(v) "Groundwater" means water below the land surface in the zone of saturation.
(w) "Grout" means a mixture of not more than six gallons of clear water to one 95 pound bag of portland cement or a mixture of clear water and bentonite adequate to create an impervious seal. The mixture may contain additives in proper amounts as necessary to reduce shrinkage and increase compatibility of the grout to injection and formation fluids.
(x) "Hazardous waste" means a hazardous waste as defined by the Georgia Hazardous Waste Management Act, Georgia Laws 1979, p. 1127, et seq., and the rules adopted pursuant to the Act
(y) "Hazardous waste management facility" means all contiguous land and structures, other appurtenances and improvements on the land used for treating, storing, or disposing of hazardous waste. A facility may consist of several treatment, storage, or disposal operational units.
(z) "Improved sinkhole" means a naturally occurring karst depression or other natural crevice found in other geologic settings which has been modified by man for the purpose of directing and emplacing fluids into the subsurface.
(aa) "Injection" means the subsurface emplacement of fluids.
(bb) "Injection well" means a well into which fluids are being, or intended to be, injected.

(cc) "Injection zone" means a geological formation, group of formations, or part of a formation receiving fluids through a well.

(dd) "Packer" means a device lowered into a well to produce a fluid-tight seal.

(ee) "Person" means any individual, corporation, association, partnership, county, municipality, State agency, Federal agency or facility or other entity.

(ff) "Plugging" means the act or process of stopping the flow of all fluids, including water, oil or gas into or out of a formation through a borehole or well penetrating that formation.

(gg) "Point of injection" means the last accessible sampling point prior to waste fluids being released into the subsurface environment through an injection well. For example, the point of injection of a Class V septic system might be the distribution box -- the last accessible sampling point before the waste fluids drain into the underlying soils. For a drywell, it is likely to be the well bore itself.

(hh) "Radioactive waste" means any waste which contains radioactive material.

(ii) "Sanitary waste" means liquid or solid wastes originating solely from humans and human activities, such as wastes collected from toilets, showers, wash basins, sinks used for cleaning domestic areas, sinks used for food preparation, clothes washing operations, and sinks or washing machines where food and beverage serving dishes, glasses, and utensils are cleaned. Sources of these wastes may include single or multiple residences, hotels and motels, restaurants, bunkhouses, schools, ranger stations, crew quarters, guard stations, campgrounds, picnic grounds, day-use recreation areas, other commercial facilities, and industrial facilities provided the waste is not mixed with industrial waste.

(jj) "Septic system" means a "well" that is used to emplace sanitary waste below the surface and is typically comprised of a septic tank and subsurface fluid distribution system or disposal system.

(kk) "Site" means the land or water area where any facility, operation or activity is physically located or conducted, including adjacent land used in connection with the facility, operation or activity.

(ll) "Stratum (plural strata)" means a single sedimentary bed or layer, regardless of thickness, that consists of generally the same kind of rock material.

(mm) "Subsidence" means the lowering of the natural land surface in response to: earth movements; lowering of fluid pressure; removal of underlying supporting material by mining or solution of solids, either artificially or from natural causes; compaction due to wetting (hydrocompaction); oxidation of organic matter in soils; or added load on the land surface.

(nn) "Subsurface fluid distribution system" means an assemblage of perforated pipes, drain tiles, or similar mechanisms intended to distribute fluids below the surface of the ground.

(oo) "Underground source of drinking water" means all aquifers or portions of aquifers which are not exempted aquifers.

(pp) "Waters or Waters of the State" includes any and all rivers, streams, creeks, branches, reservoirs, ponds, drainage systems, springs, wells, and all other bodies of surface or subsurface water, natural or artificial, lying within or forming a part of the boundaries of the State which are not entirely confined and retained completely upon the property of a single individual, partnership, or corporation.

(qq) "Well" means an open bored, drilled or driven shaft, whose depth is greater than the largest surface dimension; or an open dug hole whose depth is greater than the largest surface dimension; or, an improved sinkhole; or a subsurface fluid distribution system. Ditches and drains, open or filled, are not wells.

(rr) "Well head protection area" means that land area delineated in accordance with Rule 391-3-5-.40

(ss) "Well injection" means the subsurface emplacement of fluids through a well.

(tt) All other technical terms shall be defined in accordance to the definitions provided in Driscoll, F.G., 1996, Groundwater and wells, Johnson Division, St. Paul, MN 55112.

(3) Classification of Injection Wells. Amended.

(a) Class I Wells. This class consists of industrial and municipal disposal wells that inject fluids other than hazardous waste or radioactive waste below the lowermost formation containing, within two (2) miles of the well bore (or greater distance if determined by the Director), an underground source of drinking water.

(b) Class II Wells.

1. This class consists of wells which inject fluids:

(i) which are brought to the surface in connection with conventional oil or natural gas production and which may be commingled with waste waters from gas plants which are an integral part of production operations, unless those waters are classified as a hazardous waste at the time of injection;

(ii) for enhanced recovery of oil or natural gas; and

(iii) for storage of hydrocarbons which are liquid at standard temperature and pressure.

(c) Class III Wells.

1. This class consists of wells which inject fluids for the extraction of minerals including:

(i) mining of sulfur by the Frasch method;

(ii) in situ production of uranium or other metals; this category includes only in situ production from ore bodies which have not been conventionally mined. Solution mining of conventional mines such as stops leaching is included in Class V; and

(iii) solution mining of minerals, such as salt or potash.

(d) Class IV Wells.

1. This class consists of injection wells used by generators of hazardous waste or of radioactive waste, by owners or operators of hazardous waste management facilities, or by owners or operators of radioactive waste disposal sites to dispose of hazardous waste or radioactive waste into the subsurface or ground water.

2. Any septic tank, well or cesspool used by generators of hazardous or radioactive waste, or by owners or operators of hazardous or radioactive waste management facilities, to dispose of fluids containing hazardous or radioactive wastes into the subsurface or ground water.

3. The subsurface emplacement of hazardous waste or radioactive waste by well injection into the subsurface or waters of the State is hereby prohibited. No permit authorizing or establishing an effluent limitation inconsistent with the foregoing shall be issued.

(e) Class V wells consists of all injection wells not included in Classes I, II, III or IV. Typically, Class V wells are shallow wells used to place a variety of fluids directly below the land surface. However, if the fluids placed in the ground qualify as a hazardous waste under the Resource Conservation and Recovery Act (RCRA), the well is a Class IV well, not a Class V well. Class V wells include, but are not limited to:

1. Air conditioning return flow wells or any other open-loop system used to return to the supply aquifer or any aquifer the water used for heating or cooling in a heat pump;
2. Large-capacity cesspools including multiple dwelling, community or regional cesspools, or other devices that receive sanitary wastes, containing human excreta, which have an open bottom and sometimes have perforated sides. These requirements do not apply to single family residential cesspools nor to non-residential cesspools which receive solely sanitary waste and have the capacity to serve fewer than 20 persons a day;
3. Cooling water return flow wells used to inject water previously used for cooling;
4. Drainage wells used to drain surface fluid, primarily storm runoff, into a subsurface formation;
5. Drywells used for the injection of wastes into a subsurface formation;
6. Recharge wells used to replenish or store water in an aquifer;
7. Remediation wells used to inject water, air, oxygen, nutrients, or partly clean water to remediate sites contaminated with hydrocarbons or chemicals;
8. Salt water intrusion barrier wells used to inject water into a fresh water aquifer to prevent the intrusion of salt water into the fresh water;
9. Sand backfill and other backfill wells used to inject a mixture of water and sand, mill tailings or other solids into mined out-portions of subsurface mines whether what is injected is a radioactive waste or not;
10. Septic system wells used to inject the waste or effluent from a multiple dwelling business establishment, community or regional business establishment septic system. These rules do not apply to single family residential septic system wells, nor to non-residential septic system wells that are used solely for the disposal of sanitary waste and have the capacity to serve fewer than 20 persons a day;

(4) Identification of Underground Sources of Drinking Water and Exempted Aquifers. Amended.

(a) The Director may identify by narrative description, illustrations, maps, or other means, and shall protect, except where exempted under subparagraph (b) of this paragraph, as an underground source of drinking water, all aquifers or parts of aquifers which meet the definition of an □underground source of drinking water□ for the purposes of these rules. Unless specifically exempted by the Director under subparagraph (b) of this paragraph, all aquifers shall be considered, for the purposes of these rules, as underground sources of drinking water.

(b) The Director may identify by narrative description, illustrations, maps, or other means, all aquifers or parts of aquifers which the Director proposes to designate as an exempted aquifer, for the purposes of these rules, if it meets the following criteria:

1. It does not currently serve as a source of drinking water;
2. The total dissolved solids (TDS) is greater than 3,000 milligrams per liter;

3. Injection into the aquifer will not cause salt-water to move into and contaminate underground sources of drinking water; and
4. It cannot now and will not in the future serve as a source of drinking water because:
   (i) it is mineral, hydrocarbon or geothermal energy producing or can be demonstrated by a permit applicant for a Class II or III operation to contain minerals or hydrocarbons, that considering their quantity and location, are expected to be commercially producible based on available information; or
   (ii) it is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical; or
   (iii) it is so contaminated that it would be economically or technologically impractical to render the water fit for human consumption; or
   (iv) it is located over a Class III mining area subject to subsidence or catastrophic collapse.

(c) For Class III wells, the Director shall require an applicant for a permit which necessitates an aquifer exemption to furnish the data necessary to demonstrate that the aquifer is expected to be mineral or hydrocarbon producing. Information contained in the mining plan for the proposed project, such as a map and general description of the mining zone, general information on the mineralogy and geochemistry of the mining zone, analysis of the amenability of the mining zone to the proposed mining method and a timetable of planned development of the mining zone shall be considered by the Director in addition to the information required by Rule 391-3-6-.13(6). Approval of the aquifer exemption shall be treated as a program revision under this paragraph.

(d). For Class II wells, a demonstration of commercial productibility shall be made as follows:
1. For a Class II well to be used for enhanced oil recovery processes in a field or project containing aquifers from which hydrocarbons were previously produced, commercial productibility shall be presumed by the Director upon a demonstration by the applicant of historical production having occurred in the project area or field.
2. For Class II wells not located in a field or project containing aquifers from which hydrocarbons were previously produced, information such as logs, core data, formation description, formation depth, formation thickness and formation parameters such as permeability and porosity shall be considered by the Director, to the extent such information is available.

(e) No designation of an exempted aquifer, for the purposes of these rules, shall be final until the Director has provided public notice and opportunity for a public hearing on the proposed designation and the designation has been approved by the Administrator.

(5) Prohibition of Movement of Fluid into Underground Sources of Drinking Water. Amended.

(a) No owner or operator shall construct, operate, maintain, convert, plug, abandon, or conduct any other injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under Georgia's Rules for Safe Drinking Water, Chapter 391-3-5-.1B, or may otherwise adversely affect the health of persons. The applicant for a permit shall have the burden of showing that the requirements of this paragraph are met.

(b) Except for remediation wells, injection of fluids shall be prohibited in the inner management zone of any well head protection area defined by Rule 391-3-5-.40.

(6) Permit Application for Class I, II and III Wells. Amended.

(a) No person shall, in accordance with Section 10 of the Act, construct or operate a Class I, II, or III injection well without first having applied for, and obtained, an injection well permit from the Director. The requirements for Class II wells do not include permits for exploration, drilling and well construction for oil and/or gas production.

(b) The subsurface emplacement of hazardous waste or radioactive waste by well injection into the subsurface or waters of the State is hereby prohibited. No permit authorizing or establishing an effluent limitation inconsistent with the foregoing shall be issued.

(c) Applications for injection well permits for Class I, II or III injection wells shall be in accordance with Federal Regulations, 40 C.F.R. 144.11, 144.21, and 144.31. Applications shall be on forms as may be prescribed and furnished from time to time by the Division and shall be accompanied by all pertinent information as the Division may request including, but not limited to, the information the Director must consider for authorizing Class I, II or III wells as set forth in the Federal Regulations, 40 C.F.R. 146.14, 146.24 and 146.34.

(d) All permit applications and reports for Class I, II, or III injection wells shall be signed in accordance with the Federal Regulations, 40 C.F.R. 144.32, 146.12 and 146,22.

(e) When a facility or activity is owned by one person but is operated by another person, it is the operator's duty to obtain a permit.

(7) Notice and Public Participation for Class I, II and III Wells. Amended.

(a) When the Division is satisfied that the application is complete, a tentative determination will be made to issue or deny the permit. If the tentative determination is to issue the permit, a draft permit will be prepared in accordance with Federal Regulations, 40 C.F.R. 124.6 and applicable State laws prior to the issuance of a public notice.

(b) Public notice of the draft permit will be prepared and circulated in a manner designated to inform interested and potentially interested persons of the proposed injection and of the proposed determination to issue or deny a permit for the proposed injection. Procedures for circulation of the public notice shall include the following:

1. Within the geographical area of the proposed injection the public notice shall be circulated by at least one of the following: posting in the post office or other public buildings near the premises of the applicant in which the injection is located or posting at the entrance of the applicant's premises or nearby; and publication in one (1) or more newspapers of general circulation in the area affected by the injection;
2. Posting of the public notice in the Office of the Secretary of State;
3. A copy of the public notice shall be mailed to the applicant;
4. Mailing of the public notice to any person or group upon written request including persons solicited from area lists from past permit proceedings. The Division shall maintain a mailing list for distribution of public notices and fact sheets. Any person or group may

request that their names be added to the mailing list. The request should be in writing to the Division and shall be renewed in December of each year. Failure to renew the request shall result in the removal of such name from the mailing list;

5. The Division shall provide a period of not less than thirty (30) days following the date of the public notice in which interested persons may submit their written views on the tentative determination with respect to the draft Injection Well Permit. All written comments submitted during the thirty (30) day comment period will be retained by the Division and considered in the final determination with respect to the permit application and shall be responded to in accordance with Federal Regulations, 40 C.F.R. 124.17. The comment period may be extended at the discretion of the Director;
6. The contents of the public notice will be in accordance with Federal Regulations, 40 C.F.R. 124.10;
7. The Division will prepare and distribute a fact sheet in accordance with Federal Regulations, 40 C.F.R. 124.8 and applicable State laws. A copy of the fact sheet will be available for public inspection at the Division office in Atlanta. Any person may request in writing a copy of the fact sheet and it will be provided. The Division shall add the name of any person or group upon request to the mailing list to receive copies of fact sheets;
8. The Division will prepare and distribute a statement of basis in accordance with Federal Regulations, 40 C.F.R. 124.7;
9. Copies of the draft permit shall be transmitted to the Regional Administrator for review and comments in such manner as the Director and Regional Administrator shall agree.

(c) The Director shall provide an opportunity for an applicant, any affected state or interstate agency, the Regional Administrator or any other interested agency, person or group of persons to request a public hearing with respect to an Injection Well Permit. Any such request for public hearing shall be filed within the 30 day comment period prescribed in subparagraph 391-3-6.13(7)(b) 5. and shall indicate the interest of the party filing such a request, the reasons why a hearing is requested, and those specific portions of the application or information to be considered at the public hearing. The Director shall hold a hearing if he determines that there is sufficient public interest in holding such a hearing or if the Director desires to clarify a permitting decision:

1. Any public hearing held pursuant to this subparagraph shall be held in the geographical area of the proposed injection or other appropriate location at the discretion of the Director;
2. The Director may hold one public hearing on groups of related permit applications;
3. Public notice of any hearing held pursuant to this subparagraph shall be provided at least thirty (30) days in advance of the hearing date and shall be circulated in accordance with Federal Regulations, 40 C.F.R. 124.10(c) where applicable to State-issued permits.

(d) A copy of the administrative record for the final permit (40 C.F.R.124.18(b)(1)), including but not limited to the Injection Well Permit Application, public notice, fact sheet, statement of basis, draft permit and other well forms related thereto, written public comments of all governmental agencies thereon and other reports, files and information not involving methods or processes entitled to protection as trade secrets, and not including written public comments by any person, shall be available for public inspection and copying during normal business hours at the Division office in Atlanta and in addition shall be distributed in accordance with Federal Regulations, 40 C.F.R. 124.10(e). Public access to such information shall be in accordance with Federal Regulations, 40 C.F.R. 14.5.

(e) Any information submitted in an Injection Well Permit Application form together with reports, records or plans that are considered confidential by the applicant should be clearly labeled □Confidential□ and be supported by a statement as to the reasons that such information should be considered confidential. If the Director, with the concurrence of the Regional Administrator, determines that such information is entitled to confidential protection, he shall label and handle same accordingly:

1. When the information being considered for confidential treatment is contained in the application, the Director shall forward such information to the Regional Administrator for his concurrence in any determination of confidentiality.
2. Any information accorded confidential status, whether or not contained in the application, shall be made available, upon written request, to the Regional Administrator or his authorized representative who shall maintain the information as confidential.

(f) Claims for confidentiality for the following will be denied:

1. The name and address of any permit applicant or permittee; or
2. Information which deals with the existence, absence, or level of contaminants in drinking water.

(8) Terms and Conditions of Permits for Class I, II, or III Wells. Amended.

(a) Terms and conditions under which an Injection Well will be permitted will be specified on the permit issued and shall be in accordance with Federal Regulations, 40 C.F.R. 144.4, 40 C.F.R. 144.51 and 40 C.F.R. 144.52, Rule 391-3-6-.13(9) of this Chapter and as may be additionally required by the Director.

(b) No Injection Well Permit shall be issued authorizing the movement of fluid containing any contaminant into underground sources of drinking water if the presence of that contaminant may cause a violation of any primary drinking water regulation set forth in Georgia Rules for Safe Drinking Water, Chapter 391-3-5, or may otherwise adversely affect the health of persons. The applicant for a permit shall have the burden of showing that the requirement of this paragraph is met.

(c) When the corrective action plan as required in Paragraph 391-3-6-.13(9) is adequate, the Director shall incorporate it into the permit as a condition. Where the Director's review of an application indicates that the permittee's plan is inadequate (based on the factors in Federal Regulations 40, C.F.R. 146.07), the Director shall require the applicant to revise the plan, prescribe a plan for corrective action as a condition of the permit under paragraph (b) of this section, or deny the application.

1. No owner or operator of a new injection well may begin injection until all required corrective action has been taken.
2. The Director may require as a permit condition that injection pressure be so limited that pressure in the injection zone does not exceed hydrostatic pressure at the site of any improperly completed or abandoned well within the area of review. This pressure limitation shall satisfy the corrective action requirement. Alternatively, such injection pressure

limitation can be part of a compliance schedule and last until all other required corrective action has been taken.

3. When setting corrective action requirements for Class III wells the Director shall consider the overall effect of the project on the hydraulic gradient in potentially affected underground sources of drinking water, and the corresponding changes in potentiometric surface(s) and flow direction(s) rather than the discrete effect of each well. If a decision is made that corrective action is not necessary based on the determinations above, the monitoring program required in Federal Regulations, 40 C.F.R. 146.33(b) shall be designed to verify the validity of such determination.

(d) The permittee shall report any monitoring or other information which indicates any contaminant that may cause an endangerment of an underground source of drinking water, any noncompliance that may endanger health or the environment, or any noncompliance with a permit condition or malfunction of the injection system which may cause fluid migration into or between fresh water zones or underground sources of drinking water. Any noncompliance with a permit condition or a malfunction of the injection information shall be reported by telephone to the Director within twenty four (24) hours from the time the permittee becomes aware of the noncompliance and a written submission within five (5) days of the oral notification. The written submission shall contain a description of the noncompliance and its cause, the period of noncompliance including exact dates and times, the corrective action taken to reduce or eliminate the noncompliance, and the steps planned to prevent a recurrence of the noncompliance.

(e) The permittee is required to maintain financial responsibility and resources to close, plug and abandon the underground injection operation in a manner prescribed by the Director. The permittee must show evidence of financial responsibility to the Director by the submission of surety bond, or other adequate assurance, such as financial statements or other materials acceptable to the Director.

(f) The permittee shall operate the well so as not to exceed maximum injection volumes and pressures as necessary to assure that fractures are not initiated in the confining zone; that injected fluids do not migrate into fresh water zones or underground sources of drinking water; or that formation fluids are not displaced into underground sources of drinking water. The Director shall establish such volumes and pressure limits as permit conditions.

(g) Injection may not commence until construction is complete and written approval to commence has been given by the Director. The permittee shall submit notice of completion of construction to the Director including:

1. All available logging and testing program data on the well;
2. A demonstration of the mechanical integrity of the well;
3. The anticipated maximum pressure and flow rate at which the permittee will operate;
4. The results of the formation testing program;
5. The actual injection procedure;
6. The compatibility of injected waste with the fluids in the injection zone; and
7. The status of corrective action on defective wells in the area of review to prevent fluid movement into underground sources of drinking water.

(h) The permittee shall notify the Director in writing of any proposal to abandon an injection well and that the plugging and abandonment plan approved as part of the permit will be followed.

(i) A permit shall be issued for a period not to exceed five (5) years from the date of issuance. On expiration of the permit the permit shall become invalid and the injection prohibited unless application is made at least ninety (90) days prior to the expiration date for a reissuance of the permit. When a permittee has submitted a timely and sufficient application for a new Injection Well Permit and the Director is unable, through no fault of the permittee, to issue the new permit before the expiration date of the existing permit, then the Director shall extend the existing permit until a new permit is issued.

(j) A permit may be transferred to any person provided the permittee notifies the Director in writing at least 30 days in advance of the proposed transfer date and the transfer is approved by the Director.

(k) The permit does not convey any property rights of any sort or any exclusive privilege.

(l) The permit may be modified, revoked and reissued, or terminated for cause, or minor modifications may be made in accordance with Federal Regulations, 40 C.F.R. 124.5, 144.39 and 144.41. The permittee shall furnish the Director any information which the Director may request to determine whether cause exists for modifying, revoking and reissuing or terminating a permit or to determine compliance with the permit.

(m) The Director may terminate a permit during its term or deny a permit renewal for the following causes:

1. Noncompliance by the permittee with any conditions of the permit;
2. The permittee's failure in the application or during the permit issuance process to disclose fully all relevant facts, or the permittee's misrepresentation of any relevant facts at any time;
3. A determination that the permitted activity endangers human health or the environment and can only be regulated to acceptable levels by permit modification of termination; or
4. A failure by the permittee to demonstrate that continuation of the operation under the permit will not result in degradation of the water quality.

(n) For Class I, II and III Wells, if any water quality monitoring of an underground source of drinking water indicates the movement of any contaminant into the underground source of drinking water, the Director shall prescribe such additional requirements for construction, corrective action, operation, monitoring or reporting (including closure of the injection well) as are necessary to prevent such movement.

(o) Notwithstanding any other provisions of this rule the Director may issue a temporary permit for a specific injection in accordance with the Federal Regulations, 40 C.F.R. 144.34.

(9) Corrective Action.

(a) Applicants for Class I, II, or III injection well permits shall identify the location of all known wells within the injection well's area of review which penetrate the injection zone, or in the case of Class II wells operating over the fracture pressure of the injection formation, all known wells within the area of review penetrating formations affected by the increase in pressure. For such wells which are improperly sealed, completed, or abandoned, the applicant shall also submit a plan consisting of such steps or modifications as are necessary to prevent movement of fluid into underground sources of drinking water (corrective action). Where the plan is adequate, the Director shall incorporate it into the permit as a condition. Where the Director's review of an application indicates that the permittee's plan is inadequate (based on the factors in subparagraph 391-3-6-.13(8)(c)), the Director shall require the applicant to revise the plan, prescribe a plan for corrective action as a condition of the permit under subparagraph (b) of this paragraph or deny the application.

(b) In determining the adequacy of corrective action proposed by the applicant under this paragraph and in determining the additional steps needed to prevent fluid movement into underground sources of drinking water, the following criteria and factors shall be considered by the Director:

1. Nature and volume of injected fluid;
2. Nature of native fluids or by-products of injection;
3. Potentially affected population;
4. Geology;
5. Hydrology;
6. History of the injection operation;
7. Completion and plugging records;
8. Abandonment procedures in effect at the time the well was abandoned; and
9. Hydraulic connections with underground sources of drinking water.

(10) Criteria and Standards Applicable to Class I, II, and III Injection Wells.

(a) Each permittee shall comply with the criteria and standards for underground injection control for Class I, II and III injection wells as set forth in the Federal Regulations, 40 C.F.R. 146.12, 146.22 and 146.32 and as may be additionally prescribed by the Director.

(b) All Class I wells shall be sited in such a fashion that they inject into a formation which is beneath the lowermost formation containing, within a two (2) mile radius of the well bore or greater if determined by the Director, an underground source of drinking water.

(c) All Class II wells shall be sited in such a fashion that they inject into a formation which is separated from an underground source of drinking water by a confining zone that is free of known open faults or fractures within the area of review.

(d) Operating, monitoring and reporting requirements shall be in accordance with Federal Regulations, 40 C.F.R. 146.13, 40 C.F.R. 146.23 and 40 C.F.R. 146.33 and as may be additionally prescribed by the Director.

(11) Permit Application for Class V Wells. Amended.

(a) Except as identified in subparagraph 1. below, no person shall, after the effective date of this rule, construct or operate a Class V injection well for the injection of contaminants or fluids unless authorized by a permit issued by the Director.

1. In accordance with O.C.G.A. 12-5-30 (f.), the use of a Class V septic system that handles only sanitary wastes shall be permitted under a General Permit issued by the Director. Coverage under this permit shall be automatic upon notification by the Georgia Department of Human Resources that such a system meets requirements of 290-5-26 and 391-3-16-.02. Such notification shall be in the form of an annual inventory of new and existing systems.

The General Permit and a list of all Class V septic systems shall be maintained in the offices of the Division.

(b) After the effective date of this rule, use of a new or existing Class V septic system that handles sanitary and/or other wastes shall be permitted by the Director provided that a written hydrogeologic determination has been made by a professional geologist or professional engineer registered in the State of Georgia in accordance with Chapter 19 or Chapter 15, respectively, of Title 43 that such a system does not endanger an underground source of drinking water nor is such a system within the inner management zone of any existing well head protection area.

(c) The use of a Class V remediation well that is used as part of a Division - approved plan to remediate a site having contaminated soil and /or ground water shall be permitted by the Director provided that such an approved plan has been prepared and signed and sealed by a professional geologist or professional engineer registered in the State of Georgia in accordance with Chapter 19 or Chapter 15, respectively, of Title 43.

(d) Class V wells apply to all injection wells not included in Classes I, II, III or IV. Class V wells are defined in subparagraph 391-3-6-.13(3)(e).

(e) Exclusive of the authorizations indicated in subparagraphs (a) 1. above of this paragraph, any person desiring to construct a Class V well shall apply in writing to the Director for an injection well permit. Any persons owning or operating any unpermitted well meeting the definitions of a Class V well, exclusive of the authorizations described in subparagraph (a) 1. above of this paragraph, prior to the effective date of this rule shall submit an application and information to the Director no later than July 1, 2001. The application shall include, but need not be limited to, the following information:

1. Name, mailing address telephone number, latitude and longitude and location of the facility;
2. Name and address of the owner and operator, telephone number, if different than the facility;
3. A map showing the location of each existing or proposed injection well at the facility;
4. A diagram showing the details of the construction existing injection well(s) and the proposed construction of any proposed injection well(s).
5. Proposed or existing injection rate and injection pressure or gravity flow;
6. The chemical, physical and radioactive characteristics of the fluid injected or to be injected; and
7. Signature of the applicant.

(d) Upon receipt of the application, the Director shall:

1. Determine if the facility is a Class V well.
2. Determine if additional information is required to evaluate the facility.
3. Assess the potential adverse affect upon the underground source of drinking water.
4. Determine any construction and operating requirements to protect the underground drinking water source.

(e) After an evaluation of the application, the Director shall:

1. Issue a permit in the form of a letter containing any special permit conditions as may be necessary such as well construction, operation, monitoring and reporting. The permit shall be for a period not to exceed ten (10) years.

2. If the Director determines that the facility is not a Class V well, he shall require the applicant to submit a permit application in accordance with Rule 391-3-6-.13(6) of this Chapter. The application processing and permit issuance shall be in accordance with Rules 391-3-6-.13(6) and 391-3-6-.13(7).
3. Deny the issuance of a permit.

(f) No person shall be issued a permit to operate a Class V well where the movement of fluid, in the judgment of the Director, may cause a violation of any primary drinking water rule under the Georgia Rules for Safe Drinking Water, Chapter 391-3-5, or which may adversely affect the health of persons.
1. If at any time the Director learns that a permitted Class V well may cause a violation under this paragraph, the Director shall:
(i) order the injector to take such actions as may be necessary to prevent the violation, including where required closure of the injection well; or
(ii) take enforcement action.
2. Notwithstanding any other provisions of this paragraph, the Director may take emergency action upon receipt of information that a contaminant which is present in, or is likely to enter a pubic water system, may present an imminent and substantial endangerment to the health of persons.

(g) Any persons operating an existing unpermitted Class V well and injecting fluids after the effective date of this rule shall be authorized to continue the operation under conditions of permits or other authorization in effect prior to the effective date of this rule, provided an application is submitted within twelve months after the effective date of this rule. An exception to this rule is that any person injecting fluids that may endanger an underground source of drinking water shall notify the Director within thirty (30) days of the effective date of this rule.

(12) Standards and Criteria Applicable to Class V Wells. Amended.

(a) Except as identified in subparagraph 391-3-6-.13(11)(a)1. above, no person shall construct a Class V well without first having applied for and obtained a permit from the Director.

(b) Class V wells shall be sited so that the injection fluid does not contaminate an underground source of drinking water.

(c) Except for remediation wells, the injected fluid, upon reaching any underground source of drinking water, shall not contain any chemical constituents that exceed any Maximum Contaminant Levels (MCL) identified in Rule 391-3-5-.18. For Class V septic systems, the fluid leaving the subsurface distribution system may exceed any maximum contaminant levels (MCLs) identified in Rule 391-3-5-.18 provided that the MCL is not exceeded upon the fluid reaching any underground source of drinking water.

(d) With the exception of remediation wells, no Class V well shall be located within the inner management zone of any well head protection area after the effective date of this rule.

(e) Class V well construction.
Subsections 1., 2. and 3. below shall not apply to Class V septic systems as identified in subparagraphs 391-3-6-.13(11)(a)1. and (b.) above:

1. The person constructing the well shall be a licensed water well contractor in the State of Georgia in accordance with the provisions of Chapter 5 of Title 12.
2. Casing shall extend at least five (5) feet into the injection zone unless otherwise specified by the Director.
3. The annular space around the entire length of the casing shall be grouted and sealed to prevent pollution by surface waters, other formation fluids or pollutants into the formation above the injection zone.
4. Special construction requirements may be specified by the Director or the permit to prevent contamination of an underground source of drinking water.
5. Septic systems shall be constructed in accordance with the Georgia Department of Human Resources requirements in 290-5-26.

(f) An injection permit may be transferred to any person provided the permittee notifies the Director in writing at least 30 days in advance of the proposed transfer date and the transfer is approved by the Director.

(g) A permit issued by the Director may include permit conditions for the monitoring, testing and reporting of the injection facility.

(h) Plugging and Abandonment.
Except for septic systems identified in subparagraphs 391-3-6-.13(11)(a)1. and 2. above, the following shall apply:

1. The Director may order a Class V well plugged and abandoned by the owner when it no longer performs its intended purpose, or when it is determined to endanger underground sources of drinking water.
2. It shall be the owner's responsibility to have any injection well plugged and abandoned by the water well contractor before removing the drilling equipment from the site if the well is not completed for its intended purpose.
3. It shall be the owner's responsibility to have any exploratory and/or test well(s) constructed for the purpose of obtaining information on an injection well site, plugged and abandoned by the water well contractor.
4. The entire depth of the well shall be completely filled with cement grout, which shall be introduced into the well by a pipe which extends to the bottom of the well and is raised as well is filled, unless otherwise approved by the Director.

(13) Mechanical Integrity. Amended.
Except for septic systems as identified in subparagraphs 391-3-6-.13(11)(a)1. and 2. above, the following shall apply:

(a) An injection well has mechanical integrity if:

1. There is no detectable leak in the casing, tubing or packer; and
2. There is no detectable fluid movement into an underground source of drinking water through vertical channels adjacent to the injection well bore.

(b) One of the following methods must be used to evaluate the absence of detectable leaks under subparagraph 391-3-6-.13(13)(a)1:

1. Monitoring of annulus pressure; or
2. Pressure test with liquid or gas.

(c) The methods used to determine the absence of detectable fluid movement into an underground source of drinking water shall be the results of a temperature or sonic log.

(d) In conducting and evaluating the tests for mechanical integrity, the owner or operator and the Director shall apply methods and standards generally accepted in the industry. When the owner or operator reports the results of mechanical integrity tests to the Director, the report shall include a description of the test(s) and method(s) used. The Director, in making an evaluation shall review monitoring and other test data submitted since the previous evaluation.

(e) The Director may waive mechanical integrity testing of remediation wells in shallow unconfined aquifers.

(14) Plugging and Abandoning Class I, II and III Wells. Amended.

(a) The permittee shall inform the Director in writing of the permittee's intent to abandon an injection well at least forty-five (45) working days prior to the abandonment.

(b) The permittee shall be responsible for the plugging of any injection well that is abandoned. Such plugging shall be in accordance with the criteria identified in Chapter 5 (120-138) of Title 12.

(c) Wells shall be plugged with cement in a manner which will not allow the movement of fluids either into or between underground sources of drinking water.

(d) The placement of the cement shall be accomplished under pressure from bottom to top.

(e) The well to be cemented shall be in a state of static equilibrium with the mud weight equalized top to bottom, either by circulating the mud in the well at least once or by a comparable method prescribed by the Director, such as the use of a packer, prior to the placement of the cement plugs.

(f) The Director may require ground water monitoring after well abandonment if contamination of an underground source of drinking water is suspected.

(g) The permittee shall certify to the Director within thirty (30) days of plugging that the injection well was plugged according to permitted procedures.

(15) Emergency Action. If at any time the Director learns that an injection well may cause or has caused the movements of any fluids containing contaminants into an underground source of drinking water or otherwise adversely affect the water quality or adversely affect the public health, the Director shall:

(a) Order the injector to cease the operation and take such actions as may be necessary to prevent the violation;

(b) Order the injector to take such actions as may be necessary to correct the violation;

(c) Take enforcement action; or

(d) Take emergency action upon receipt of information that a contaminant is likely to enter a public water system and present an imminent and substantial endangerment to the health of the public.

(16) Prohibited Wells. Amended. The following types of wells are specifically prohibited Statewide.

(a) All Class IV wells that are used to emplace hazardous waste or radioactive waste into the subsurface.
(b) New drainage wells, except where such wells have been permitted and designed by a professional geologist or professional engineer registered in the State of Georgia in accordance with Chapter 19 or Chapter 15, respectively, of Title 43 and the injected fluid does not contain any chemical constituent that exceeds any Maximum Contaminant Level (MCL) identified in Rule 391-3-5-.18.
(c) New large-capacity cesspools are prohibited. A large-capacity cesspool receives sanitary waste from multiple dwellings and community or regional establishments serving more than 20 persons a day. Existing large-capacity cesspools shall be closed by April 5, 2005. Such closure shall include a 30 day notification prior to closure. Well closure shall include removal of contaminated materials, disinfection, and plugging with an impervious bentonite-cement mixture. Closure shall be in accordance with criteria identified in the Chapter 5 (120-138) of Title 12.
(d) Open loop heat pump systems where return water is discharged into a well.
(e) Motor vehicle waste disposal wells.

Authority O.C.G.A. Sec. 12-5-23 (Ga. L. 1957) p. 629, Sec. 4; Ga. L. 1964, p. 416, Secs. 5, 24; Ga. L. 1966, p. 316, Sec 1; Ga. L. 1972, p. 1015, Secs. 1517, 1534; Ga. L. 1972 p. 1266, Sec. 1; Ga. L. 1974, p. 599, Secs. 6, 7; Ga. L. 1977, p. 368, Sec. 2. Administrative History: Original Rule entitled "Underground Injection Control" was filed on Dec. 9, 1983, eff. Dec. 29, 1983.

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