

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>1 of 2</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:</b>	<b>TABLE OF CONTENTS</b>		

## TABLE OF CONTENTS

TABLE OF CONTENTS.....	1
1. INTRODUCTION .....	1
1.1. Purpose and Scope .....	1
1.2. Previous Studies .....	2
1.3. Study Methods .....	5
2. DESCRIPTION OF THE STUDY AREA .....	7
2.1. Geologic Setting .....	7
2.2. Geologic and Hydrogeologic Units .....	9
2.2.1. Upper Floridan Aquifer.....	9
2.2.2. Miocene Unit.....	12
2.2.3. Pleistocene - Recent Unit.....	13
3. STUDY RESULTS .....	14
3.1. Subbottom Geophysical Survey.....	14
3.1.2. Analysis of Geophysical Data and Correlation with Core Borings... 14	
3.1.3. Buried Relict Stream Channels.....	24
3.2. Core Borings .....	26
3.3. Borehole Geophysical Logging .....	28
3.4. Core Permeability Analysis .....	29
3.5. Test Well Installation.....	32
3.6. Ground-water Quality and Hydraulic Head Assessment .....	33
3.7. Effects of Dredging in the Channel Area .....	36
3.7.1. Leakage Through the Miocene Confining Unit.....	36
3.7.2. Leakage Through Pleistocene Paleochannels .....	38
4. SUMMARY AND CONCLUSIONS .....	39
5. REFERENCES .....	41
Appendix A. Core Boring Logs.....	44
Appendix B. Permeability Analysis Data.....	45
Appendix C. Ground-water Quality Analysis Data.....	46

### TABLES

Table 1. Existing and Proposed Channel Depths.....	1
Table 2. Stratigraphic-Hydrogeologic Units.....	8
Table 3. Correlation of Geophysical Reflectors and Core Borings.....	23
Table 4. Approximate Penetration of Buried Relict Channels Into Miocene B.....	25
Table 5. Summary of Permeability and Index Testing.....	30
Table 6. Well Data from Cluster Sites in Chatham County, Georgia.....	35

### FIGURES

Figure 1. Study Area with Core Boring and Test Well Locations.....	3
Figure 2. Subbottom Geophysical Survey Lines.....	5
Figure 3. Regional Geologic Section.....	7
Figure 4. Potentiometric Map of Upper Floridan Aquifer.....	10
Figure 5. Geologic Section Sta. 31+000 to Sta. -21+500.....	15
Figure 6. Geologic Section Sta. 87+000 to Sta. 31+000.....	16
Figure 7. Subbottom Geophysical Survey Section at SHE-1.....	17
Figure 8. Subbottom Geophysical Survey Section at SHE-2.....	18
Figure 9. Subbottom Geophysical Survey Section at SHE-3.....	19
Figure 10. Subbottom Geophysical Survey Section at SHE-4.....	20

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>2 of 2</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:TABLE OF CONTENTS</b>			

**FIGURES (continued)**

Figure 11. Subbottom Geophysical Survey Section at SHE-5.....21

Figure 12. Subbottom Geophysical Survey Section at Relict Channels.....22

Figure 13. Locations of Buried Relict Stream Channels.....24

Figure 14. Geologic Section at Tybee Well Cluster.....33

Figure 15. Geologic Section at Fort Pulaski Well Cluster.....34

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	1 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:1.	INTRODUCTION		

## SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY POTENTIAL GROUND-WATER IMPACTS

### 1. INTRODUCTION

The Savannah Harbor Expansion Feasibility Study is a multi-faceted study to determine the feasibility of expanding and deepening the present Savannah Harbor and entrance channel. The study is the first step in determining the engineering, environmental, and economic feasibility of the proposed project. The proposed project would deepen the harbor and entrance channel to various depths below Mean Low Water (MLW) in the reaches indicated in table 1 below.

**Table 1**

**Existing and Proposed Channel Project Depths**

Station	Existing Project Depth (FT, MLW) *	Proposed Project Depth (FT, MLW) *
103+000 to 102+000	-42	-52
102+000 to 70+000	-44	-54
70+000 to 24+000	-46	-56
24+000 to 0+000	-44	-54
0+000 to -85+000	-44	-54

\* - With authorized over-depth for advanced maintenance.

This report on Potential Ground-Water Impacts was prepared as part of a separate technical study and is being included as an attachment to the Engineering Appendix of the Feasibility Study.

#### 1.1. Purpose and Scope

Growing concern by State and Federal agencies regarding the vulnerability of ground-water resources in the coastal area due to overuse and seawater encroachment is well known. The principal aquifer known as the Floridan aquifer, which is the largest source of fresh water in the coastal area, has received particular attention as State ground-water agencies have begun to search for alternative ground-water resources. Measures to relieve some of the stress on the Floridan

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>2 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:1.</b>	<b>INTRODUCTION</b>		

aquifer have already been put into effect by State ground-water agencies in an attempt to force ground-water users to explore and develop alternative sources.

The principal objective of this investigation was to determine if deepening of the Savannah Harbor channel has the potential to impact aquifers, in particular the upper Floridan aquifer, within the project area. In order to answer this question, a three-part study was used. The first part of the study was a state-of-the-art, high-resolution subbottom geophysical survey to determine the attitude of significant acoustic horizons below the project area. The second part of the study was a series of core borings that were drilled to "ground-truth" the subbottom geophysical survey data. The locations of the borings were, in part, based on data obtained from the survey. The continuous core samples from the boreholes provided detailed stratigraphic and lithologic data, thicknesses of the various sediments, and samples for laboratory permeability analyses. Geophysical logs were also obtained.

The third part of the study included the installation of four test wells to better characterize hydraulic properties and ground-water quality of the various sediments. The investigation detailed in this report provides the most comprehensive hydrogeologic evaluation of potential impacts to ground-water resources by dredging to be performed to date for Savannah Harbor. Figure 1 is a map of the study area showing the location of core borings and test wells.

## **1.2. Previous Studies**

The possibility of impacting the upper Floridan aquifer due to dredging was first addressed in a report by the Savannah District Corps of Engineers in 1980 (USACE, 1980). That report was completed as part of a larger long term planning document and did not address site specific information. A follow up report, which included two deep core holes (SH-65 and SH-66) and limited subbottom geophysical surveying, was completed in 1982 (USACE, 1982).

Preliminary to deepening the Savannah Harbor, an extensive, site-specific subbottom geophysical surveying effort was initiated in late 1991 by the Savannah District Corps of Engineers to better determine the relationship of the various stratigraphic units below the existing Savannah River channel. A detailed study of these sub-bottom seismic records was performed and reported by Henry (1992). That study revealed the existence of several buried relict stream channels that had entrenched into the Miocene confining unit overlying the upper Floridan aquifer. These relict channel cuts became the focus of further study, since it was postulated that there was a possibility, due to the effects of dredging, that seawater could enter the buried channels. If the channels were in-filled with higher permeability sediments, a more direct path through the confining units might then exist, thus potentially allowing seawater intrusion into the upper Floridan aquifer.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>3 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:1.</b>	<b>INTRODUCTION</b>		

Much broader scope studies detailing the geology and hydrogeology of the Savannah area include the work of Counts and Donsky (1963); McCollum and Counts (1964); Furlow (1969), Huddleston (1988); and Clarke, Hacke, and Peck (1990). These studies were reviewed for information pertinent to this study.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>4 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:1.</b>	INTRODUCTION		

**FIGURE 1 - Study Area with Core Boring and Test Well Locations**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>5 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:1.</b>	<b>INTRODUCTION</b>		

### 1.3. Study Methods

The methods employed in this study were intended to build and expand on the information from previous studies, particularly the internal studies done by the Savannah District Corps of Engineers and the report by Clarke and others (1990). The study was implemented in the phased approach described below.

During the period 3-6 October 1997, a subbottom geophysical survey was performed in the Savannah Harbor entrance channel and inner harbor by Ocean Surveys, Inc. (OSI). Approximately 38 miles of survey were performed along the centerline of the present navigation channel, with approximately 12 miles of additional survey "tie-lines" performed across the centerline and parallel to the centerline in selected areas. Figure 2 is a map showing the lines of survey. The survey was designed to determine the depth to various recognizable stratigraphic units underlying the navigation channel between river stations 113+000 and -85+000. The data were also used to select areas where core borings were needed, and core borings were, in turn, used to "ground-truth" survey data.

During the period 21 October to 20 December 1997, eight core borings were drilled to better determine the stratigraphic relationship of the sediments below the project area. The locations of these borings are shown on Figure 1, and the logs of the borings are included in Appendix A. Six of the borings were drilled within or near the present Savannah River navigation channel from the Savannah District's self-elevating drill barge. Two of the borings were drilled on land near the navigation channel. Mud rotary drilling with wire-line coring was used in all boreholes. An attempt was made to obtain continuous samples from river bottom (or land surface) to maximum hole depth. Core recovery was generally good with only occasional core losses due to soft unconsolidated sediments being washed away during coring. Natural gamma logs were obtained from all borings, since previous investigations had shown this to be an effective tool for correlating stratigraphic units within the project area.

Laboratory permeability tests were performed on 22 samples, as well as grain size distribution and other geotechnical parameters. Vertical permeabilities ( $K'$ ) are important in defining the water transmitting characteristics of sediments above the upper Floridan aquifer, in particular the potential of those sediments to allow downward migration of seawater into the Floridan.

Four test wells were installed to obtain information on hydraulic head distribution and water quality within selected strata above the upper Floridan aquifer. These wells were located near two existing monitoring well clusters, which are part of a regional U.S. Geological Survey (USGS) ground-water quality monitoring network. The four wells were designed to provide ground-water data from shallower zones that would be contemporaneous with that of the existing USGS wells. The USGS Water Resources Division laboratory in Atlanta, Georgia performed ground-water quality analyses on samples taken from the wells.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>6 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:1.</b>	<b>INTRODUCTION</b>		

**Figure 2 - Subbottom Geophysical Survey Lines**

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	7 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:2.	DESCRIPTION OF THE STUDY AREA		

A water use well survey was performed to obtain data on the number and design of wells which currently obtain water from zones within the shallow surficial sediments and the deeper Miocene sediments.

## 2. DESCRIPTION OF THE STUDY AREA

### 2.1. Geologic Setting

Southeastern Chatham County is underlain by approximately 4,000 feet of sedimentary Coastal Plain sediments ranging in age from Holocene to Cretaceous. From land surface to a depth of about 500 feet, these sediments are generally unconsolidated to somewhat indurated beds of sand and clay of Recent (Holocene) age to indurated limestones of Oligocene and Eocene age. The Oligocene and Eocene limestones comprise what is commonly referred to as the upper Floridan aquifer. A regional west-east geologic cross-section (Figure 3) from the report by Clarke and others (1990) illustrates the attitude and thickness of the upper Floridan aquifer and overlying strata in the area from updip in Bulloch County to downdip in eastern Chatham County.

In general, Tertiary strata in Chatham County dip at 10 to 15 feet/mile to the south-southwest off the flank of the Cape Fear arch and northeastern flank of the Southeast Georgia embayment. However, the dips are locally controlled by structural "highs" and "lows". The more prominent major structures are the *Tybee high*, an anticlinal structure with a northwest-southeast trending axis near the mouth of the Savannah River (Furlow, 1969), the *Beaufort arch*, a domal structure near Beaufort, SC (Siple, 1960), and the *Ridgeland trough*, a structural low with a northeast-trending axis extending northeastward through northern Chatham County, GA into Jasper County, SC.

The structural feature of importance in this study is the Tybee high, where Miocene strata and the top of the upper Floridan aquifer are nearer land surface. A structure map of the top of the Oligocene unit (Furlow, 1969, Fig. 3), the uppermost unit of the Floridan aquifer, indicates that the elevations of the top of the Oligocene unit over the crest of the Tybee high range from -110 feet MSL beneath Tybee Island to -130 feet MSL at the channel at Fields Cut (near Savannah River station 30+00). As illustrated on the regional cross section (Figure 3), the elevation of the top of the Oligocene ranges from greater than -250 ft MSL in the Ridgeland trough to about -110 ft MSL at Ft. Pulaski. The greatest thickness of Miocene sediments, approximately 180 feet, occurs near the axis of the Ridgeland trough northwest of Savannah. The subbottom profiles indicated these sediments trend upward to the east and partially outcrop at the surface (in the bottom of the present harbor channel) in the Tybee high. Dredging operations in the proposed Savannah Harbor Expansion Project will be concerned with only material contained within the upper sediments between elevations -42 MLW and -56 feet MLW. This stratigraphic horizon is composed primarily of Pleistocene-Recent and Upper Miocene sediments.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>8 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:2.</b>	<b>DESCRIPTION OF THE STUDY AREA</b>		

**Figure 3 - Regional Geologic Section**

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	9 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:2.	DESCRIPTION OF THE STUDY AREA		

## 2.2. Geologic and Hydrogeologic Units

This study focused on the hydrogeology of the upper 150 or so feet of Pleistocene to Recent, Miocene, and Oligocene sediments within the proposed project area. The nomenclature and stratigraphic intervals and basic hydrogeologic framework of the Floridan (Tertiary limestone) aquifer and overlying geologic units in the Savannah area (Table 2) were established in the late 1950's and early 1960's by Herrick (1960), Siple (1960), Counts and Donsky (1963) and McCollum and Counts (1964). As part of a later study of eastern Chatham County, Furlow (1969) generally used the terminology and stratigraphic intervals established earlier. The geologic formations can be grouped hydrologically into three broadly defined hydrogeologic units: the upper Floridan aquifer; the Miocene confining unit; and the Pleistocene-Recent unit (surficial aquifer).

**Table 2**  
**Stratigraphic-Hydrogeologic Units in Eastern Chatham County**

<p><b>Pleistocene-Recent Unit</b> Recent sediments Pleistocene aquifer (surficial aquifer)</p> <p><b>Miocene Unit</b> upper Miocene = Duplin Formation middle Miocene = Hawthorne Formation lower Miocene = "Tampa Limestone" or Tampa Limestone equiv.</p> <p><b>Upper Floridan Aquifer</b> Oligocene unit (uppermost unit) Ocala Limestone (Late (Jackson) Eocene)</p>
--

### 2.2.1. Upper Floridan Aquifer

A voluminous amount of literature has accumulated on the geology and hydrogeology of what is now most commonly referred to as the *Floridan aquifer system*, which is also referred to by some authors as the principal artesian aquifer or the Tertiary limestone aquifer. The more permeable upper part of this aquifer system, referred to as the upper Floridan aquifer by some authors, consists of highly permeable limestones of mainly Oligocene and Late Eocene age (Ocala Limestone) alternating with less permeable zones. The upper two permeable zones (zones 1 and 2) described by McCollum and Counts (1964) are essentially within the upper Floridan aquifer and in the Savannah area contain fresh water and supply most of the water pumped from this aquifer system from large-diameter open-hole wells.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>10 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:2.</b>	<b>DESCRIPTION OF THE STUDY AREA</b>		

Most of the hydraulic data available on the Floridan aquifer system are from wells tapping the upper Floridan. In the area between Port Royal Sound in SC and Savannah, the transmissivity of the upper Floridan aquifer commonly is in the range from 27,000 ft<sup>2</sup>/d (200,000 gpd/ft) to about 80,000 ft<sup>2</sup>/d (600,000 gpd/ft) (Counts and Donsky, 1963, Hayes, 1979; Spigner and Ransom, 1979). The permeabilities (K) are commonly considered to be in the 350 to 500 ft/d range. Significantly, the radial permeabilities (K) of the upper Floridan are typically more than 350 times greater than the vertical permeabilities (K') of the overlying Miocene unit. In practical terms, this permeability difference means that most of the water entering the cone of depression at Savannah (and other cones of depression) is derived from lateral movement through the upper Floridan as opposed to downward vertical movement (leakage) through or from storage within the Miocene confining unit.

In general, the Oligocene unit, a lithologically heterogeneous sequence of mainly limestones and dolomitic limestones, is typically considered as part of the upper Floridan aquifer in the Savannah area. The Oligocene-Miocene contact is a lithologically and geophysically distinctive contact between the phosphate-rich Miocene and sparsely phosphatic Oligocene. The top of the upper Floridan aquifer in the Savannah area occurs at a depth of on the order of -150 feet to -200 feet MSL at Savannah to less than -100 ft MSL over the crest of the Tybee high, and is on the order of 150 to 250 ft thick. The Oligocene sediments consist of buff colored porous limestone that contains abundant forams, micrite, and nonparticulate phosphate. The Oligocene unconformably overlies the Upper Eocene Ocala Limestone. The Oligocene is distinguished from the underlying bryzoan-rich, Ocala Limestone by the abundance of forams and from the overlying Miocene carbonate sediments by the absence of particulate phosphate. The difference in phosphate content between the Oligocene and the Miocene sediments is shown as a sharp decrease on the natural gamma log. The Oligocene sediments range in thickness from about 60 to 80 feet in the study area.

The importance of the upper Floridan aquifer to the question of dredging impact is mainly in the pumping from this aquifer, which causes artesian pressure to decline and thereby increases the vertical hydraulic gradient (dh'/dl'). Potentiometric maps of the upper Floridan aquifer were reviewed to determine the difference in head (dh') between this aquifer and shallow Pleistocene sands (surficial aquifer). Figure 4 is a potentiometric map of the upper Floridan aquifer in the Savannah area for May 1985 when 82 mgd of ground water were being withdrawn from this aquifer in the Savannah area. The elevation of the potentiometric surface ranged from about -20 ft MSL near Tybee Island to about -110 ft MSL near the center of the cone of depression at Savannah, where the largest part of the 82 mgd withdrawal was concentrated.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>11 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:2.</b>	<b>DESCRIPTION OF THE STUDY AREA</b>		

**Figure 4 - Potentiometric Map of Upper Floridan Aquifer**

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	12 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:2.	DESCRIPTION OF THE STUDY AREA		

### 2.2.2. Miocene Unit

Strata of Miocene age have been referred to as the Miocene unit or differentiated into the Duplin Formation (upper Miocene), Hawthorn Formation (middle Miocene), and the Tampa Limestone (lower Miocene). Based on lithostratigraphy (rock type), Huddleston (1988) grouped these units mainly in updip outcrop areas into the Hawthorn Group. From the 1940's (Warren, 1944) to the present time, most hydrogeologists have referred to the Miocene unit in the coastal counties, in a somewhat general sense, as "the confining bed" or the "confining unit" overlying the upper Floridan aquifer. The Miocene is a lithologically complex sequence of predominately clastics that mainly contain low-permeability clays, silts, clayey silts, and sandy or silty clays that are confining units.

According to Clarke and others (1990), Miocene sediments in the Savannah area consist of three similar depositional sequences of upward-coarsening sediments indicative of three cycles of transgression and regression. Each of the sequences is bounded above and below by an unconformity, and each sequence comprises a geologic unit that consists of a basal carbonate layer, a middle clay layer, and an upper sand layer. These units were each defined by persistent geophysical markers which they designated as A, B, and C. These markers represent the base of their A, B, and C Miocene units. Clarke and others (1990) felt these three units best fit the stratigraphic framework of McCollum and Herrick (1964), whereby units A, B, and C correlate to upper, middle, and lower Miocene respectively. The Miocene sediments generally range from about 60 to 100 feet thick in the study area.

Thin beds of typically fine-grained sands occur in the Hawthorn Formation both in the Savannah area and outside of the Savannah area. These beds could be regarded as aquifers since they are sufficiently permeable to yield some water to wells. Hayes (1979) referred to these Miocene strata between two high gamma activity signatures as the Hawthorn aquifer. This "Hawthorne aquifer" is separated from the upper Floridan aquifer by a high gamma activity phosphatic sandstone. Essentially the same stratigraphic interval in the Savannah area has been referred to by the USGS (Clarke and others, 1990) as the "upper Brunswick aquifer". In the project area however, no permeable sands occur within the Miocene that could be considered as aquifers. In addition, a water-use inventory failed to identify any Miocene (Hawthorn) wells in the area within several miles on either side of the Savannah River. Even most rural domestic wells are either drilled into the underlying upper Floridan aquifer or tap the basal Pleistocene sands (surficial aquifer).

As illustrated on geologic cross-sections in reports by Counts and Donsky (1963), Hayes (1979), and Spigner and Ransom (1979), the Miocene section thins and lies progressively nearer land surface in the area from eastern Chatham County, Georgia into southern Jasper County, South Carolina and the Beaufort arch area in coastal Beaufort County, South Carolina. There probably is some vertical downward leakage from water-bearing sandy limestones in the "Hawthorne aquifer" described by Hayes, (1979) into the upper Floridan aquifer in adjacent areas of Jasper and southern Beaufort Counties.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>13 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:2.</b>	<b>DESCRIPTION OF THE STUDY AREA</b>		

### **2.2.3. Pleistocene - Recent Unit**

The shallow sands and clays from land surface to a depth of typically 60 to 75 feet, but locally as much as 130 feet, unconformably overlie the Miocene unit in the Savannah area and have been referred to as the Pleistocene to Recent (or Pleistocene-Recent unit) by Counts and Donsky (1963) and Furlow (1969). The Pleistocene-Miocene contact is an erosional unconformity, which is sharp in some areas but gradational in others. Pleistocene deposits in the Savannah area were described by Herrick (1965) and Furlow (1969). Most of the details of the lithology and geometry of the Pleistocene to Recent sediments in the Savannah area have been accumulated as part of ground-water studies of the Floridan aquifer system. However, considerable detail has been added during studies performed by the USACE Savannah District, including this study.

Pleistocene to Recent sediments in the Savannah area consist of phosphatic, micaceous, and clayey sand of Pliocene age; arkosic sand and gravel containing discontinuous clay beds of Pleistocene age; and mud, sand, and gravel of Holocene age according to Clark and others (1990). According to Miller (1986), post-Miocene sediments generally can be divided into a basal sequence of marginal to shallow marine beds overlain by a series of sandy, marine terrace deposits that are in turn capped by a thin layer of fluvial sand or residuum, or both. The Pleistocene to Recent sediments generally range in thickness from about 50 to 70 feet in the study area.

The Pleistocene-Recent unit consists of off-channel deposits of Pleistocene sands and clays; and in-channel deposits of fluvial sands, silts, and clays (riverine deposits), and in-filled relict paleochannels. As illustrated on the geologic cross-sections, Pleistocene and Recent sediments unconformably overlie the Miocene unit and are dominated by clays and silts, particularly within the area of the present navigation channel.

Although the geometry and lithologies of these Pleistocene-Recent sediments are geologically complex, with typically lenticular bodies of sand or clay, aquifer sands near the base of the Pleistocene are laterally persistent, although not necessarily continuous throughout the coastal zone. These Pleistocene sands collectively constitute one of the most important aquifer systems (surficial aquifer) as a source of water for irrigation.

Ground water within these Pleistocene sands occurs under both unconfined (water table) and confined (artesian) conditions in the coastal zone. These sands are recharged by local rainfall, and ground water moves laterally with typically very low hydraulic gradients toward local streams and tidal water bodies. In places, a basal Pleistocene sand, typically about 15 to as much as about 40 ft thick, is separated from an upper fine-grained sand by a low-permeability dark-gray clay.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>14 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

### 3. STUDY RESULTS

#### 3.1. Subbottom Geophysical Survey

As part of the present Savannah Harbor Expansion Feasibility Study, previously available geophysical data and reports concerning earlier channel deepening projects (Henry, 1992; USACE Savannah, 1993) were examined to address possible impacts of harbor deepening. Although it was concluded that the upper Floridan aquifer would not be directly impacted by the deepening, the extent of impacts on the Miocene *upper Brunswick aquifer* as described by Clarke and others (1990), and on the buried relict stream channels that extend into the upper portion of the Miocene, could not be ascertained. Also, the lithostratigraphic and seismostratigraphic relationships among the Miocene units and the upper Floridan aquifer could not be accurately determined. It was determined, therefore, that a high-resolution geophysical survey using state-of-the-art technology be carried out in conjunction with stratigraphic core drilling and that additional permeability tests be performed on selected relict buried channels and Miocene strata.

During the period 3-6 October 1997, a subbottom geophysical survey was performed in the Savannah Harbor entrance channel and inner harbor by Ocean Surveys, Inc. (OSI). Approximately 38 miles of survey were performed along the centerline of the present navigation channel, with approximately 12 miles of additional survey "tie-lines" performed across the centerline and parallel to the centerline in selected areas (see figure 2). The investigation was specifically designed to acquire depth of water measurements and the depth to various recognizable stratigraphic horizons/units underlying the navigation channel between Savannah River stations 113+000 and -85+000. The data were also used to select areas where core borings were needed, and core borings were, in turn, used to "ground-truth" the survey data.

#### 3.1.2. Analysis of Geophysical Data and Correlation with Core Borings

The value of subbottom geophysical data in this study was to relate regional continuity of reflectors and to detect features such as buried relict channels. Due to velocity changes in different (changing) media, the vertical resolution of subbottom geophysical data is usually, at best, around two feet. Multi-layered strata can exhibit data with even less resolution. In any survey, an average velocity must be determined which allows the best over-all fit of data. The average velocity chosen for a given set of data, along with the actual pick of the reflector itself (for instance in the case of multiple closely spaced reflectors) can cause the indicated depth to various reflectors to be greater than or less than the actual depth, when compared to boring data.

The average velocity chosen for the most recent survey was 5,300 feet per second. Although this velocity gave the best over-all fit for reflectors, the indicated depth to reflectors in some areas varied as much as 10 feet when compared to core boring data. The

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>15 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

following discussion of the new, as well as previously acquired, geophysical survey data is based on geophysical survey data alone, except as noted.

As has already been mentioned, the elevation, thickness and dip of the Miocene and older strata in eastern Chatham County are controlled by the Tybee high. Figures 5 and 6 are geologic sections that show the thinning and elevation of the Miocene, Oligocene, and Eocene units across the structure. The Miocene unit is particularly affected, decreasing in thickness from approximately 150 feet at Sta. 87+000 (SHE-5) to less than 55 feet at Sta. 5+000 near the top of the Tybee High some 15 miles down-river.

As indicated in the Geologic Sections (Figures 5 and 6) and the Subbottom Geophysical Survey Sections (Figures 7 through 12), four prominent subbottom reflectors were identified. From deepest to shallowest, the reflectors correlated with the approximate tops of the upper Eocene (Reflector 4), Oligocene (Reflector 3), Miocene unit B (Reflector 2) and Miocene unit A (Reflector 1). Miocene unit C described by Clark and others (1990) could not be identified from either the geophysical or the core drilling data. The quality of the down-river subbottom records was very good from Sta. 42+000 to approximately Sta. -45+000 where the sea-state worsened, decreasing the quality slightly. Although the up-river records from Sta. 42+000 to Sta. 113+000 were interrupted by segments of occluded seismic returns, i.e. multiples (probably the result of recent dredging and/or gaseous chemical deposits that block the initial acoustic energy pulse), "windows" into the reflectors were frequent enough to allow adequate interpretation of the data. However, the tops of Reflectors 3 and 4 could not be positively identified in the final segment from Sta. 95+000 to Sta. 113+000.

In the reach from Sta. 24+000 near Fields Cut to Sta. 5+000 near the U.S. Coast Guard Station at Fort Pulaski, the top of the Miocene unit A (Reflector 1) is at or just below the bottom of the present navigation channel (Figure 5). It appears also that unit A dips below the channel bottom up-river between Sta. 63+000 and Sta. 70+000. Elsewhere in the project area, the navigation channel cuts into but not through unit A. Although the present channel has not cut into Miocene unit B (Reflector 2), this unit is closest to the channel bottom (within 10 feet) near Sta. -6+000. The proposed deepening in this area is -54 ft. MLW and the existing channel water depth is -48 ft. MLW (USACE Savannah District Survey May 1996). The top of the upper Floridan aquifer (Reflector 3) is also closest to the present channel bottom at this location (within about 50 feet). Near Sta. 29+000, Reflector 2 begins to dip upriver from a below-channel depth of 30 feet to 96 feet at Sta. 44+000 where it remains to Sta. 113+000, the upriver end of the project. Table 3 shows the proximity of Reflectors 2-4 to the present navigation channel bottom based on the interpretation and cross-correlation of the geophysical and core boring data. Although there are some discrepancies in the correlations, they are very good considering the nature and variables inherent in the geophysical data.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>16 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

Figure 5 - Geologic Section Sta. 31+000 to Sta. -21+500

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>17 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

Figure 6 - Geologic Section Sta. 87+000 to 31+000

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>18 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

**Figure 7 - Subbottom Geophysical Survey Section at SHE-1**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>19 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

**Figure 8 - Subbottom Geophysical Survey Section at SHE-2**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>20 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

**Figure 9 - Subbottom Geophysical Survey Section at SHE-3**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>21 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

**Figure 10 - Subbottom Geophysical Survey Section at SHE-4**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>22 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

Figure 11 - Subbottom Geophysical Survey Section at SHE-5

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>23 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

**Figure 12 - Subbottom Geophysical Survey Section at Relict Channels**

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	24 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:3.	STUDY RESULTS		

**Table 3**  
**Correlation of Geophysical Reflectors and Core Borings**  
**(Depths of Units Below Bottom of Present Navigation Channel)**

Core Boring	Miocene Unit B/Refl. 2 Depth Below Bottom (ft.)	Oligocene/Refl. 3 Depth Below Bottom (ft.)	Eocene/Refl. 4 Depth Below Bottom (ft.)
SHE-5 (sta. 86+500)	82 (87)	Approx. 150	Approx. 200
SB-2 (sta. 78+000)	86 (90)	Approx. 150	Approx. 200
SH-65 (sta. 31+000)	30 (30)	74	120
SHE-1 (sta. 16+000)	30 (33)	66 (71)	124
SH-318 (sta. 9+000)	24	64	122
SHE-2 (sta. 5+000)	20 (32)	58 (55)	116
SH-327 (sta. -3+000)	18	58	107
Sta. - 6+000 *	10	50	107
SHE-3 (sta. -14+500)	14 (22)	58 (56)	107 (120)
SHE-4/6 (sta. -21+500)	33 (33)	66 (72)	124

Notes: - Refer to geologic sections (figures 5 and 6) and subbottom geophysical survey sections (figures 7 through 12).  
- Core boring depths in parentheses.  
\* No boring at sta. -6+000, inferred from subbottom record.

### 3.1.3. Buried Relict Stream Channels

The geophysical data also showed the occurrence of 11 buried relict stream channels along and beneath the present navigation channel between Sta. 30+000 and Sta. -60+000 (Figure 13). The location of these relict channels appears to be coincident with the shallowing and thinning of the Miocene and upper Floridan Aquifer units over the Tybee High. The importance of these features is their potential to act as pathways to transmit seawater to underlying units if the necessary hydrogeologic conditions are present. Table 4 shows the extent to which the relict stream channels penetrate into Miocene units A and B. Relict channels 1-2 and 7-10 penetrated but did not completely breach unit A. Relict channels 3-6 and 11 breached unit A and penetrated unit B a maximum of about 10 feet. Relict channel penetrations of from 2-22 feet cited in Henry (1997) were based on the best information at the time but were proved to be incorrect when analyzing the recent geophysical data, which provided a much clearer identification of the top of Miocene unit B. The current geophysical data also showed the presence of three relict channels not previously observed (9-11).

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>25 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

**Figure 13 - Locations of Buried Relict Stream Channels**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>26 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

It is reasonable to question whether these relict channels could be potential pathways for downward movement of seawater into the upper Floridan aquifer. Ground-water movement and leakage are discussed in Section 3.7.

### 3.2. Core Borings

Core borings performed for this study were intended as a means to better define the stratigraphic sequence in the study area, to provide samples for permeability testing, and to act as "ground-truth" for subbottom geophysical survey data. The location of boreholes was determined initially by reviewing the recent, as well as past, subbottom survey data for areas where it was felt that cores could provide the most useful information. Final locations were based partly on the need to fill data gaps and partly on the requirement to

**Table 4**

**Approximate Penetration of Buried Relict Channels Into Miocene Unit B (Reflector 2) And Depth to Top of Unit B and Floridan Aquifer Below Navigation Channel, Based on Subbottom Geophysical Data.**

<b>Relict Channel</b>	<b>Location (Sta.)</b>	<b>Penetration Into Unit B (ft.)</b>	<b>Depth To Unit B (ft.)</b>	<b>Depth To Upper Floridan Aquifer (ft.)</b>
1	22+000	0	33	66
2	19+000	0	33	68
3 (SHE-1)	15+000	5	30	66
4 (SH-318)	9+750 to 6+750	10	24	64
5 (SH-327)	-2+000 to -4+000	10	18 *	58
6	-11+000	8	19	63
7 (SHE-4)	-20+250 to -22+500	0	33	66
8	-37+000 to -38+250	0	24	61
9	-46+500 to -50+250	0	28	74
10	-53+000	0	27	76
11	-58+000	8	28	70

\*Unit B is within about 10 feet of the bottom of the present navigation channel at Sta. -6+000.

explore areas where dredging for the proposed project would have the greatest potential to affect strata of concern.

Previous studies by the Savannah District Corps of Engineers for dredging projects, as well as numerous studies by others, have indicated that an area along the present navigation

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>27 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

channel between approximate river stations 30+000 and -30+000 warranted particular attention. This portion of the entrance channel lies roughly between the Intra-Coastal Waterway (ICW) at Fields Cut and the area immediately offshore from Tybee Island. Five of the six borings drilled in or near the existing navigation channel (SHE-1, SHE-2, SHE-3, SHE-4, and SHE-6) were placed in this area as shown on Figure 1. An additional boring (SHE-5) was placed in the channel near river station 87+000, about 1.5 miles upriver from the new high bridge to Savannah.

This discussion on the findings of the core drilling phase of the study is based on the above mentioned borings, as well as several borings from previous studies by Savannah District. Figures 5 and 6 are stratigraphic sections of data from these core borings constructed generally parallel to the present Savannah Harbor entrance channel. Logs for these borings can be found in Appendix A.

Pleistocene to Recent sediments encountered consisted of poorly graded sands (SP), silty sands (SM), silt (ML), clayey silt (MH), low plasticity clays (CL), and high plasticity clays (CH). These sediments were typically tan to gray with occasional small gravel and organic debris. Since they were usually unconsolidated to loose materials, they were sampled using a standard split-spoon sampler.

The Pleistocene to Recent sediments in the channel area between stations 30+000 and -30+000 varied in thickness, depending on the proximity of the boring to the channel. Since the average existing depth of the channel in this area is about -44 feet MLW, only those borings located on the channel side slopes or out of the channel produced samples above this elevation. In this area, Pleistocene to Recent sediments were generally above the range of -40 to -50 MLW, except in the case of those borings placed in the relict channels cutting down into the underlying Miocene. In two previous borings (SH-318 and SH-327) in relict channels, Pleistocene to Recent materials were found as deep as -73 MLW, and in another (SHE-4), at -65 MLW.

Continuous wireline coring was begun upon encountering the typically olive green Miocene sediments. These sediments proved to be well suited to wireline soil coring methods and usually produced good core recovery in runs up to ten feet in length.

Miocene sediments typically consisted of dark to light olive green silty sands (SM), clayey sands (SC), silt (ML), clayey silt (MH), and low plasticity clay (CL). Also characteristic of the Miocene were seams of calcareous clays, silts, and sands and limestone. Frequent thin partings or varves of very fine micaceous sand and silt were found in cores throughout the Miocene sediments.

Miocene unit A, as described by Clarke and others (1990), was typically represented by 20 to 30 feet of compact, sometimes dense, clayey silt or sand, or silty, sandy clay; the lower portion of which contained ten feet or so of a highly phosphatic zone (Tybee Phosphorite) immediately above a several tenths of a foot to 2.5 feet thick moderately hard to hard, sometimes brittle, calcareous clay, sandstone, or dolomitic limestone seam. A prevalent

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>28 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

feature of unit A was the abundance of small brown fish scales described by Huddleston (1988). The dark green to black phosphate rich zone and the cream colored, hard to brittle calcareous clay/limestone seams were also distinctly evident in each boring. A clear distinction between the lower carbonate of unit A and the mixed clay, silt and sand material above was evident in all the borings; however, no distinction between a "middle clay and upper sand" (as described by Clarke and others, 1990) was apparent in any of the borings. The highest occurrence, in the core borings, of the top of unit A found beneath the existing navigation channel as it crosses over the Tybee high, was at -41 MLW in boring SHE-3 (station -14+500).

Miocene unit B was typically represented by about 25 to 40 feet of materials similar to the A unit, but with several noticeable differences. Unit B materials in general appeared to contain a lower percentage of sand and a higher percentage of clay than unit A. The occurrence of phosphatic sand in B seemed to be greatest in the top and bottom few feet of that unit. Typically the B material became more dense and indurated with depth and often exhibited mottled light green to green bioturbated zones. The "lower carbonate, middle clay and upper sand" sequence was also not apparent within B. The highest occurrence of the top of unit B in the core borings was over the Tybee high at -66 MLW in boring SHE-3.

The Oligocene unit, considered in this study to be the first occurrence of continuous limestone below Miocene unit B and generally accepted as the top of the upper Floridan aquifer, was typically characterized by a light gray to white, highly fossiliferous limestone. The first few feet of the limestone were generally dense, moderately hard to hard, pitted, vuggy, somewhat phosphatic, and in several borings, very sandy. The contact between the limestone and the olive green lower Miocene material immediately above was usually very distinct, with the first few tenths of a foot of limestone consisting of a very weathered, hard, gray to black cap. Occasionally however, it was characterized by a transitional zone of a mixture of re-worked limestone and Miocene material or with Miocene material filling voids or burrows in the limestone. The highest occurrence of the top of the Oligocene limestone in the core borings was at -100 MLW in SHE-3.

The lower reflector (Reflector 4) identified in the subbottom geophysical survey was determined to best correlate with a zone of very hard, dense, sandy, fossiliferous limestone encountered in core boring SHE-3 at about -164.0 MLW. Although this reflector (and lithologic change) is 10 to 15 feet above the top of the upper Eocene as described by Counts and Donsky (1963) and McCollum and Counts (1964), it may represent the top of the upper Eocene (Ocala limestone) in the study area.

### **3.3. Borehole Geophysical Logging**

Borehole geophysical logging was performed in core borings, using a natural gamma-logging tool to help differentiate stratigraphic horizons. The occurrence of distinctive, characteristic natural gamma peaks within the Miocene sediments has long been acknowledged as a useful tool for correlating strata since they are known to occur

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>29 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

throughout coastal Georgia and South Carolina. The A and B gamma markers, as described by Clarke and others (1990), are associated with highly phosphatic carbonate beds within the Miocene and are generally found a few feet above the unconformities separating Miocene units A and B, and B and the Oligocene. The gamma logs obtained from core borings for this study were almost without exception, uniquely characteristic of their associated strata (see figures 5 and 6). The shapes of the gamma curves representing the two markers were distinctly different. The upper marker associated with the bottom of unit A (contact between A and B) was typically represented by a thick, multi-lobed, somewhat blunt peak. The lower marker associated with the bottom of unit B (contact between B and Oligocene) was typically a single thin, very sharp peak. Occasionally, either of these peaks crossed over the contact (unconformity) instead of always remaining above the contacts. The gamma markers are particularly useful when the carbonate zones they are associated with are not readily recognizable or missing in cores.

#### **3.4. Core Permeability Analysis**

A total of 22 undisturbed core samples were taken from six borings for determination of vertical permeability. Four samples were taken from each of five deeper borings, and two from one shallower boring. Two samples were taken from Miocene unit A and two from Miocene unit B within each of the five deeper borings (SHE-1 through SHE-5). In boring SHE-6, a shallower boring placed in a buried relict stream channel, one sample was taken from a lower zone of the relict channel and one from Miocene unit A immediately below. All permeability samples were taken from below the maximum proposed depth of dredging for the project, with the exception of one sample (SHE-1-1).

In addition to vertical permeability analysis, particle size and plasticity analyses were performed on the samples. Table 5 below is a summary of the results of all permeability analyses from this study, as well as several from previous studies. Laboratory data for permeability analysis of samples from the study area are located in Appendix B.

As indicated in Table 5, the range of vertical permeability for Miocene sediments was from  $1.5 \times 10^{-5}$  to  $2.1 \times 10^{-8}$  cm/sec ( $4.3 \times 10^{-2}$  to  $6.0 \times 10^{-5}$  ft/day). The average vertical permeability for all Miocene samples (units A and B) tested was  $2.0 \times 10^{-6}$  cm/sec ( $5.7 \times 10^{-3}$  ft/day). The average ratio of sand/silt/clay percentages for Miocene sediments was 71.4 /13.0/15.4.

Upon visual inspection of the core samples from the Miocene sediments, one of the most noticeable characteristics was the significant clay content. The clay material obviously serves as the cohesive binder for the remaining generally fine to very fine-grained sand and silt. Another noticeable feature is the recurrent very thinly laminated alternating zones or partings of clay and silt. When handled, the core tends to break at these thin partings. The rather high average percentage of sand in the samples is not remarkable at first inspection due to the predominance of very fine-grained sand.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>30 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

The low permeability values of the samples are indicative of material with over 15 percent clay and nearly 30 percent total fines (material passing a number 200 sieve). It should also be noted that the average ratio of sand/silt/clay percentages of the Miocene A sediments (79.6/9.3/11.0), when compared to those of the Miocene B sediments (62.4/17.1/20.2) indicate a downward decrease in sand and an increase in clay content. These changes are further evidenced by the average permeability values of  $3.5 \times 10^{-6}$  cm/sec ( $9.9 \times 10^{-3}$  ft/day) for Miocene A and  $1.9 \times 10^{-7}$  cm/sec ( $5.4 \times 10^{-4}$  ft/day) for Miocene B.

The average vertical permeability of four samples of in-filling material from buried relict stream channels was  $2.7 \times 10^{-6}$  cm/sec ( $7.7 \times 10^{-3}$  ft/day).

Vertical permeabilities for Chatham County from one core sample in Miocene A and 18 samples in Miocene B discussed in Clarke and others (1990), including work done by Furlow (1969), indicated a value of  $4.0 \times 10^{-4}$  ft/day for Miocene A and a range of  $1.3 \times 10^{-2}$  to  $5.3 \times 10^{-5}$  ft/day for Miocene B.

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	31 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:3.	STUDY RESULTS		

**Table 5**  
**Summary of Permeability and Index Testing**

Boring	Sample	Geol. Unit	Depth (ft)	Atterberg Limits		Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Vertical Permeability	
				LL	PI					(cm/sec)	(ft/day)
SHE-1	1	A	62.3 - 63.9	----	----	0.0	88.2	5.8	6.0	3.4 x 10E-6	9.6 x 10E-3
SHE-1	2	A	67.1 - 68.0	----	----	0.0	88.8	7.3	3.9	3.5 x 10E-6	9.9 x 10E-3
SHE-1	3	B	90.7 - 91.8	----	----	0.0	78.9	6.2	14.7	5.5 x 10E-8	1.6 x 10E-4
SHE-1	4	B	97.1 - 98.2	----	----	0.0	89.2	3.1	7.7	4.5 x 10E-7	1.3 x 10E-3
SHE-2	1	A	57.4 - 58.1	57	23	0.4	74.5	12.1	13.0	4.1 x 10E-6	1.2 x 10E-2
SHE-2	2	A	67.5 - 68.6	60	24	0.2	77.9	16.5	5.4	7.5 x 10E-7	2.1 x 10E-3
SHE-2	3	B	81.6 - 83.0	145	74	2.2	25.2	48.7	23.9	2.8 x 10E-8	7.9 x 10E-5
SHE-2	4	B	97.2 - 98.2	97	47	0.8	66.5	11.3	21.4	5.4 x 10E-8	1.5 x 10E-4
SHE-3	1	A	50.6 - 51.4	----	----	0.0	82.2	7.3	10.5	1.0 x 10E-5	2.8 x 10E-2
SHE-3	2	A	60.3 - 61.4	----	----	0.0	87.6	5.0	7.4	1.8 x 10E-6	5.1 x 10E-3
SHE-3	3	B	80.4 - 81.3	----	----	0.0	69.7	12.7	17.6	5.5 x 10E-8	1.6 x 10E-4
SHE-3	4	B	90.3 - 91.4	----	----	0.0	48.5	25.4	26.1	3.7 x 10E-8	1.0 x 10E-4
SHE-4	1	A	67.2 - 67.7	----	----	0.3	87.5	7.1	5.1	4.7 x 10E-6	1.3 x 10E-2
SHE-4	2	A	75.4 - 76.3	----	----	0.3	89.9	4.1	5.7	1.3 x 10E-6	3.7 x 10E-3
SHE-4	3	B	89.1 - 89.9	----	----	0.0	34.0	28.9	37.1	2.1 x 10E-8	6.0 x 10E-5
SHE-4	4	B	99.8 - 100.5	----	----	0.0	51.1	15.6	33.3	2.5 x 10E-8	7.1 x 10E-5
SHE-5	1	A	64.4 - 65.1	----	----	0.1	37.8	21.0	41.1	1.2 x 10E-7	3.4 x 10E-4
SHE-5	2	A	78.2 - 79.1	----	----	0.0	71.5	10.7	17.8	4.1 x 10E-7	1.2 x 10E-3
SHE-5	3	B	142.8 - 144.0	----	----	0.0	73.4	14.2	12.4	9.4 x 10E-8	2.7 x 10E-4
SHE-5	4	B	151.7 - 152.4	----	----	0.0	87.3	4.5	8.2	4.9 x 10E-7	1.4 x 10E-3
SHE-6	1	CF	68.1 - 69.0	----	----	0.0	11.4	33.9	54.7	3.0 x 10E-7	8.5 x 10E-4
SHE-6	2	A	71.6 - 72.6	----	----	0.0	89.5	5.6	4.9	1.5 x 10E-5	4.3 x 10E-2
SH-65	1	A	79.3 - 80.9	87	27	----	----	----	----	2.2 x 10E-7	6.2 x 10E-4
SH-65	2	A	96.2 - 98.0	59	30	----	----	----	----	6.0 x 10E-7	1.7 x 10E-3
SH-65	3	B	115.8 - 117.2	66	38	----	----	----	----	7.9 x 10E-7	2.2 x 10E-3
SH-318	1	CF	69.9 - 71.3	150	80	----	----	----	----	4.0 x 10E-7	1.1 x 10E-3
SH-318	2	CF	71.3 - 73.5	145	64	----	----	----	----	8.2 x 10E-6	2.3 x 10E-2
SH-327	1	CF	50.5 - 52.5	124	45	----	----	----	----	1.8 x 10E-6	5.1 x 10E-3
<b>Unit A Average</b>						<b>0.1</b>	<b>79.6</b>	<b>9.3</b>	<b>11.0</b>	<b>3.5 x 10E-6</b>	<b>9.9 x 10E-3</b>
<b>Unit B Average</b>						<b>0.3</b>	<b>62.4</b>	<b>17.1</b>	<b>20.2</b>	<b>1.9 x 10E-7</b>	<b>5.4 x 10E-4</b>
<b>Miocene Average (A+B)</b>						<b>0.2</b>	<b>71.4</b>	<b>13.0</b>	<b>15.4</b>	<b>2.0 x 10E-6</b>	<b>5.7 x 10E-3</b>
<b>Channel Fill Average</b>						----	----	----	----	<b>2.7 x 10E-6</b>	<b>7.7 x 10E-3</b>
<b>Over-all Average</b>						<b>0.2</b>	<b>68.7</b>	<b>14.0</b>	<b>17.2</b>	<b>2.1 x 10E-6</b>	<b>6.0 x 10E-3</b>

Notes: A = Miocene Unit A.  
B = Miocene Unit B.  
CF = Relict Channel Fill.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>32 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

### 3.5. Test Well Installation

Four test wells were installed to obtain information on hydraulic head distribution and water quality within selected zones of the sediments above the Floridan aquifer. These wells were located near two existing USGS monitoring well clusters on the north end of Tybee Island and on Cockspur Island near Ft. Pulaski National Monument. These well clusters are part of a regional ground-water quality monitoring network. The four new wells were designed to provide ground-water data from shallower zones that were not screened in the existing USGS wells.

The two new wells installed at Tybee Island as SHE-MW-1 and SHE-MW-2 (now designated 39Q029 and 39Q028 respectively) were located within a group of four existing wells referred to as TYBEE 1, 2, 3, and 4 (these wells were later designated by USGS as 39Q024, 39Q025, 39Q026 and 39Q027). The location of these wells is at the extreme north end of Tybee, about 5,000 feet south of the existing navigation channel (station -11+000).

Core boring SHE-7 was drilled at the Tybee cluster site to better determine the shallow stratigraphy at that location, before installing the wells. This boring indicated that two of the existing wells at the site thought to have been screened in the Miocene were screened mostly in the upper Floridan, and one well thought to be screened in surficial sands was screened in the Miocene.

Figure 14 is a stratigraphic section at the site which shows the relationship of the six wells to the stratigraphy. The target zone of well SHE-MW-1 was within the shallow, Pleistocene to Recent sands. Cores from SHE-7 indicated that a zone from about -1 to -21 MLW would be appropriate for screening. The well was drilled to a total depth of 42.0 feet or -26.0 MLW. The well was completed with 20 feet of 4-inch diameter schedule 80, 0.010-slot, PVC well screen and an appropriate length of PVC riser. A sand filter pack was then tremied to the bottom of the well and brought up to two feet above the top of the screen.

Four feet of bentonite pellets were tremied above the sand pack and allowed to hydrate overnight. The next day, a cement-bentonite mixture was used to seal the well to ground surface.

Well SHE-MW-2 was installed in a similar manner in the upper portion of Miocene Unit B, with a target zone of 94.0 feet (-78.0 MLW) to 104.0 feet (-88.0 MLW). Although this zone is predominately a clayey sand, it was screened to allow a comparison of hydraulic head and water quality with the shallower surficial sands above and the upper Floridan aquifer below.

The two new wells installed at Ft. Pulaski as SHE-MW-3 and SHE-MW-4 (now designated 38Q208 and 39Q209 respectively) are located near existing USGS well 39Q002. The location of these wells is in an area behind the bar pilots office, about 800 feet south of the centerline of the existing navigation channel (approximate river station 4+000).

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>33 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

Core boring SHE-8 was drilled near Ft. Pulaski well 38Q002 to better determine the shallow stratigraphy at that location, before installing the wells. Figure 15 is a stratigraphic section at the site, which shows the relationship of these three wells to the stratigraphy. The target zone of well SHE-MW-3 was within the shallow, Pleistocene-Recent sands from about -10 to -50 MLW. Both of these wells were constructed like those at Tybee.

### **3.6. Ground-water Quality and Hydraulic Head Assessment**

The USGS Water Resources Division in Atlanta, Georgia was asked to provide ground-water quality sampling and analysis at the Tybee and Ft. Pulaski well clusters (see Appendix D). Water samples were collected from the two well clusters and analyzed during 5-7 January 1998 to determine the water chemistry of selected zones.

At Ft. Pulaski, dissolved solids concentrations decreased from about 16,000 mg/l in the surficial aquifer to 718 mg/l in the Miocene unit. Water from the surficial aquifer and the upper portion of Miocene unit B contains higher dissolved solids than water in the upper Floridan aquifer, and some constituent concentrations exceed Georgia Environmental Protection Division (EPD) drinking-water regulations. Water from the surficial aquifer is a mixture of sodium chloride and calcium sulfate type water; water from Miocene unit B is a sodium-chloride type water; and water from the upper Floridan aquifer is a calcium-bicarbonate type.

At Tybee Island, the constituent concentrations are similar to those at Ft. Pulaski, with concentrations generally highest in the surficial aquifer and decreasing with depth into the upper Floridan aquifer. Water from the surficial aquifer at Tybee is a mixed type; water from Miocene units A and B is a sodium-chloride type, and water from the Upper Floridan aquifer was a calcium-bicarbonate type.

The extreme water quality differences between water from the Pleistocene-Recent unit and upper Floridan aquifer indicated that these units are not in direct hydraulic communication.

Water levels were measured in the three wells at Ft. Pulaski and five wells at Tybee Island on 22 January 1998. At both sites, there is a general decrease in head with depth, indicating a downward hydraulic gradient. At both Ft. Pulaski and Tybee Island, hydraulic separation of the surficial aquifer and the Miocene B unit, and of the upper Floridan and Miocene B is further supported by head differences.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>34 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

Figure 14 - Geologic Section at Tybee Well Cluster

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>35 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	6/27/02		
<b>Sponsor:</b>	Georgia Ports Authority		
<b>Section:3.</b>	<b>STUDY RESULTS</b>		

Figure 15 - Geologic Section at Fort Pulaski Well Cluster

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	36 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:3.	STUDY RESULTS		

**Table 6**  
Well Data from Cluster Sites in Chatham County, Georgia

Well	Location	Unit	Open Interval (ft. MLW)	Water Level 22 Jan. 1998 (ft. MSL)
SHE-MW-1	Tybee Island	Pleistocene-Recent	-1.0 to -21.0	3.6
GGG-Tybee-3	Tybee Island	Miocene Unit A	-64.0 to -84.0	0.8
SHE-MW-2	Tybee Island	Miocene Unit B	-78.0 to -88.0	0.7
GGG-Tybee-2	Tybee Island	Upper Floridan	-109.0 to -129.0	-22.8
GGG-Tybee-4	Tybee Island	Upper Floridan	-109.0 to -129.0	----
GGG-Tybee-1	Tybee Island	Lower Floridan	-836.0 to -884.0	-27.0
SHE-MW-3	Ft. Pulaski	Pleistocene-Recent	-12.0 to - 52.0	1.6
SHE-MW-4	Ft. Pulaski	Miocene Unit B	-82.0 to -92.0	-2.1
USNPS	Ft. Pulaski	Upper Floridan	-100 to -338.0	-24.7

### 3.7. Effects of Dredging in the Channel Area

The only regional, relatively persistent shallow aquifers overlying the upper Floridan aquifer in the area east and southeast of Savannah are the Pleistocene sands in the off-channel areas. Within the present navigation channel, the Pleistocene sands have mostly been removed, and Recent sediments rest directly on the Miocene confining unit. The possible effects of increasing the depth of the navigation channel would relate to the quality and quantity of ground water moving vertically downward and into the upper Floridan aquifer. The avenues for this movement would be by diffuse-type leakage of saline water through the Miocene confining unit or by leakage of saline water through the Pleistocene paleochannels and Miocene confining beds underlying these paleochannels and into the upper Floridan aquifer.

#### 3.7.1. Leakage Through the Miocene Confining Unit.

Any significant downward vertical movement of saline water from surface-water bodies (i.e., the Savannah River channel) through the Miocene confining unit and into the upper Floridan aquifer would depend upon the thickness ( $b'$ ) and vertical permeability ( $K'$ ) of the Miocene confining unit and the vertical hydraulic gradient ( $dh'/dl'$ ) established between the upper source (channel sands or Pleistocene sands in off-channel areas) and the lower source (upper Floridan aquifer).

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	37 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:3.	STUDY RESULTS		

Any calculation of vertical leakage is necessarily an approximation because of the typically wide ranges in the values of the variables needed to calculate leakage. In the Savannah area; however, there is a degree of lithologic consistency, at least in terms of permeability (K) of the Miocene unit, and numerous vertical permeability values are available (Table 5) that permit calculation of an "average" vertical permeability (K'). Inspection of this table indicates that the vertical permeabilities range from approximately  $4.3 \times 10^{-2}$  ft/d to  $6 \times 10^{-5}$  ft/d. The average vertical permeability (K') of the Miocene confining unit is approximately  $6 \times 10^{-3}$  ft/d (0.045 gpd/ft<sup>2</sup>).

The quantity of leakage (Q<sub>c</sub>) moving vertically downward through the Miocene confining unit and into the upper Floridan aquifer can be approximated with the well-known modified form of Darcy's equation:

$$Q_c = (K') (dh'/dl') (A)$$

Where      Q<sub>c</sub> = quantity of leakage, in ft<sup>3</sup>/d  
               K' = vertical permeability, in ft/d  
               b' = thickness of confining bed, in ft  
               dh'/dl' = vertical hydraulic gradient, ft/ft  
 and         A = confining bed area in sq.ft. through which leakage occurs.

By substituting average values of vertical permeability (K' = a conservatively low  $6 \times 10^{-3}$  ft/d), Miocene confining unit thickness (b' = 55 ft) and using the vertical hydraulic gradient ( $26.3/55$  ft = 0.48 ft/ft) at the Ft. Pulaski well cluster and letting A = 1 ft<sup>2</sup>, the leakage would be approximately

$$\begin{aligned} Q_c &= (6 \times 10^{-3} \text{ ft/d}) (0.48 \text{ ft/ft}) (1 \text{ ft}^2) \\ &= 2.9 \times 10^{-3} \text{ ft}^3/\text{d}, \text{ or about } 2.2 \times 10^{-2} \text{ gpd for each sq. foot} \\ &\quad \text{of confining bed area through which leakage occurs.} \end{aligned}$$

This 0.021 gpd/ft<sup>2</sup> (about 900 gpd/acre) is considerably higher than Furlow's (1969) leakage rate of 0.0036 gpd/ft<sup>2</sup> (about 160 gpd/acre).

The quantity of leakage is highly variable because of the wide range of hydraulic properties of Miocene confining beds and differences in hydraulic heads between shallow sands and the upper Floridan aquifer. Even though the vertical head difference (dh') between the upper Floridan aquifer and Pleistocene sands increases nearer the center of the cone of depression at Savannah, the Miocene confining unit also becomes thicker. Consequently, the quantity of leakage (Q<sub>c</sub>) does not increase substantially toward the center of the cone of depression.

In quantitative terms, in the area of Ft. Pulaski, removing about 10 ft of the Miocene confining unit would result in an increase in the vertical hydraulic gradient (dh'/dl'). This would result in a leakage (Q<sub>c</sub>) of about  $3.5 \times 10^{-3}$  ft<sup>3</sup>/d, or about  $2.6 \times 10^{-2}$  gpd per sq. foot of

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	38 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:3.	STUDY RESULTS		

confining bed area. This is a leakage increase of about 0.005 gpd per square foot of confining bed area. If this increased leakage occurs over an area of about 1 acre (about 43,000 ft<sup>2</sup>), it would amount to an increase of about 200 gpd (rounded). Realistically, then, increasing the downward leakage by 200 gpd of water into the upper Floridan aquifer over an area of one acre would be negligible as compared to the quantity of ground water moving laterally through one acre of this highly transmissive aquifer. Therefore, increasing the depth of the navigation channel will have little effect on the quality of ground water moving through the upper Floridan aquifer beneath the project area.

### 3.7.2. Leakage Through Pleistocene Paleochannels

Calculation of the quantity of leakage ( $Q_c$ ) moving vertically downward through the Pleistocene paleochannels and Miocene beds below these channels, and into the top of the upper Floridan aquifer involves the same hydraulic variables. As illustrated by the logs of core borings drilled through these paleochannel sediments (SH-318, SH-327, SHE-4) (see Figure 5), they are dominated by low permeability clays and silts with only thin beds of mainly fine-grained sands that would be water-bearing. Beneath paleochannels 4 and 5 (Figure 13), the Miocene unit is on the order of 30 to 35 ft thick (SH-318, SH-327). Since the average existing water depth in the area of these two paleochannels is about -46 MLW, dredging in the area where these paleochannels occur will involve the removal of a maximum of about 8 ft of in-filling Recent sediments.

Using an average vertical permeability of ( $K' = 7.0 \times 10^{-3}$  ft/d) for the combined paleochannel sediments and Miocene material below, the quantity of leakage ( $Q_c$ ) presently moving downward through the paleochannel and thinned Miocene confining material into the upper Floridan aquifer, in the area of paleochannel 5 (SH-327), can be approximated as:

$$\begin{aligned}
 Q_c &= (K) (dh/dl) (A) \\
 &= (7.0 \times 10^{-3} \text{ ft/d}) (26/50 \text{ ft/ft}) (1 \text{ ft}^2) \\
 &= 3.6 \times 10^{-3} \text{ ft}^3/\text{d per sq. foot of confining bed area} \\
 &= 2.7 \times 10^{-2} \text{ gpd per sq. foot of confining bed area through which leakage occurs.}
 \end{aligned}$$

This quantity of leakage (0.027 gpd per sq. ft) would amount to a maximum of about 1160 gal/day over one acre of paleochannel/confining bed area.

Removing about 10 ft of material in this area would result in a leakage ( $Q_c$ ) of about  $4.6 \times 10^{-3}$  ft<sup>3</sup>/d or about  $3.4 \times 10^{-2}$  gpd per sq. ft, which would be an increase of about 300 gpd of water per acre. Again, this would be a small quantity of water that would have little overall affect on the quality of ground water in the upper Floridan aquifer.

SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY			
Section	1	Page	39 of 46
Revision No:			
Revision Date:	6/27/02		
Sponsor:	Georgia Ports Authority		
Section:4.	SUMMARY AND CONCLUSIONS		

#### 4. SUMMARY AND CONCLUSIONS

The hydrogeology of Eocene to Recent sediments beneath the project area was evaluated by a combination of: extensive review of previous studies; review of State and Federal (USGS) well-record files; eight new core borings; a sub-bottom geophysical survey; analysis of ground water from new and existing test wells; and laboratory analyses of physical properties of the Miocene confining unit. The major conclusions of the study are summarized in this section. Additional conclusions and supporting data are provided in the body and appendices to the report.

1. Geologic strata to a depth of about 500 ft consist of three broadly defined geologic or hydrogeologic units. These are the Pleistocene-Recent unit, the Miocene confining unit, and upper Floridan aquifer.

2. The **upper Floridan aquifer**, the most important source of ground water in the study area, has been extensively developed in the Savannah area where some 82 mgd of ground water are withdrawn from this aquifer system. This pumping has created a cone of depression where the potentiometric (artesian pressure) surface of the upper Floridan aquifer is lower than that of aquifer sands within the Pleistocene-Recent unit.

3. The upper Floridan aquifer is overlain by the **Miocene unit**, a confining unit consisting of low-permeability clays, clayey silts, and clayey sands. The Miocene unit consists of two lithologic units, referred to as unit A and unit B. Within unit B in the project area, no permeable sands occur that could be correlated with what has been referred to by the USGS (Clarke and others, 1990) as the "*upper Brunswick aquifer*". Numerous vertical permeability (K') values of the Miocene unit indicate low vertical permeabilities, typically in the range from about  $4 \times 10^{-2}$  ft/d to  $6 \times 10^{-4}$  ft/d.

4. Shallow sands, silts, and clays unconformably overlie the Miocene unit. This **Pleistocene-Recent unit**, typically about 60 to 75 ft thick, contains mainly low-permeability confining beds but contains thin permeable sands in some areas that are mostly used by small irrigation wells. Ground water within these sands occurs under both water-table (unconfined) and artesian (confined) conditions, and the elevation of the water table is typically higher than the heads of underlying aquifers. What little water enters the Miocene is supplied by downward leakage from the Pleistocene.

5. A reasonably comprehensive subbottom **geophysical survey** was performed in the channel where the proposed dredging will occur. This survey was important because it provided critical stratigraphic and thickness information on strata beneath the proposed dredging areas, thereby reducing the number of core holes drilled in the channel.

6. The focus of this study was on the area along the present navigation channel between approximate stations 20+000 and -23+000. This area is where a local structural feature, the Tybee high, causes strata to be elevated and thinned, which places the top of the upper Floridan aquifer at its highest elevation along the channel (about -95 MLW).

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>40 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:4.</b>	<b>SUMMARY AND CONCLUSIONS</b>		

Paleochannel 5 (at SH-327) in this area has cut down about 23 ft below the existing channel into the thinned Miocene confining unit above the Floridan. From the focus area westward towards Savannah, the Miocene confining unit becomes thicker and the upper Floridan is much deeper (about -200 MLW). From the focus area eastward to offshore as far as Sta. - 85+000, the confining unit is generally exposed in the existing channel bottom and continues at a thickness of about 50 ft, with a slight increase in thickness in the offshore direction.

7. Using average values for permeability ( $K_a$ ), confining bed thickness ( $b$ ), and hydraulic gradient ( $dh'/dl'$ ), leakage rates were computed for water moving vertically downward through the Miocene confining unit (and paleochannel/Miocene unit) into the upper Floridan aquifer. This quantity of water ( $Q_c$ ) is only a small fraction of the quantity of water moving laterally through the upper Floridan aquifer. Therefore, the proposed dredging will have no noticeable effect on the quality and quantity of ground water within the upper Floridan aquifer.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>41 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:5.</b>	<b>REFERENCES</b>		

## 5. REFERENCES

- Clarke, J.S., 1987, Potentiometric surface of the upper Floridan aquifer in Georgia, May 1985, and water-level trends, 1980-1985: Georgia Geol. Survey Hydrologic Atlas 16.
- Clarke, J.S., Hacke, C.M., and Peck, M.F., 1990, Geology and ground-water resources of the coastal area of Georgia: Georgia Geol. Survey Bull. 113, 61p.
- Clarke, J.S., Joiner, .N., Longsworth, S.A., Mcfadden, K.W., and Peck, M.F., 1986, Ground-water data for Georgia, 1985: U.S. Geol. Survey Open-File Rept.86-304, 159p.
- Counts, H.B., and Donsky, Ellis, 1963, Salt-water encroachment, geology, and ground-water resources of Savannah area, Georgia and South Carolina: U.S. Geol. Survey Water-Supply Paper 1611, 100p.
- Furlow, J.W., 1969, Stratigraphy and economic geology of the eastern Chatham County phosphate deposit: Georgia Dept. Mines, Mining, and Geology, Bull.82, 40p.
- Hayes, L.R., 1979, The ground-water resources of Beaufort, Colleton, Hampton, and Jasper Counties, South Carolina: S.C. Water Resources Commission Report No.9, 91p.
- Henry, V.J., Jr., 1992, An investigation of the potential for penetrating the Floridan aquifer due to deepening of Savannah Harbor to -46.0 ft MLW: Consulting report to U.S. Army Corps of Engineers, Savannah District, 7p.
- Heron, S.D., and Johnson, H.S., 1966, Clay mineralogy, stratigraphy, and structural setting of the Hawthorn Formation, Coosawhatchie District, South Carolina: Southeastern Geology, v.7, no.2, p.51-62.
- Herrick, S.M., 1961, Well logs of the Coastal Plain of Georgia: Georgia Geol. Survey Bull.70, 462p.
- Herrick, S.M., 1965, A subsurface study of Pleistocene deposits in coastal Georgia: Georgia Dept. Natural Resources, Div.Mines, Mining, and Geology, Inf. Circular 31, 8p.
- Huddlestun, P.F., 1988, A revision of the lithostratigraphic units of the Coastal Plain of Georgia, the Miocene through Holocene: Georgia Geol. Survey Bull.104, 162p.
- Huddlestun, P.F., and Hetrick, J.H., 1986, Upper Eocene stratigraphy of central and eastern Georgia: Georgia Geol. Survey Bull. 95, 78p.
- Joiner, C.N., Reynolds, M.S., Stayton, W.L., and Boucher, F.G., 1988, Ground-water data for Georgia, 1987: U.S. Geol. Survey Open-File Rept.88-323, 172p.
- Krause, R.E., and Randolph, R.B.,1985, Hydrology of the Floridan aquifer system in southeast Georgia and adjacent parts of Florida and South Carolina: U.S. Geol. Survey Prof. Paper 1403D.
- McCollum, M.J., 1964, Salt-water movement in the principal artesian aquifer of the Savannah area: Ground Water, v.2, no.4, p.4-8.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>42 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:5.</b>	<b>REFERENCES</b>		

- McCollum, M.J., and Counts, H.B., 1964, Relation of salt-water encroachment to the major aquifer zones, Savannah area, Georgia and South Carolina: U.S. Geol. Survey Water-Supply Paper 1613-D, 26p.
- McCollum, M.J., and Herrik, S.M., 1964, Offshore extension of the Upper Eocene to Recent stratigraphic sequence in southeastern Georgia: U.S. Geol. Survey Prof. Paper 51-C, p.C61-C63.
- Miller, J.A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida, and in parts of Georgia, Alabama, and South Carolina: U.S. Geol. Survey Prof. Paper 1403-B, 91p.
- Randolph R.B., and Krause, R.E., 1984, Analysis of the effects of the proposed pumping from the principal artesian aquifer, Savannah Georgia area: U.S. Geol. Survey Water Res. Investigations Rept. 84-4064, 26p.
- Randolph, R.B., Pernik, M., and Garza, R., 1991, Water-supply potential of the Floridan aquifer system in the coastal area of Georgia- a digital model approach: Georgia Geol. Survey Bull. 116, 30p.
- Siple, G.E., 1960, Geology and ground-water conditions in the Beaufort area, South Carolina: U.S. Geol. Survey, Open-File Rept., Columbia, SC
- Smith, B.S., 1988, Ground-water flow and salt-water encroachment in the upper Floridan aquifer, Beaufort and Jasper Counties, South Carolina: U.S. Geol. Survey Water Resources Investigations Report 87-4285, 61p.
- Spigner, B.C., 1991, Review of ground-water availability Savannah-Southwestern South Carolina area: Atlanta Testing & Engineering, Report No.91236.
- Spigner, B.C., and Ransom, C., 1979, Report on ground-water conditions in the Low Country area, South Carolina: S.C. Water Resources Commission Rept.No.132, 144p.
- Spigner, B.C., and Sanders, D., 1986, Ground-water availability of the Miocene aquifer system, Colonels Island, Georgia: Unpubl. consulting report no. 4486-046, Soil & Material Engineers, Columbia, S.C.
- Spigner, B.C., Sanders, D., and Craig, K., 1986, Ground-water availability of the Pliocene-Recent aquifer system, Skidaway Island, Georgia: Unpubl. consulting report no. 4486-049, Soil & Material Engineers, Columbia, S.C.
- U.S. Army Corps of Engineers, 1980, Savannah Harbor comprehensive study, SASEN-GG, Corps of Engineers, Savannah District, 9p.
- U.S. Army Corps of Engineers, 1982, Savannah Harbor, comprehensive study, preformulation report: Corps of Engineers, Savannah District, SASEN-GG, 96p.
- U.S. Army Corps of Engineers, 1984, Executive summary, Metropolitan Savannah area water resources management study Corps of Engineers, Savannah District, 336p.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>43 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:5.</b>	<b>REFERENCES</b>		

U.S. Army Corps of Engineers, 1993, Report on possible impact on the upper Floridan aquifer due to deepening of Savannah harbor: Corps of Engineers, Savannah District, 13p.

Warren, M.A., 1944, Artesian water in southeastern Georgia, with special reference to the coastal area: Georgia Geol. Survey Bull.49, 140p.

Watson, T.W., 1982, Aquifer potential of the shallow sediments of the coastal area of Georgia, in Proceedings of the Second Symposium on the Geology of the Southeastern Coastal Plain: Georgia Geol. Survey Inf. Circular 53, p.183-194.

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>44 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:</b>			

**APPENDIX A. CORE BORING LOGS**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>45 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:</b>			

**APPENDIX B. PERMEABILITY ANALYSIS DATA**

<b>SAVANNAH HARBOR EXPANSION FEASIBILITY STUDY</b>			
<b>Section</b>	<b>1</b>	<b>Page</b>	<b>46 of 46</b>
<b>Revision No:</b>			
<b>Revision Date:</b>	<b>6/27/02</b>		
<b>Sponsor:</b>	<b>Georgia Ports Authority</b>		
<b>Section:</b>			

**APPENDIX C. GROUND-WATER QUALITY ANALYSIS DATA**