Savannah Harbor Expansion Project
Dissolved Oxygen Mitigation
Outline

► Savannah Harbor Expansion, Important Points
► Why expand the harbor?
► Why add dissolved oxygen to the harbor?
► DO Mitigation Objectives
► DO Injection Technology
► DO Mitigation System Design
Savannah Harbor Expansion Project
Important Points

► Savannah’s Garden City Terminal is the largest single container terminal in North America
► Savannah 2nd largest Container Port on the East Coast, 4th Largest in Country
► Expansion Studies and Planning conducted over past 15+ years
► $706 Million Project Estimate (Federal and State funding)
► Deepens the Harbor depth (MLW) from – 42 ft. to – 47 ft. (– 49 ft. at entrance channel), extend the entrance channel (“outer harbor”), plus other improvements and mitigation measures
► Dissolved oxygen delivery system needed to mitigate predicted DO impacts of harbor deepening
► Project requires the downriver DO system to be operational and demonstrated effective before dredging the “inner harbor”
Why Expand the Harbor?

- Port of Savannah is tide-restricted for larger (new Panamax) ships (must either light load or sail with the tides)
- Tide restrictions reduce large ship handling efficiency of the Port
- The Panama Canal expansion and increased use of containers will increase large ship traffic (new Panamax)
- Completion of the $5.5 + Billion Panama Canal expansion project June 2016
- Deepening Savannah Harbor will improve efficiency (more goods with fewer ships)
Panamax Ship Specifications

► Old Panamax Ships:
  ► < 40 foot draught
  ► < 110 feet wide
  ► < 4,600 TEU
  ► No tide restrictions with Savannah Harbor

► New Panamax Ships:
  ► < 50 foot draught
  ► < 180 feet wide
  ► < 12,000 TEU
  ► Tide restrictions apply

New Panamax ships ~ 3x larger

Savannah Harbor navigation channel deepened by 5 feet to -47 feet MLW substantially eliminates tide restrictions for New Panamax ships
Savannah Harbor and Navigation Channel
Why is More Oxygen Needed?

- Bacteria and aquatic organisms consume oxygen in river and harbor
- Surface oxygen transfer and algae provide natural DO levels
- A larger volume of water needs more oxygen to maintain DO concentration
- Deeper channels require more mixing to maintain bottom DO

A deeper harbor needs more oxygen to maintain the same DO
SHEP DO Mitigation Objectives

- Replace oxygen deficit caused by the harbor expansion (as determined through WQ modeling)
- Operate supplemental DO system during Critical Periods
  - Daily average DO maintain 5.0 mg/L
  - Minimum DO no less than 4.0 mg/L
  - Critical Periods during warm summer months
- Do not harm local aquatic life (no effervescence)
DO System Design Requirements

► Supply 40,000 lbs/day of DO into the Savannah River/Harbor
► Use high-purity oxygen for supply
► Operate ~ 6-months out of the year
► Provide 28,000 lbs DO/day at an upriver location near Rincon Georgia
► Provide 12,000 lbs DO/day at a downriver location on Hutchinson Island
► Provide 10% installed reserve capacity
► Provide fish protection water intakes (meeting 316(b) requirements)
  ► Less than 0.5 feet/sec through-screen velocity
  ► Fish return system
Why Pure Oxygen (Henry’s Law)?

Chemistry Basics (Henry’s Law governs DO saturation)

\[ C = K_H \times P_{O_2} \]

Where:
- \( C \) = concentration of dissolved oxygen, mg/L
- \( K_H \) = Henry’s Law constant (45 mg/L/ATM @ 20°C)
- \( P_{O_2} \) = Partial Pressure of Oxygen in Gas, ATM

For the example above at ambient air pressure:

Air is 20% oxygen so

\[ C = 45 \times 0.2 = 9 \text{ mg/L DO saturation concentration} \]

But for pure oxygen (100%)

\[ C = 45 \times 1.00 = 45 \text{ mg/L DO saturation concentration} \]

*Water saturated with pure oxygen is 5 times more concentrated than if saturated with air*
Effervescence

- Effervescence is the spontaneous formation of gas bubbles when pressure on a liquid is released
  - Think Champagne bubbles
  - SCUBA-diver “bends”
  - Fish injury below dams (supersaturation with nitrogen)

- DO system designed to avoid oxygen effervescence
- With oxygen dissolved at 1 ATM pressure (ambient) effervescence is impossible, submerged deep diffusers provide further protection
- Entrained air bubbles may still be visible
- High dissolved oxygen plume quickly disperses in the harbor
Technology: Speece Cone has no moving parts

- Operates with oxygen, not air
- Downward water flow: as cone diameter increases, velocity decreases
- Oxygen bubble “swarm” suspended inside cone
- Exiting dissolved oxygen concentration \( C_2 \) much greater than inlet concentration \( C_1 \)
- Small amount of oxygen lost as entrained bubbles
Georgia Ports Authority conducted a large-scale demonstration of the applicability of oxygen injection technology in the harbor.

Used a temporary barge-mounted system with two 12-foot-diameter Speece Cones, four 400-hp pumps to withdraw 20 mgd of river water, liquid oxygen storage and evaporators, and discharge pipes to return the oxygenated water back to the river.
Approved SHEP Mitigation Plan

- Installation of permanent, land-based Speece Cone oxygen injection systems at two locations (12 cones total)
- Operation during summer months
- Adding 40,000 lbs/day total DO to harbor system
- Fish protection via traveling screens with through-screen velocity less than 0.5 fps and fish return systems
DO Mitigation System Operation

► Operate 10 of 12 Speece Cone Oxygenation Units
► Dissolve 4,000 lbs of oxygen per day per Speece Cone
► Up River Site – 7 Speece Cones (plus 1 installed spare) & 1 diffuser location
► Down River Site – 3 Speece Cones (plus 1 installed spare) & 2 diffuser locations:
  ► Front River
  ► Back River
► Provide on-site oxygen generation (VSA) to supply system (avoids liquid oxygen delivery trucks)
GEORGIA'S PORT OF SAVANNAH stands to benefit considerably from the expansion of the Panama Canal. Expected to be completed this summer, the expansion will enable much larger cargo ships from Asia to travel in less time to Savannah and other East Coast ports. To ensure that the Port of Savannah can accommodate the greater drafts of these larger ships, the Savannah District of the U.S. Army Corps of Engineers is conducting the Savannah Harbor Expansion Project. The endeavor involves deepening the federal navigation channel serving the port by 9 ft and includes several features designed to mitigate the project's untoward effects on the environment. Among these is the design and construction of a system capable of injecting 40,000 lb of dissolved oxygen per day into the harbor. Intended to compensate for the greater water depth, the additional oxygen will help to maintain adequate levels of this key element and thereby protect fish and other aquatic organisms.

Opened in 1914, the Panama Canal connects 160 countries and 1,700 ports around the world. Because of its strategic location, it serves more than 1,400 trade routes and accommodates some 14,000 ship passages annually. The United States is the key beneficiary of the Panama Canal, as more than two-thirds of the cargo passing through the canal either originates from or is bound for U.S. ports.

Shipping patterns for East Coast cities will change dramatically with the completion of the $6-billion Panama Canal expansion project. The original Panama Canal locks can accommodate "Panamax" class container ships, which are 856 ft long by 106 ft wide with a 350,500 long ton and an ability to carry 4,500 shipping containers. This is referred to as twenty-foot equivalent units (TEUs). By adding a much larger set of locks, the expansion project will enable "New Panamax" ships traveling from Asia to pass through the canal and route to the eastern seaboard of the United States. At 1,300 ft long by 126 ft wide, New Panamax ships can carry 12,000 TEUs and have a draft of 50 ft when fully loaded. At present New Panamanian ships carrying cargo from Asia to the United States are capable of offloading their cargo at West Coast ports. From there, the TEUs are shipped by surface transportation to the East Coast, adding $600 to the cost of transporting each shipping unit. An alternative, New Panamanian ships entering the United States can pass through Egypt's 80 ft deep Suez Canal, which has no locks. However, this route takes approximately 10 days longer than the one through the Panama Canal.

It is anticipated that the new locks of the Panama Canal will see 2,000 passages of New Panamanian container ships per year. Because of their greater size, the ships will essentially double the available cargo capacity compared with current levels. At present only three East Coast ports—Baltimore, Miami, and New York City—stand to gain, as they are the only ones that can accept fully loaded New Panamanian ships. In response, Savannah and other East Coast ports have embarked on a "race to the bottom" to deepen their harbors so that they too can accommodate the larger vessels.

The Savannah Harbor Expansion Project is expected to add the initial overlay to surfacing and extend the reach of the Savannah Harbor to the new 50 ft depth level. Savannah Harbor will begin work on the expansion project in 2013, and completion is expected in 2016. The project will add 5,000 ft of new navigation channel to the existing 85,000 ft of channel, and add 1,000 ft of new berthing for 2,000 TEUs. Savannah Harbor is currently the nation's fourth busiest container terminal and its second busiest container exporter. The largest U.S. container facility and one of Georgia's strongest economic engines, the Port of Savannah handled nearly 3.7 million TEUs in 2015. Located 35 mi up the Savannah River from its mouth on the Atlantic Ocean, the port is served by a navigational channel that is maintained at a minimum depth of 42 ft at mean low water. As a result, New Panamanian ships calling at the Port of Savannah must arrive lightly loaded and must travel only at high tide, which effectively increases the depth of the navigation channel by approximately 7 ft. For container ships with daily operating expenses of roughly $40,000, waiting offshore several hours for high tide increases shipping costs significantly and makes port operations less efficient. About one-third of the vessels calling at Savannah are too big for the Panama Canal, and are either part of a transatlantic service or are taking the longer, Suez Canal route from the Far East.

Deepening Savannah's harbor from 42 ft to 47 ft at mean low water to accommodate New Panamanian ships more efficiently will reduce the cost per container by an estimated 20 to 40 percent on the larger vessels. Shippers using the Port of Savannah will enjoy annual savings of $213 million, while U.S. businesses will save $174 million annually. Boasting a 5.51 benefit-to-cost ratio, the $706-million Savannah Harbor Expansion Project is expected to recoup the initial overlay in slightly more than three years. The environmental impact study associated with the deepening of Savannah's harbor has been one of the most extensive ever completed for a harbor deepening project, taking 16 years. Among the critical issues evaluated were the potential effects of the project on dissolved oxygen levels within the

Savannah River. Because such levels are crucial for ensuring wildlife diversity within the river, years of studies had to be conducted to obtain the necessary regulatory approvals from federal, state, and local officials. As part of its water quality assessment duties under section 303(d) of the Clean Water Act, the State of Georgia has designated the lower Savannah River, including the harbor, as "impaired" because of the waterway's low levels of dissolved oxygen. Therefore, ensuring adequate levels of dissolved oxygen throughout the harbor after dredging is of paramount importance in the deeperening project.

Just as we need oxygen to live, so do fish and the numerous other species that live in the water. The health of an aquatic system is normally reflected in ecological diversity, which is the number of different species that can thrive in the system. A positive correlation exists between dissolved oxygen concentrations and ecological diversity.

Few constituents in water have such significant wide-ranging effects as dissolved oxygen, which can be considered the "core of the aquatic realm." For example, the concentration or absence of dissolved oxygen directly affects the behavior of such heavy metals as arsenic, mercury, chromium, iron, and manganese in aqueous environments. Dissolved oxygen concentrations also affect the types of microbial transformations, as well as invertebrate and fish populations, in a given aquatic setting. For Savannah's harbor, the minimum required level of dissolved oxygen is 5 mg/L, a concentration that ensures the well-being of the fishery.

If dissolved oxygen concentrations decrease to unacceptable levels, detrimental effects on fish and other aquatic organisms could result. Lower levels of dissolved oxygen also reduce the ability of the entire 33 mi stretch of the Savannah River to safely assimilate the load of oxygen-demanding substances introduced through natural or man-made processes upstream and entering the river from point and nonpoint sources. For instance, organic matter enters the river from extensive wetlands and marshes, and wastewater discharges and decaying algae contribute additional oxygen-demanding substances.

A critical resource in the harbor, dissolved oxygen has historically proved challenging to maintain at acceptable levels, especially during warm summer months, when river flows decrease and water temperatures increase. For its part, the U.S. Environmental Protection Agency has imposed a "no additional discharge" limitation on the river and harbor, and established a net total maximum daily load for existing permitted discharges of 150,000 lbs of oxygen-demanding substances.

Two basic factors concerning the harbor deepening raise concerns regarding dissolved oxygen levels. The first involves the atmosphere-ocean exchange rates—that is, milligrams of dissolved oxygen per liter per day—which decrease because of the resulting greater depths and lower water velocities. The second factor has to do with lower water velocities, which increase surface salinity intrusion farther into the harbor and, in turn, cause lower dissolved oxygen saturation levels. In other words, the theoretical maximum concentration possible for a given temperature and salinity is decreased. In the absence of supplemental oxygenation, deepening the harbor would adversely affect dissolved oxygen levels, especially during periods of lower river flows and higher water temperatures.

Unit treatment rates in the harbor are an inverse function of water depth: the deeper the river, the lower the unit treatment rate. This relationship holds true because there remains the same water surface area across which oxygen is absorbed from the atmosphere into the water. However, the deeper harbor has a greater water volume and less top-to-bottom vertical mixing. Modeling conducted by the Corps of Engineers envisioned ways of offsetting the reduction in unit treatment within the harbor caused by deepening it from 42 ft to 47 ft at mean low water revealed that an additional 40,000 lbs of supplemental oxygenation would be required per day.

Although oxygen in ordinary air may be "free," ordinary air has the following disadvantages when used for the supplemental oxygenation of water:

- Because air is only 21 percent oxygen, it provides relatively limited amounts of dissolved oxygen. For example, air that mixes with water at a temperature of 32°C and a salinity of 5,000 mg/L has a dissolved oxygen solubility of approximately 7 mg/L.
- Dissolving oxygen from ordinary air into water requires excessive amounts of energy. For example, the energy needed to dissolve oxygen from air into water at 32°C at a concentration of 5 mg/L amounts to more than 2,000 kWe per ton of dissolved oxygen, or about 8,000 kWe per ton of oxygen dissolved at 10.10 per kilowatt-hour.
- Nitrogen in ordinary air can become supersaturated in pressurized water and effervesce in the gills of fish, causing the equivalent of "bends" experienced by humans.

An alternative to atmospheric oxygen, high-purity oxygen is available for use in supplemental oxygenation systems from two different sources. The first is commercial oxygen liquid oxygen, which is approximately 100 percent oxygen and can be trucked in and stored on-site in special tanks until needed. For the past few decades, the Corps has used this option to apply approximately 80 tons of oxygen per day that is seasonally injected at depth within the Richard B. Russell and J. Simen Thurmond.
Down River – Front River

The CORPS selected on-site generation of high-purity oxygen for the two permanent dissolved oxygen mitigation stations now under construction in the harbor.

The system consists of the most appropriate and most efficient technology for dissolving the gaseous oxygen in the harbor water. In 1977 one of the authors, R.E. Speece, designed and installe

duced effects of the oxygen generation system, which dissolved 100 tons of oxygen per day. That project validated the concept for the two generation systems now used by the Corps to oxygenate the bottoms of the--
The 184 ft depths of the reservoirs facilitate efficient dissolution of oxygen from the rising bubbles. However, Savannah’s harbor is much shallower, and no oxygenation equipment may be placed within the harbor water.

To efficiently dissolve pure oxygen at a lesser depth, an oxygen transfer reactor is needed that can generate a significant interfacial area in which gas bubbles and water come into contact and can remove bubbles for extended periods. The ECO SuperOxyGeneration System achieves both goals. The system pumps water down through a conical vessel referred to as a Spence cone, and gas oxygen is injected into the water. The resulting extensive bubble swarm has an exceptionally large interface of gas to water, maximizing oxygen transfer. The water flow rate through the cone traps the oxygen bubbles for the necessary prolonged retention time because the high interfacial water velocity prevents the bubbles from escaping. What is more, the bubbles cannot be swept out of the cone because the buoyant force of the bubble is greater than the downward exerted water velocity from the cone’s bottom.

The system thus achieves the prolonged oxygen bubble contact times required for efficient oxygenation. Pre- saturation of the reactor produces even higher dissolved oxygen concentrations in the discharge. Spence cones have been installed at numerous locations, including California’s Carquinez Reservation; the Cowhorn Canal, in New York City; the Logan Martin Dam, on the Coosa River in Alabama; Colorado’s Marion Reservoir; and Washington State’s Newman Lake.

Natural resource agencies had reservations about the ECO SuperOxyGeneration System would work effectively in Savannah’s tidal harbor and also were concerned that the resulting dissolved oxygen levels might be too high near the discharge site. The ECO SuperOxyGeneration System, developed by ECO Oxygen Technologies LLC, of Indianapolis, was cho

Savannah, contracted Artec Foster Wheeler to design, install, and operate a temporary, barge-mounted ECO SuperOxyGeneration System high purity oxygen absorption and subsequence injection into the harbor. The project was intended to demonstrate that such supplemental oxygenation technology could be successfully adapted and used in Savannah’s tidal harbor to mitigate the anticipated dissolved oxygen deficit and to directly address the potential fish toxicity question. Dubbed the ReOx demonstration system, the temporary installation contained of two barge mounted reactors 12 ft in diameter and 20 ft high supplied by ECO Oxygen Technologies and the necessary supporting equipment and facilities, including water intake, pumps and piping, shore-based liquid oxygen storage, and a shore-to-barge power supply.

The ReOx demonstration system had a nominal design capacity of 1,000 lb of supplemental dissolved oxygen per day. The system was operated and monitored in 2007 from August through mid-September. Overall, the limiting factor for oxygen dissolution by the temporary ReOx system was the water flow and pressure available from the water intake pumps. These limitations contributed to episodic belching of oxygen bubbles from the submerged discharge to the river when oxygen gas flow to the cones exceeded the water flow and pressure capacity available from the pumps. Overall, the ReOx demonstration system reliably added 20,000 lb of dissolved oxygen per day to the harbor for 50 days. The operational limitations amounted to “lessons learned” that were addressed in the design of the full-scale system.

Modeling of the near-field dissolved oxygen plumes indicated that the discharge plume diffused from its initial concentration of 85 mg/L to about 10 mg/L within the one to two seconds required to move about 15 ft away from the point at which the dissolved oxygen was injected. Because the ECO SuperOxyGeneration System would work effectively in Savannah’s tidal harbor and also were concerned that the resulting dissolved oxygen levels might be too high near the discharge site and p

The water intake structures would include screens designed to reduce the intake of fish and trash. The screens would be covered to prevent fish velocities from exceeding 0.5 ft/s, and they would ensure gentle return of fish to minimize impairment mortality. The intake and primary discharge would be located on Hutchinson Island along the bank of the Front River and would not encroach on the maintained navigation channel. A second, larger system for adding dissolved oxygen will be located for upstream on the free-flowing Savannah River near Rincon. This system will pump...
Typical Intake Structure Design
Discharge Diffuser Design

- Tideflex diffuser systems
Conclusion

► Expansion Needed to Improve Port of Savannah efficiency
► Expansion Impacts DO in Savannah Harbor
► Oxygen injection needed to mitigate reduced DO
► Systems inject 40,000 pounds of oxygen per day (three locations)
► Operate ~180 days per year (warmest months)
► DO Mitigation Project Status – Design complete, construction underway with scheduled completion in 2017
Acknowledgement

The STOA-Amec Foster Wheeler Design Team completed the complex design of the Savannah Harbor ReOxygenation System for the U. S. Army Corps of Engineers, Savannah District with the teamwork and dedication of the Savannah District’s PMs and the numerous stakeholders working with our team to develop the design. This was truly a team effort accomplished with the partnership that was deserving of this groundbreaking project.
What else would you like to know about harbor reoxygenation?
Equipment Specs

► Speece Cones:
  ► 12,12-ft diameter, 22-ft tall (8 upriver, 4 downriver), 316 SS
  ► 10,070 gpm/cone (14.5 MGD)
► Water Intake pumps: Vertical Turbine
  ► Upriver: 3 - 38,700 gpm pumps, 1,500 hp (VFD), 316 SS
  ► Downriver: 4 – 11,077 gpm pumps, 500 hp (VFD), 316 SS
► On-Site Oxygen Generation System
  ► Type: Vacuum Swing Adsorption (VSA)
  ► Capacity: ~ 6,000 lbs/day/unit, 93-95% oxygen/unit/day
  ► 10 units, 8 upriver, 3 downriver
► Water Intake Bays
  ► 3 bays upriver and 4 bays downriver, 1 pump per bay
  ► Traveling water screens (dual entry) with fish-protection returns
  ► Through-screen velocity 0.5 fps at low tide/low river stage
  ► Designed for sediment/debris removal