GEORGIA DOT RESEARCH PROJECT 19-03

Final Report

SUSTAINABLE WASTE MANAGEMENT THROUGH THE BENEFICIAL USE OF DREDGE MATERIALS IN PARTNERSHIP WITH THE CITY OF SAVANNAH

Georgia Department of Transportation

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16. Abstract:

The Savannah Harbor's dredged material containment areas are spread across 7,000 acres along the South Carolina side of the lower Savannah River. A demonstration project to determine whether dredged material could feasibly serve as landfill cover was undertaken. As such, the long-term project viability, including post-construction geotechnical and environmental monitoring was conducted. The results from the geotechnical tests indicate that the dredged materials were classified as poorly graded sands according to the Unified Soil Classification System. The soils contained a little amount of silt and clay that passed through a #200 sieve and exhibited the typical fine and coarse sand's permeability, which made the dredged materials suitable for landfill. Water quality monitoring over the course of six months found that the limits stipulated by the Environmental Protection Division under Section 20 of the Clean Water Act "Monitoring of Surface Water and Underdrain Systems at Solid Waste Facilities" were not exceeded, further indicating material suitability. An economic analysis revealed that cost savings for the landfill was possible, but highly dependent on variables including distance to site, labor, and diesel cost.

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GDOT Research Project No. 19-03

Final Report

SUSTAINABLE WASTE MANAGEMENT THROUGH THE BENEFICIAL USE OF DREDGE MATERIALS IN PARTNERSHIP WITH THE CITY OF SAVANNAH

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

Dredging often is focused on maintaining or increasing the depth of navigation channels to ensure the safe passage of boats and ships. A crucial requirement for maintaining a deepened harbor is having a designated placement area for sediment. USACE calls these designated areas “dredged material containment areas” (DMCA). For this study, the DMCA 2A with a location station of 93+000 to 103+000, with an acreage of 240 was analyzed. Area 2A was chosen for its accessibility and material characteristics. A demonstration project to determine long-term project viability, including post-construction geotechnical and environmental monitoring is needed before a full-scale, sustainable, strategic implementation plan can be developed. The main purpose of the field program was to establish geotechnical and environmental impact monitoring on a small section of the landfill simulating both daily cover and final cap design configurations Several different physical and geotechnical test, including moisture content, sieve analysis, hydrometer analysis, specific gravity of solids, compaction, and hydraulic conductivity, were carried out by the research team. The results from the geotechnical tests indicate that the dredged materials were classified as poorly graded sands according to the Unified Soil Classification System. The soils contained a little amount of silt and clay that passed through a #200 sieve and exhibited the typical fine and coarse sand’s permeability, which made the dredged materials suitable for landfill. Water quality monitoring over the course of six months found that the limits stipulated by the Environmental Protection Division under Section 20 of the Clean Water Act “Monitoring of Surface Water and Underdrain Systems at Solid Waste Facilities” were not exceeded, further indicating material suitability. An economic analysis revealed that cost savings for the landfill was possible, but highly dependent on variables including distance to site, labor, and diesel cost.

CHAPTER 1. INTRODUCTION

BACKGROUND

Dredging is the removal of sediments and debris from the bottom of lakes, rivers, and other water bodies. It is a necessary routine maintenance task in waterways around the world because sedimentation, the natural process of sand and silt washing downstream, gradually fills up channels and harbors. Every year in the United States, the dredging of shipping channels, harbors, waterways, canals, and lakes produces large quantities of valuable sediment material in some locations and an unwanted inconvenience in others.

Dredging often is focused on maintaining or increasing the depth of navigation channels to ensure the safe passage of boats and ships. Vessels require a certain amount of water in order to float and not touch the bottom. When the natural depth of water cannot accommodate the size of ships calling on the port, the U.S. Army Corps of Engineers (USACE) administers contracts in order to make the harbor deeper by dredging/removing sediment from the riverbed. Nationwide, the USACE dredges 300 million cubic yards (CY) of material annually to maintain the nation's navigation channels. Maintaining adequate water depth in harbors is crucial, which leads to a choice of management alternatives, including environmental acceptability, technical viability, and economic feasibility of the chosen alternative (Great Lakes Commission 2013). USACE has been dredging sediment from the Savannah River since the 19th century. A crucial requirement for maintaining a deepened harbor is having a designated placement area for sediment. USACE calls these designated areas "dredged material containment areas" (DMCA). The Savannah Harbor's DMCAs spread across 7,000 acres along the South Carolina side of the lower Savannah River.

Dredging is also performed to reduce the exposure of fish, wildlife, and people to contaminants and to prevent the spread of contaminants along the water body. This is known as environmental dredging. These pollutants are introduced to waterways or water bodies from point sources, such as sewer overflows, municipal and industrial discharges, and spills, or they may be introduced from nonpoint sources such as runoff and atmospheric deposition. The disposal of dredged material is managed and carried out by federal, state, and local governments, as well as by private entities such as port authorities. The USACE issues permits for the disposal; the U.S. Environmental Protection Agency (USEPA) provides oversight and authorization for this disposal. About 5 million CY is dredged each year from the inner harbor channel at a cost of approximately $26 million a year. To put the amount into perspective, the average dump truck holds about 8 CY, which would equal 625,000 truckloads of material moving from the river into the DMCAs every year (Bell 2020).

Contractors and clients now focus on finding uses for dredged material and for coordinating the supply of dredged material with a concurrent demand. For instance, if a harbor is dredged, and a nearby beach needs replenishment, then the newly retrieved sediment may be suitable for beach nourishment and/or coastal protection. Not all dredged material is suitable as a resource, but a good amount is. U.S. federal agencies, Georgia state agencies, and individual communities have an increasing awareness that much of the material dredged from the Savannah Harbor is clean enough to be managed not as a solid waste burden, but as a sustainable resource and a commodity with value. This use may require treatment of the sediments, but generally speaking, dredged material, such as rock, gravel and sand, consolidated clay, silt, or soft clay, can to varying degrees be used as a resource.

The characteristics of dredged materials vary widely depending on time and source (Yozzo et al. 2004). Testing of the physical and chemical characteristics of the dredged material obtained from the Savannah Harbor is essential in determining under what conditions the raw dredged materials can be used for various applications. There are two forms of dredged material: raw and sintered. In New Jersey, Ohio, and Wisconsin, raw dredged material was used in different green infrastructure applications in the built environment and successfully incorporated (Appelbaum 2016, Likos et al. 2015, Yozzo et al. 2004). The sintering process of raw dredged material involves the manufacturing and processing of this material from its raw form to a commercial lightweight aggregate (LWA). The use of raw and sintered dredged material has proven to be an economically viable alternative to traditional construction and green infrastructure materials (Brils et al. 2014, Frihy et al. 2016, Harrington et al. 2016).

PROBLEM STATEMENT

The Georgia Department of Transportation (GDOT) Office of Waterways estimates that more than 150,000 CY of good-quality, low-sediment dredged material is currently stored in the Jones/Oysterbed Island (JOI) dredge material containment area. With this area rapidly approaching capacity, there is an urgent need for impactful solutions that will transfer and curtail a substantial amount of existing and incoming material in an ongoing and sustainable way. Necessitated and supported by GDOT's Office of Waterways, USACE, and the City of Savannah Sanitation Department this study focuses on the direct implementation of a significant amount use of dredge material for use as cover in the City of Savannah's Dean Forest Landfill Extension.

Current GDOT-funded projects regarding dredged material research are primarily focused on material characterization, its potential chemical transformation to LWA, and its use in cementitious materials (GDOT Research Project [RP] 17-14). These methods are significantly limited in scope, and have not meaningfully impacted the significant sheer volume of dredged material currently stored at the DMCA facility, the primary concern of GDOT's Office of Waterways.

OBJECTIVE

To address this urgent matter, the research proposed here does not duplicate the work currently being untaken by RP 17-14; instead, it focuses on a sustainable, adaptable, and scopeable implementation solution. Specifically, this research proposes:

1. The chemical screening of selected material for any toxicity related to sedimentation for the purposes of landfill capping.
2. The implementation of a demonstration project to determine economic efficiency, transportation, and accessibility coordination challenges related to the use of dredged material as daily cover and cap at the Dean Forest Landfill.
3. The creation of a DMCA material database with current information regarding the composition of the material siloed in 2A.

This research is expected to remove a substantial amount of material from the silos on an ongoing and sustained basis, as well as curtail future siloed material and provide an efficient and crucial solution to this persistent challenge.

STUDY SITE

The dredged material is placed in nine dredged material containment areas located throughout the project (table 1), which have been designated by the non-Federal sponsor for use for the proj ect. The DMCAs with their station location and acreage are listed in table 1. For the purpose of this study, the DMCA 2A with a location station of 93+000 to 103+000, with an acreage of 240 will be analyzed. Area 2A was chosen for its accessibility and material characteristics; however, if this project proves feasible in terms of cost and material suitability, the potential exists to extend study to other DMCAs.

Table 1. Dredged material containment areas.

DMCA	Location (Station)	Acreage
2A	93+000 to 103+000	240
12A	6+500BR to 10+500BR*	1040
13A	47+800 to 57+000 (2+000BR)	1307
13B	42+000 to 47+800	540
14A	37+000 to 42+000	647
14B	28+000 to 37+000	703
Jones/Oysterbed (JOI)	10+000 to 27+000	890

*BR refers to the Back River or that portion of the channel located in the Back River.

Management by component is the approach for handling the waste generated in the community. Different types of waste, such as garbage, demolition debris, yard waste, and scrap metal have different handling characteristics and are reused, recycled, processed, or disposed of accordingly. Dean Forest Road Municipal Solid Waste Reclamation and Disposal Facility is located at 1327 Dean Forest Road, and it is available to City residents for the disposal of waste materials generated within their own domiciles.[1]

[1] For the purpose of this policy, domicile is defined as a person's fixed, permanent, principal home for legal purposes.

Materials accepted from City residents include garbage, household recyclables, yard trash, and excess household dry trash. Tires are also accepted as long as they are no more than a total of four from the residence. Commercial waste, including waste generated from the management of rental property, is not accepted. The facility is only closed on Sundays and City holidays. The initial development of the Dean Forest Road Landfill occurred in the 1970s, but there have been several expansions to meet the need for additional waste disposal areas. A current proposed expansion site consists of forested upland (i.e., pine plantations and mixed pine-hardwood). Uplands are surrounded by bottomland hardwood forest. One isolated, jurisdictional wetland exists in the northern portion of the project area. The City of Savannah is proposing the expansion of the existing Dean Forest Road Landfill onto a 98.49-acre site in Chatham County, Georgia. The project site is located west of the existing landfill and sits approximately 1.4 miles west of Dean Forest Road (GA Hwy 307) and 0.6 mile south of Interstate-16. The approximate center coordinates of the site are latitude 32°3.78′ N longitude -81°13.94′ W.

RESEARCH SIGNIFICANCE

A key thrust of this research study is its potential to serve as the foundation for a potential long-term partnership between the City of Savannah and GDOT. Incorporating dredge material into landfill management projects would serve a dual purpose:

- Significantly reducing the overall cost of material associated with landfill cover, capping, and construction.
- Meaningfully reducing the amount of total dredge material that needs to be stored in DMCAs.

Dual economic and geotechnical and environmental evaluations will inform a strategic plan for scaled implementation, and updates to the dredge material characterization database will function as an asset management tool to engage GDOT and City professionals (i.e., engineers, landscape architects, planners, public works, etc.) through dissemination of characterization data summaries. Ultimately, this research study will yield a data-driven, strategic implementation plan that can serve as a guide for GDOT, the City of Savannah, and the U.S. Army Corps of Engineers to mount a maintainable, long-term, and mutually beneficial partnership promoting sustainable waste management initiatives in Georgia.

CHAPTER 2. LITERATURE REVIEW

BENEFICIAL USE

In 2007, the U.S. Environmental Protection Agency and U.S. Army Corps of Engineers developed the *Beneficial Use Planning Manual* to provide a framework for identifying, planning, and financing beneficial use (BU) projects. Beneficial use is defined as "the use of dredged materials, by placing them where they can maximize the most good, rather than wasting them by disposal" (Nightingale and Simenstad 2001). The use of dredged material includes both environmental improvements and commercial uses, such as beach restoration as well as construction fill. Rock may range from soft marl (e.g., sandstone and coral) to hard rock (e.g., granite and basalt). Depending on size and quantity, rock can be a valuable construction material. Gravel and sand are perhaps one of the most valuable resources and are routinely used for beach nourishment, wetland restoration, and coastal protection. If the water content is low, consolidated clay can be used for engineering purposes. On the other hand, silt and soft clay are rich in nutrients because they usually come from maintenance dredging, which makes it good for agricultural purposes such as topsoil and for wildlife habitat development. Mixed materials are somewhat more restricted at the moment of usage; however, they can still be used for fill, land improvement, and topsoil.

Categories of Beneficial Uses

Dredged material or sediment provides opportunities for a number of environmental, economic, and aesthetic BUs. There are seven broad categories of BUs that have been identified by the USACE Engineer Manual:

1. Habitat development:
    a. Wetland habitat: A broad category of periodically inundated communities, characterized by vegetation that survives in moist or wet conditions (soils). These are mainly tidal freshwater and saltwater marshes.
    b. Upland habitat: A broad category of terrestrial communities, characterized by vegetation not normally subject to inundation. Typically, they range from bare ground to mature forests.
    c. Aquatic habitat: Submerged habitats extending from near sea, river, or lake level down several feet. Some examples include tidal flats, oyster beds, seagrass meadows, and freshwater aquatic plant beds.
    d. Island habitat: Islands are upland and/or high zone wetland habitats distinguished by their isolation and particular uses. They are completely surrounded by water or wetlands.
2. Beach nourishment: Shoreline stabilization and erosion control is a concern along many beaches. There are four major types of beach nourishment that occur along the U.S. shorelines:
    a. New borrow sediment not connected with maintenance dredging.
    b. Maintenance dredging of an existing channel.
    c. Placement in the littoral zone (nearshore).
    d. Rehandling of accumulated sediment.
3. Parks and recreation: Recreational uses of dredged material placement sites range from simple projects as fill for a recreation access road to a complex project as the 1,800-ha Mission Bay development in San Diego, California.

4. Cultivation:

    a. Agriculture: There is interest in the agricultural use of dredged material, especially by cost-sharing sponsors looking for partners in placement sites. The addition of this sediment can improve the physical and chemical characteristics of a questionable soil.

    b. Horticulture: Horticulture crops are generally considered vegetable, fruit, nut, and ornamental varieties of commercially grown plants. Applications on these soils do not differ from those in the agricultural sector.

    c. Aquaculture: Aquaculture in a DMCA was first explored by the USACE during the Dredged Material Research Program (DMRP). DMCAs commonly possess structural features like dikes and water control devices that can build up their suitability as aquaculture sites.

5. Solid waste landfill and alternative uses: There have been several research projects and tests that have recently substantiated three Bus of dredged material:

    a. The capping of solid waste landfills.

    b. The use of sediment to protect landfills.

    c. The use of sediment to manufacture bricks and hardened materials such as road surfaces.

6. Multipurpose uses and other land use concepts: Multipurpose use is encouraged. With careful engineering design, construction, planning, and proper implementation of operational and maintenance procedures, a placement site with combinations of uses may be developed.

7. Construction and industrial/commercial uses: The economic potential and social productivity of industrial/commercial activities provide a strong incentive for urban growth and development. These constructions have grown in natural harbors and along urban waterways where raw material can be received and finished products can be shipped.

Evaluating Materials for Beneficial Use

Evaluating the contaminant status of the dredged material is the first step to determine if the sediment is acceptable for beneficial use. As mentioned above, highly contaminated material will not be suitable for most proposed BUs, especially not wildlife habitat projects. Yet, with the appropriate examination and treatment, it may be classified as suitable. Guidance for evaluating can be obtained from local, state, or national regulatory agencies.

The technical feasibility of implementing a particular BU at a designated site must be evaluated. Several constraints must be considered, such as water depth, pumping distance, access, etc. If these constraints do not allow the proposed BU, alternate uses or disposal options must be pursued. Before any substantial work can be undertaken, the environmental impact prior to, during, and subsequent to construction of the proposed project must be investigated and evaluated. An Environmental Impact Assessment (EIA) should be performed on all projects. Beneficial use options may be pursued if it is concluded that the environmental effects will not be significantly harmful.

After one or more potential BU options have been identified and the engineering methods have been defined, estimated costs and benefits should be analyzed. These options may lower the cost for disposal of dredged material in many scenarios, but may increase costs in other cases. Costs are frequently lower when distances from dredging site to disposal site are reduced. The increase in cost may be more than offset by the value of the benefits. In some cases, intangible benefits are taken into account when assessing overall costs and benefits. These include aesthetic enhancements.

Dredged material can be composed by different sediment types:

- Rock: Rock may range from soft marl (e.g., sandstone and coral) to hard rock (e.g., granite and basalt). Depending on size and quantity, rock can be a valuable construction material and may be used for both terrestrial and aquatic projects. It may also result from blasting, cutting, or ripping. It is rarely of only one type and, it is usually not contaminated.
- Gravel and Sand: Gravel and sand are perhaps one of the most valuable resources and are routinely used for beach nourishment, wetland restoration, and coastal protection. They are suitable for most engineering uses without processing. Some additional treatment (e.g., freshwater washing) may be needed for agricultural or product uses.
- Consolidated Clay: If the water content is low, consolidated clay can be used for engineering purposes. If the water content is high, dredged clay may have to be dewatered before being transported and treated. It varies from hard to soft clay and is material obtained from capital dredging. This material may occur as lumps or as a homogenous mixture of water and clay. Manufacturing of bricks and ceramic are possible uses of consolidated clay.
- Silt/Soft Clay: Silt and soft clay are rich in nutrients because they usually come from maintenance dredging, which makes it good for agricultural purposes such as topsoil

and for wildlife habitat development. Depending on state, local, and national regulations and laws, mildly contaminated silt and soft clay may be used for some engineering purposes or product uses, such as bricks and ceramics. Due to the high water content, dewatering can require months, which results in a need for temporary storage.

- Mixture (Rock/Sand/Silt/Soft Clay): Maintenance dredged material is usually a mixture of materials (e.g., boulders, lumps of clay, gravel, organic matter, and shells) with varying densities. Mixed materials are somewhat more restricted at the moment of usage; however, they can still be used for fill, land improvement, and topsoil.

Uses for Dredged Materials

Raw dredged material has been successfully implemented in habitat, wetland creation, beach nourishment, construction materials, and waste management, among other uses. Lightweight aggregate is a structurally altered form of dredge material that has the potential to create an environmentally beneficial product and can be used in applications such as wetland restoration for coastal flood mitigation, landfill substrate, green roofs, and dune reconstruction (Barone et al. 2014, Morscheck et al. 2014, Plumlee et al. 2016).

The most cost-effective means of dredged material control has so far been landfill cover and structural fill, and has been successfully used for this purpose in Florida, New York, Texas, and New Jersey (Banks 2009, Likos et al. 2016, Yager and Chen 2014). Both the USEPA and the USACE *Guide for Beneficial Use* lists landfill cover as an approved and recommended use for this material (USACE 2010, USEPA 2014)

Specific projects include the following:

- New Jersey: The New Jersey Department of Transportation (NJDOT) has identified many confined disposal facilities (CDFs) as at or near capacity with dredged materials. Periodic dredging of channels and marinas is of significant importance to New Jersey's recreational and commercial marine transportation. Establishment of new CDFs has been deemed improbable; thus, the most efficient solution to this problem is reuse of dredged materials to increase the longevity of existing CDFs. Rutgers University was contracted to investigate the potential for utilizing dredged material from these CDFs in the closure of New Jersey's uncapped landfills. The project included an update of the existing New Jersey Department of Environmental Protection (NJDEP) landfill database, the development of a rating system to identify sites with the highest potential to utilize dredged material for their closure, and the identification and preliminary investigation of the top candidate landfills based on this rating system.[2]
- California: The beneficial reuse options addressed are: wetland creation and restoration, levee maintenance, construction fill, and daily cover at sanitary landfills. This document updates a previous San Francisco Bay Regional Water Quality Control Board document (SFBRWQCB 1992) and contains updated information on ambient concentrations of contaminants in San Francisco Bay sediments and updated biological effects concentrations (ER-Ls and ER-Ms). The project proposes screening values based on sediment and elutriate chemistry and acute toxicity characteristics and the potential for leaching of contaminants from dredged material after placement. These guidelines are based on the Regional Board's current understanding of the appropriate

[2] Further details can be found at the project site: https://www.nj.gov/transportation/refdata/research/reports/FHWA-NJ-2014-012-TB.pdf.

physical, chemical, and biological quality requirements of dredge materials for various beneficial reuse placement options. [3]

- Great Lakes: The Toledo–Lucas County Port Authority is involved with several initiatives to remove and reuse dredged material from the Toledo Harbor CDF. Most notable is a demonstration project that expands an ongoing partnership between the City of Toledo, the port authority, and a private topsoil manufacturing company. Under contract with the City, the company recycles the City's sewage sludge for a fee and provides the City with 4 CYs of topsoil for every 1 CY of sewage sludge removed. The company creates the topsoil by mixing the sewage sludge with dredged material and lime sludge, a byproduct of the drinking water treatment process. The company pays the port about 95 cents per CY to remove dredged material from the CDF for use in this process. The resulting topsoil has restricted uses due to concerns about pathogens from the sewage sludge, but has been used extensively as the final vegetative cover for the City of Toledo's landfill. [4]
- Florida: "It allows us to use our material in alternate ways to enhance the quality of the surrounding environment while alleviating the need to fill our disposal sites that have limited capacity," said Ashley N. Kleinschrodt, USACE Mobile District Navigation Section Chief. With the USACE Mobile District's efforts, some locations in Florida will benefit from dredged material in the next couple of years. The Mobile District is partnering with Franklin County, Florida, to design and construct a 20-acre beneficial use site to service the Eastpoint Navigation Channel. The containment area will be

[3] Further details can be found at the project site: https://www.spn.usace.army.mil/Portals/68/docs/Dredging/guidance/beneficialreuse.pdf.
[4] More details of the project description can be found at: https://www.csu.edu/cerc/documents/WastetoResource.pdf.

> constructed with sandy material from within the site's footprint; later on the site will be backfilled. Once the dredged material has consolidated, a local marsh vegetation will be placed on top of the site by Franklin County. The District will also be placing sandy material from Sike's Cut (i.e., the entrance channel to Apalachicola Bay) along the shoreline of the St. George Island. In Perdido Key, Florida, the District will be placing approximately 150,000 CYs of sandy O&M material from the Pensacola Entrance Channel along National Parks Service's Johnson Beach in order to restore two locations that were breached during Hurricane Sally. [5]

"All of these related projects create a way to change the perception of dredged material," said Herbert M. Bullock, Dredge Material Project Manager, USACE Mobile District. Districts are doing all they can to support and facilitate the beneficial use of dredged material, as the district is one of the primary entities responsible for habitat creation and restoration, beach nourishment, landfill cover, site remediation, and construction fill.

USE IN LANDFILL CAPPING

This study is mainly focused on reusing the dredged material on landfill capping. Landfill capping is a containment technique that forms a barrier between the contaminated area and the surface, thus shielding humans and the environment from the harmful effects of its content. A cap must restrain surface water infiltration into the contaminated subsurface to reduce the potential for contamination to leach. Waste disposal has been one of the oldest issues around the world. In the U.S., landfills have been the most common form of waste disposal. Prior to

[5] More information about the Apalachicola Bay project can be found at: https://www.sam.usace.army.mil/Portals/46/docs/planning_environmental/docs/EA/Two-Mile%20EA.pdf?ver=xDPhGyiT5bAiZ87dblbmeQ%3D%3D&timestamp=1613058412311.

environmental laws that regulate waste disposal, hazardous waste was disposed of, often in metal drums that rusted, leaving the waste to seep into the landfill. Water was also allowed to seep through the cover of the landfill, saturating the waste and allowing it come out the bottom or sides.

Cap Design

The cap design selected for a site will depend on several factors, including the types and concentrations of contaminants present, site size, the amount of rainfall the area receives, and the future use of the property. The local climate, hydrogeology, and terrain might also affect the cap design selected. Capping can range from something as simple as placing a single layer of a material over lightly contaminated soil to the placement of several layers of different materials to separate more highly contaminated wastes. For example, asphalt caps might be selected to cover low levels of soil contamination on a property that will require a parking lot. In general, less complex systems are required in dry climates and more complex ones are required in humid climates.

Standards for Landfill Caps

In 1976, Congress passed the Resource Conservation and Recovery Act (RCRA), tightening the regulatory oversight of existing landfills and establishing basic standards for covering landfills. There are two types of caps required: (1) those for hazardous waste landfills, and (2) those for nonhazardous waste landfills. The former type of cap consists mainly of three layers:

1. An upper vegetative (topsoil) layer.
2. A drainage layer.
3. A low permeability layer made up of synthetic material covering 2 ft of compacted clay.

The most critical components of a landfill cap are the *barrier layer* that minimizes water infiltration and the *drainage layer* that transmits water across the cover. The *vegetative layer* is the top layer of soil planted with grass or other vegetation that can help prevent soil erosion and make the area look more natural and attractive. An evapotranspiration (ET) cover is a vegetative cap in which the plants and underlying soil keep rain and snowmelt from soaking down into the contaminated area. The second layer from top to bottom is the drainage layer, a layer of sand and gravel, often containing rows of slotted pipes, which are built to collect and drain any water that makes it through the top layers of a cap. A geomembrane layer might also be required, depending on the hazardous waste. It is a sheet of strong plastic-like material used to prevent downward drainage of water and upward escape of gases. The geomembrane layer can be low-permeability soil (e.g., clay), geosynthetic clay liners (GCLs), or synthetic geomembrane liners. GCLs are factory-manufactured hydraulic barriers consisting of a layer of bentonite clay or other very low-permeability material. Under the geomembrane layer, a layer of compacted clay can also help prevent the downward drainage of water. Some landfill caps, such as those for municipal landfills, may also include a collection and venting system for methane and other gases that could build up underground.

REGULATIONS FOR DREDGING PROJECTS

The Water Resources Act of 1992, Section 204 – Beneficial Use of Dredged Material (Public Law 102-580) established USACE authority for implementing ecosystem restoration projects in connection with dredging. The regulation of dredged material disposal within waters of the United States is a shared responsibility of the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers. The primary Federal environmental statute governing discharge of dredged materials into inland and estuarine waters of the United States is the Federal Water Control Act Amendments of 1972 (i.e., the Clean Water Act [CWA]).

All proposed dredged material activities regulated by the CWA must also comply with the applicable requirements of the National Environmental Policy Act (NEPA) and its implementing regulations. In addition to CWA and NEPA, a number of other Federal laws and Executive Orders must be considered in the evaluation of a dredging project.

Generally, the BU of dredged material placed within the territorial sea is evaluated under the CWA (USEPA/USACE 1998). The USEPA Office of Water has maintained that once dredged material is regulated under the CWA, it will always be regulated under the CWA. The CWA does not provide guidance for the protection of the environment after dredged material is placed in an upland environment (Childs et al. 2002). If biological testing indicates the material is suitable for open-water disposal, that material would likely be deemed suitable for a wide range of BU applications from a contamination standpoint. Most BUs involve open water or confined placement. Therefore, the testing and assessment procedures as well as compliance with the 404 Guidelines must also be considered for BU (USACE/USEPA 1998).

CHAPTER 3. METHODOLOGY

The suitability of dredged material as a landfill cover material varies, depending on the physical properties of the sediment being considered. For example, very fine-grained material is generally unacceptable for use as landfill material due to poor hydraulic conductivity, susceptibility to erosion, and formation of dust. Poor drainage characteristics result in formation of leachate seeps on landfill side slopes. Salt content and pH must be appropriate to support growth of desired vegetation species for use as a final closure. The main objective of this research study is to remove a substantial amount of material from the silos on an ongoing and sustained basis, as well as curtail future siloed material and provide an efficient and crucial solution to this persistent challenge. To achieve this main objective, the research team developed more specific objectives within the research.

OBJECTIVE 1: SCREENING OF DREDGED MATERIAL FOR TOXICITY AND SUITABILITY

In order to ensure the requirements are met for both suitability and for environmental safety, as determined by the Department of Natural Resources, testing procedures established by the USEPA, as required by Section 103 of the Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972 were conducted. Sediment characterization includes:

- Grain size analysis.
- Bulk sediment chemistry.
- Elutriate and whole sediment bioassays.
- Toxicity/bioaccumulation tests.

OBJECTIVE 2: DEMONSTRATION SITES FOR LOGISTICS, ECONOMICS, AND PROJECT SUSTAINABILITY

A demonstration project to determine long-term project viability, including post-construction geotechnical and environmental monitoring is needed before a full-scale, sustainable, strategic implementation plan can be developed. Further, site selection, transportation methods, site preparation and construction coordination are required to address logistical concerns. The main purpose of the field program is to establish geotechnical and environmental impact monitoring on a small section of the landfill simulating both daily cover and final cap design configurations. Two field plots will each consist of three subplots, 150 ft wide and l00 ft long.

The thickness of the dredged material will be 6 inches across the width of the test plot, as necessitated by landfill cover guidelines. One of the field plots will consist of an additional 6-inch dredged material layer as topsoil for vegetation, simulating a final landfill cap. The plots will be surrounded by a dewatering ditch filled with sand near a retaining levee in order to facilitate lateral drainage of the leachate.

The survival rates of different vegetative species on this plot will also be monitored on a monthly basis. Geotechnical monitoring will yield data focusing on the integrity of the embankments over an annual period, recording changes in settlement, horizontal deformation, and strength gain/loss over service conditions (e.g., heavy construction machinery traffic).

OBJECTIVE 3: DATABASE UPDATE, AND DETERMINATION OF GEOTECHNICAL SUITABILITY FOR LANDFILL DEMONSTRATION PROJECT

This research will also determine the areas of the DMCA that contain the optimal for the purpose of the landfill demonstration project, and the updating of current characterization databases for the dredge material stored at the DMCA located on Hutchinson Island, an area of approximately 300 acres. This objective would utilize existing studies that have been conducted in the area by the Georgia Institute of Technology (Georgia Tech), GDOT, and the Army Corps. Wherever possible, existing data will be used to update the material characterization database, and care will be taken to extend, rather than duplicate, any studies that have already been undertaken. In areas that were not tested, supplemental American Society for Testing and Materials (ASTM) testing will be performed to ensure a complete data set. A summary of the geotechnical testing and its corresponding ASTM standard is shown in Table 2. This information will be made available to all parties involved to provide data critical to the sustainability of this partnership.

Table 2. Summary of the ASTM standard test method used.

Geotechnical Characteristics	ASTM Standard	ASTM Title
Moisture Content	D2216	Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
Sieve Analysis	D6913	Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
Hydrometer Analysis	D7928	Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis
Specific Gravity	C128	Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate
Compaction Characteristics	D698	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort
Permeability	D2434	Standard Test Method for Permeability of Granular Soils
Soil Classification	D2487	Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

OBJECTIVE 4: FEASIBILITY ASSESSMENT OF DREDGE MATERIAL FOR APPLICATIONS OF INTEREST TO GDOT AND THE CITY OF SAVANNAH

This study focuses primarily on dredge material's use as a cover for landfill; however, the physical and chemical testing that will be performed in Phase 1 of this research will provide a foundation for the consideration of this material for other uses. This specific objective is to explore the option of using this material for these alternative uses.

The State of Georgia has regularly relied on flowable fill for bridge repairs, backfill, structural fill, road bases, and mud-jacking. The State has a clear market for this type of material, and incorporating dredge material would serve a dual purpose: reducing the overall cost of this type of fill to GDOT and its contractors, and eliminating some of the dredge material from a waste site. Benefits of using this type of material in road construction includes reduced construction time, settlement minimization, and reduced labor and maintenance costs.

The potential use of dredge material for the purpose of road embankments holds significant promise in both the reduction of cost associated with the road embankment material, and the volume of dredge material wasted. Road embankments made of dredge material have been undertaken with success in New Jersey, Florida, and California. The use of dredged material as structural fill for road embankments requires a reduction in moisture content and an increase in workability. Because of its high moisture content, the strength, compressibility, and durability of dredge material present a significant concern.

This flowable fill can be made from dredged material, residential waste such as recyclables, and a proprietary binding agent. The product remains in a liquid slurry state similar to cement products, sets in a short period, and it is stable for longer periods of time. The advantage of this product is that it encapsulates any contaminants within the sediment and no leachability problems have been observed using this product at Brownfield sites (USACE 1999). Despite the encouraging results, there are still some concerns about the composition of dredged material. Since dredged material contains organics, salts, and other materials, the cement hydration may be negatively impacted in terms of workability, performance under load, and setting time.

Upon speaking to landfill operators and their observation of landfill capping plant species that grow, it was decided it was also necessary to explore the possibility of utilizing harvested plant species for other uses, including biomass production.

CHAPTER 4. MATERIAL SAMPLING AND GEOTECHNICAL CHARACTERIZATION

MATERIAL SAMPLING

In September of 2021, the research team traveled to Area 2A and collected soil samples from the dredged material at two different places (S1 and S2), as shown in figure 1. S1 is situated in close proximity to the top of the levee, which is used as a vehicle path. S2 is located close to the levee's toe. The locations of the sample collection are depicted in figure 2(a) and (b).

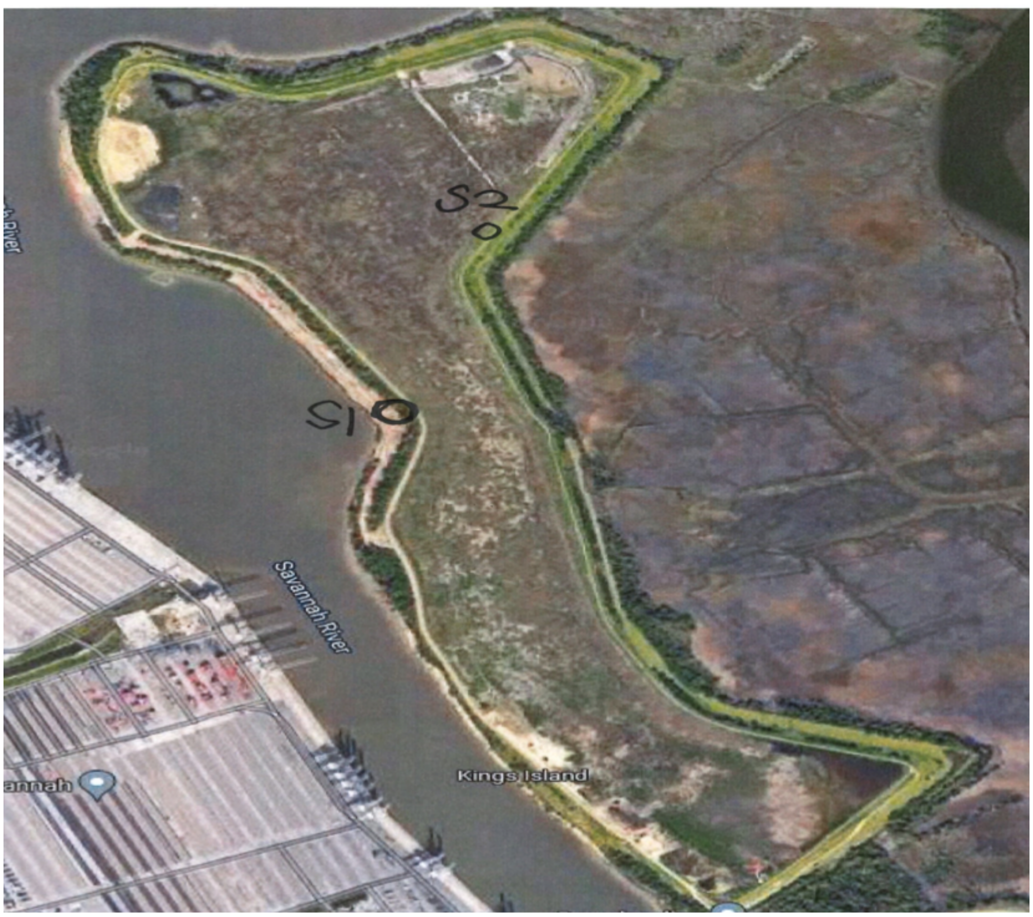


Figure 1. Photo. Sampling locations in Area 2A.

(a) S1 Location (b) S2 Location

Figure 2. Photos. Sampling using a hand auger.

To statistically analyze the different physical properties of the soil, three bore holes were drilled at each location using a hand auger. The bore holes were dug to depths of 1 ft, 3 ft, and 5 ft, and samples were gathered at each depth. As a result, for the purposes of geotechnical testing, a total of 18 samples were collected: 2 locations x 3 depths x 3 replicates = 18. The soil samples were transported to the Soil Mechanics Laboratory on the Georgia Southern University Statesboro Campus in a plastic bag that had been sealed tightly to prevent air leakage.

GEOTECHNICAL TESTING

Several different physical and geotechnical tests, including moisture content, sieve analysis, hydrometer analysis, specific gravity of solids, compaction, and hydraulic conductivity, were carried out by the research team. In addition, based on the results of the sieve study, a soil classification was also established. ASTM standards were adhered to during each one of these tests. Table 2 provides a summary of the title as well as the standard designation for each test.

Moisture Content

It is generally agreed that the moisture content of soil is one of the most important properties to consider when trying to establish a correlation between the behavior of soil and its properties. The amount of moisture in the dredged soil samples was measured, and the results can be found in table 3 and figure 3. It is worth noting that the error bar in the figure depicts the standard deviation obtained from three replicates. It was discovered that soil samples from S1 had an average moisture content of 27.3 percent, whereas soil samples from S2 had a moisture content of 60.6 percent, which indicates that the soil at the toe of the levee (S2) contains more water than that in S1.

Water content is defined as

$$w = \frac{weight\ (or\ mass)\ of\ water\ present\ in\ a\ given\ soil\ mass}{weight\ (or\ mass)\ of\ dry\ soil} \tag{1}$$

Water content is usually expressed in percent.

Table 3. Summary of moisture contents of the dredge materials.

Sample Location	Moisture Content (%)	Average Moisture Content (%)	Standard Deviation (%)
S1 at 1 ft	19.7	27.3	2.1
S1 at 3 ft	27.3		20.1
S1 at 5 ft	35.0		30.4
S2 at 1 ft	74.2	60.6	4.4
S2 at 3 ft	65.4		28.9
S2 at 5 ft	42.2		10.0

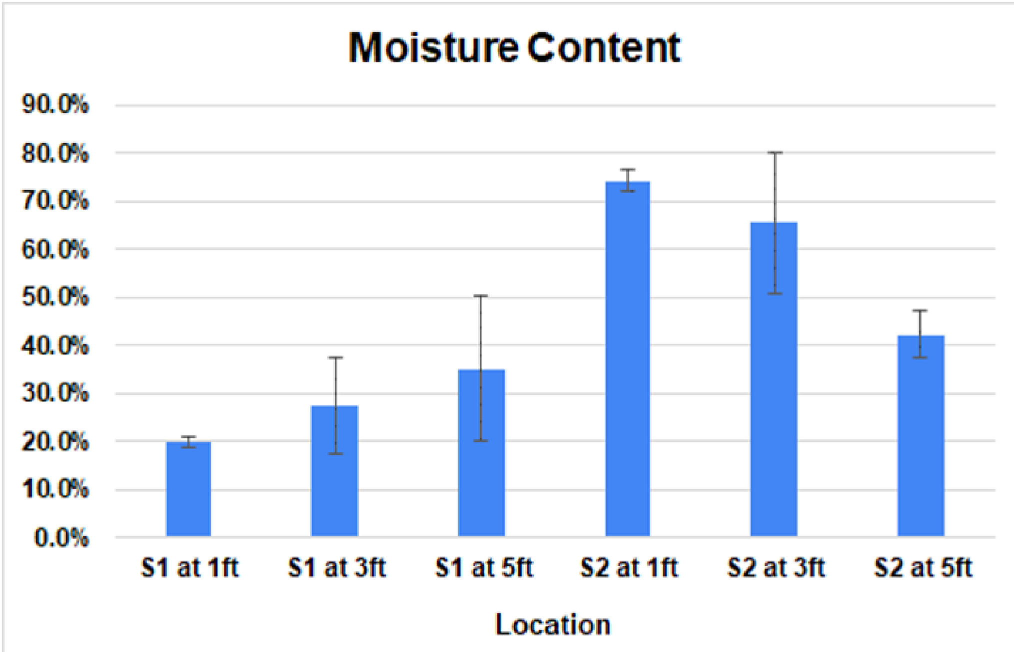


Figure 3. Graph. Moisture content result.

As mentioned previously, there are three replicas for each bore hole. The averages were calculated for result purposes.

Grain Size Analysis (Sieve and Hydrometer Analysis)

The grain size analysis was performed on each of the samples to see a grain-size proportion of the dredged soil and visualize it in a graphical form. Firstly, an evaluation using a set of mechanical sieves was carried out on the portion of a sample that consisted of coarse grains or a particle size greater than 0.075 mm. Secondly, a hydrometer test was conducted on the fine-grained fraction, which was defined as having a particle size of less than 0.075 mm or passing the #200 sieve. Combining the results of the two tests creates a single grain-size distribution curve. Figure 4 contains six grain-size distribution curves, each of which represents a sample from a different depth at a different location (e.g., 1 ft, 3 ft, and 5 ft of both S1 and S2).

The grain-size distribution results indicate that, regardless of the location, a fraction of the fines in soil that are considered clay or silt is very limited, having an average of 3.3 percent and 5.1 percent for S1 and S2, respectively.

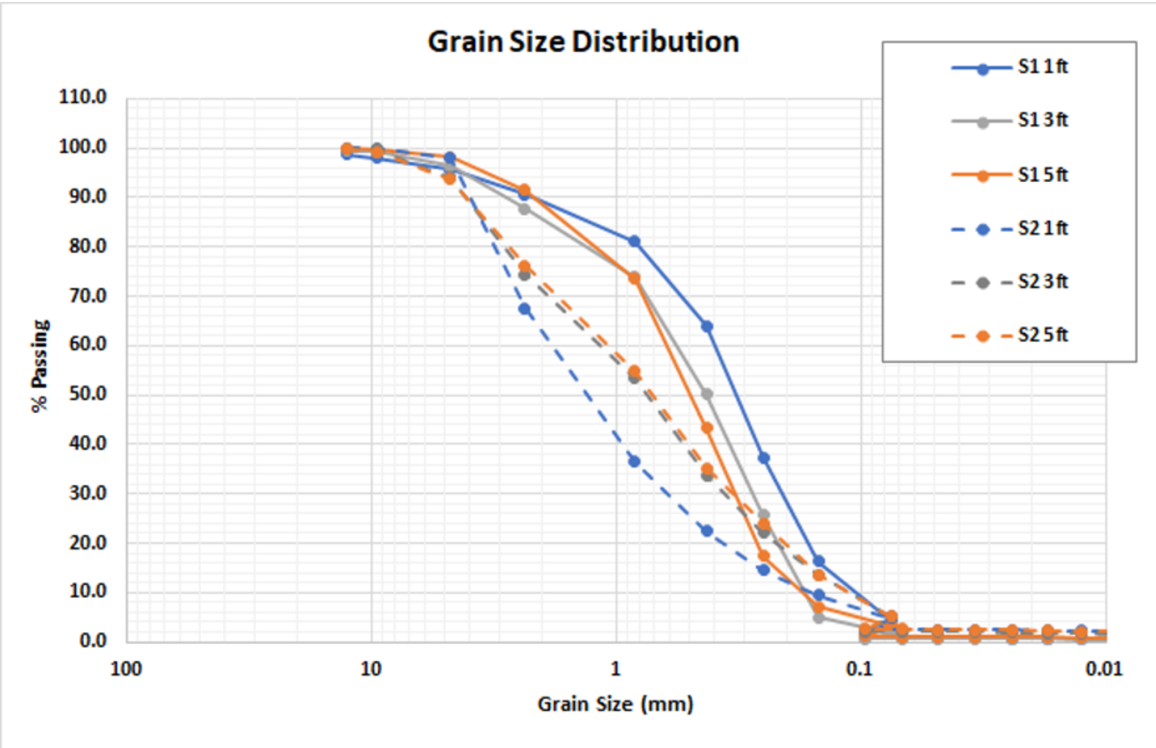


Figure 4. Graph. Grain-size distribution result.

Soil Classification

Based on the sieve analysis results, the soil samples were classified using the Unified Soil Classification System (USCS). The parameters (% passing #200 and #4 sieves, and coefficients of uniformity and curvature) that are required for the use of the USCS were obtained from the grain-size distribution curves in figure 4. The parameters and the final group symbol of each sample are presented in table .

Table 4. Summary of soil classification using USCS.

Sample Location	% Passing #200	% Passing #4	Coefficient of Uniformity	Coefficient of Curvature	USCS Group Symbol
S1 at 1 ft	4.4	95.7	3.6	2.1	SP
S1 at 3 ft	2.0	96.3	3.2	1.7	SP
S1 at 5 ft	3.4	98.2	4.2	2.6	SP
S2 at 1 ft	4.9	98.0	9.6	6.3	SP
S2 at 3 ft	5.2	94.1	9.4	5.7	SP
S2 at 5 ft	5.2	93.6	8.3	5.0	SP

As mentioned, the dredge soil contains a limited amount of clay or silt showing only approximately 5 percent or less passing the #200 sieve. In addition, most of the soil particles pass the #4 sieve or 4.75 mm, based on which it is evident that the soil falls in the "sand" category. The coefficients of uniformity (C_u) and curvature (C_c) play a role to distinguish between a well-graded soil (if $1<C_c<3$ and $C_u>6$) and a poor-graded soil (if not meeting the well-graded soil condition). The dredged soil did not meet the condition to be a well-graded soil, and hence they are all characterized as a poorly graded sandy soil or SP. These characteristics are found consistent for all samples tested.

Specific Gravity

The specific gravity (G_s) of soil is a ratio between the density of soil solids and that of water. This property is typically determined by means of a water pycnometer. Although this characteristic does not solely provide any meaning by itself, it is still important when computing other relevant properties, such as the void ratio or degree of saturation, as it is used as a conversion factor from mass to volume. In order to update the database of the dredge material of the Savannah River, a series of specific gravity tests were conducted, and the results are presented in table . Most soils found in nature are combinations of various types of minerals, therefore the ranges of the values of G_s can vary. However, no significant difference in the specific gravity values is observed between the two sample locations, though the result indicates lower than typical values that usually range from 2.65 to 2.80.

Table 5. Summary of specific gravity of the dredge materials.

Sample Location	Specific Gravity	Average Specific Gravity	Standard Deviation
S1 at 1 ft	2.446		0.049
S1 at 3 ft	2.619	2.558	0.040
S1 at 5 ft	2.609		0.037
S2 at 1 ft	2.440		0.013
S2 at 3 ft	2.558	2.540	0.057
S2 at 5 ft	2.621		0.106

The three replicas were analyzed and tested for specific gravity, having to calculate an average at the end of the testing to conclude the specific gravity at each location. The research team divided the original sample replica into two, and performed four test runs having each sample containing a mass of approximately 70–75 g.

These test methods cover the determination of the specific gravity of soil solids that pass the 4.75 mm (No.4) sieve, by means of the water pycnometer. When the soil contains particles larger than the No.4 sieve, Test Method C127 shall be used for the soil solids retained, and these test methods shall be used for the soil solids passing the 4.75 mm sieve. Soil solids for these testing purposes do not include solids which can be altered by the methods, contaminated with a substance that prohibits the use of these methods, or similar to the high organic material encountered in this research study. The research team used paper towels to remove excess water and organic matter from the flask prior to performing the test.

Laboratory Compaction Characteristics

The compaction test is used to determine the relationship between water contents and the dry unit weight of soil using a standard mold and a 5.5-lb rammer dropped from a height of 1 ft. A compaction curve is created from the test, from which two geotechnical characteristics (the optimum moisture content [OMC] and the maximum dry unit weight) are obtained. The research team used five different water contents from each of which a dry unit weight was measured. This procedure was repeated for each sample except for S1 at 1 ft due to an insufficient amount of sample. Table summarizes the OMC and maximum dry unit weight, and the four compaction curves are presented in figure 5.

It was found that samples from S1 require a lower OMC to reach the maximum dry unit weight, while samples from S2 require a relatively higher OMC, and yet the maximum dry unit weights are a lot lower. Water content plays an important role in soil compaction. The compressibility of a relatively dry soil increases as water is added to it. That is, for water content levels dry of optimum, the water acts as a lubricant, enabling soil particles to slide relative to each other, leading to a denser configuration.

Table 6. Summary of compaction characteristics.

Sample Location	Optimum Moisture Content (%)	Max Dry Unit Weight (lb/ft^3)
S1 at 1 ft	15.0	112.0
S1 at 3 ft	12.4	106.0
S1 at 5 ft	12.0	106.5
S2 at 1 ft	N/A	N/A
S2 at 3 ft	22.5	91.6
S2 at 5 ft	16.0	90.2

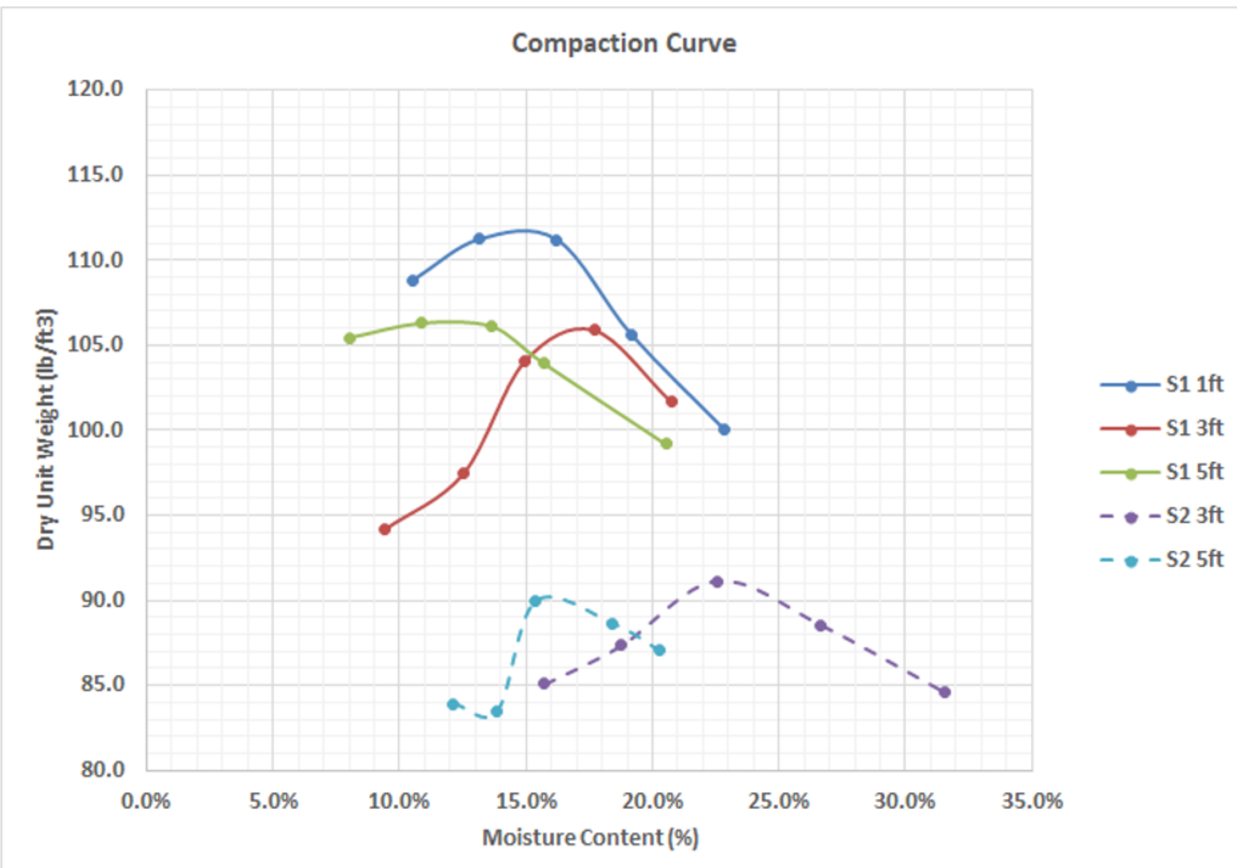


Figure 5. Graph. Compaction curve.

The determination of the dry unit weight using the Standard Proctor Compaction test was conducted by the research team testing each sample and recording the data. The water content in each trial was increased by 3 percent in order to find the optimum moisture content. The raw data for determination of dry unit weight is included in the Appendix A.

Permeability

To characterize how well water flows through soil, the standard permeability test measures the coefficient of permeability or a k-value. Because the soil is categorized as sand, a constant head permeability apparatus was utilized. The objective of the constant head permeability test is to determine the coefficient of permeability, which helps in solving issues related to: (1) stability of earthen dams, (2) embankments of canal banks, (3) seepage in earthen dams, and (4) settlement issues.

For each sample location, three permeability tests were carried out and an average k value was calculated. The results indicate that the dredge soil of S1 (k = 0.02) is more permeable than that of S2 (k = 0.01). The variability within three replicates is found very low from the standard deviation values. All k-values are visualized in figure 6.

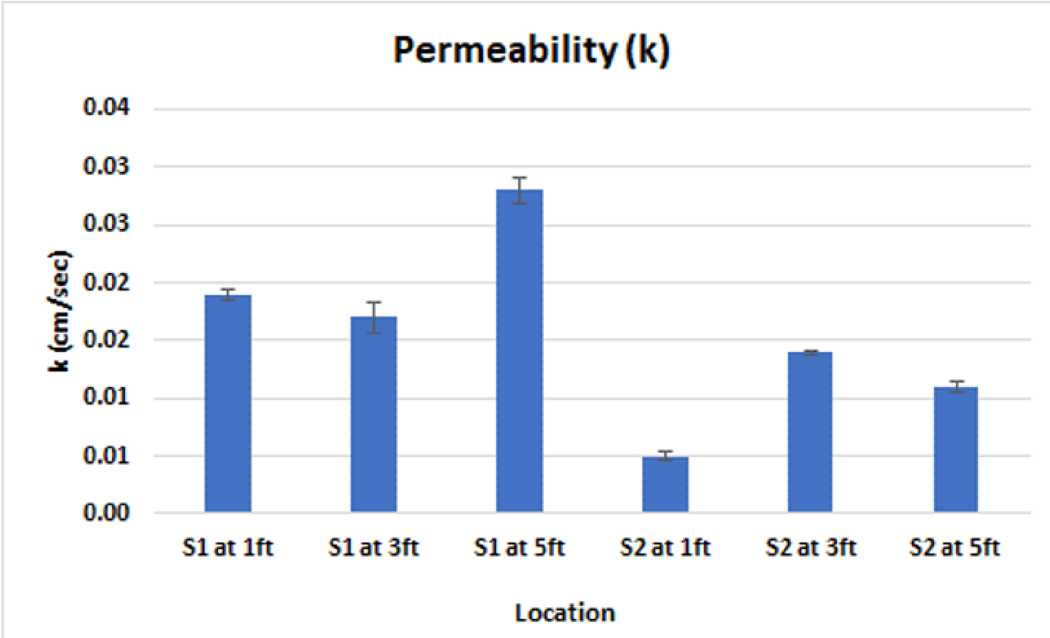


Figure 6. Graph. Permeability of dredged material.

CHAPTER 5. DEVELOPING GEOSPATIALLY ENABLED LANDFILL PROPERTY MAPS

As a first step in identifying suitable areas for a testing site in landfill sies, property maps that could be available electronically and/or geospatially enabled format were developed. An electronic property map would have information pertaining to configurations, clearance and parcel area. Having electronically property maps would likely facilitate analyses of potential sites for dredge material usage within the landfill. Electronically accessible landfill property maps that could be incorporated into a geographical information system (GIS) system would facilitate the development of a site suitability model for feedstock establishment as was observed in this study. High resolution imagery was used in this study to facilitate the development of a geospatially enabled property map for selected

SELECTING SUITABLE SITES FOR DREDGE MATERIAL SITES

One of the main objectives of the project was to evaluate the effects of dredge materials within different landfill setups. However, before establishing dredge materials in the landfill, there was a need to develop a tool or method that can be used to select optimum sites for establishment. In addition, it was necessary to collect soil information from different areas and incorporate that information into the proposed tool to be developed. To account for the heterogenous nature of soils distributed across the highway landfills, a GIS model would be developed to facilitate site evaluations for feedstock establishment. Using ArcGIS modelbuilder, the parameters described in section 3.2.2 were incorporated into a series of geoprocessing (GIS operation used to manipulate data) steps to develop a site selection model used in this study. The resulting tool or model was used in this study to select the sites where the pilot study was performed. For this study, the results of the model represented a spatial delineation of suitable landfill along I-16 to establish the sites selected for the pilot study. The selected site was located at the Dean Forest Landfill in Savannah, Georgia.

Conducting a Baseline Survey of the Landfill Sites

Measuring the soil quality of landfill land previously affected by earthwork was necessary to properly evaluate the success of the study. Due to the selected sites for the pilot study being located on these lands there was an interest in establishing a baseline survey of the soil quality for the selected areas. The baseline survey was a preliminary assessment done through soil core collection and analyses to evaluate the initial status of the sites terms of soil quality to determine the initial conditions at all sampling sites in the landfill. Results from the baseline survey were also used to develop a GIS based model for the selection of suitable sites for establishment in landfill areas

Developing a Cost Analysis Method for Evaluating Feasibility for Biomass Production in the Landfill

The ultimate goal of the feasibility assessment was to provide the GDOT with information pertaining to expected costs and break-even payback period associated with establishing, maintaining, and delivering high-value substitution of dredged material to landfills for daily cover and capping. As a result, a cost analysis associated with this GDOT was produced.

Assessing Impacts of Dredge Material Pilot Study

This study assesses the management, environmental and economic impacts of using the dredged material for the purpose of landfill management. Environmental assessments were done to determine if excessive amount of organic matter and nutrients were transported downstream as a result of the tilling activities initially done to prepare the sites for dredged material establishment. The environmental assessments were done to provide GDOT with information pertaining to expected costs and break-even payback period associated with establishing, maintaining and delivering sanitary conditions to end-users that would be able to process the dredged products as source for landfill maintenance. Additional environmental effects like carbon cycling were also analyzed as part of the study.

Observed Vegetative Species During Observation

Of particular interest to the study was the significant vegetation observed on the landfill site. These included but were not limited to:

Big Bluestem

Table 7. Big Bluestem description/attributes.

Big Bluestem  Source: roundstoneseed.com	Family: Poaceae Distribution: Throughout U.S including GA Habitat: Found in open woods, prairies, meadows and roadsides Higher Heating Value: 18.14 Mj/kg Ethanol Recovery: 122 L/ac SOC Storage: 32 Mg C ha−1 after 6 years of establishment (0-10 cm)

Woodland Sunflower

Woodland sunflower is a non-invasive plant that is capable of producing thermal energy by combustion. Previous studies have suggested that woody residue from plants could be used in a bioenergy market**.** Furthermore, woodland sunflowers are found in open fields with partial shade or full sun which is reminiscent of landfill areas. The presence of woodland sunflower on the landfill could be beneficial from a biodiversity perspective as woodland sunflowers tend to attract a range of insects, such as bees, wasps, flies and butterflies.

Table 8. Woodland sunflower description/attributes.

Woodland Sunflower  Source: illinoiswildflowers.info	Family: Asteraceae Habitat: Dry woods and openings Height: 2-6 ft Environmental Notes: Nectar serves as food for 'Silvery Checkerspot butterfly' and 'Bordered Parch butterfly'. Birds and small mammals eat the seeds. Bioenergy: Energy generation through combustible wood material

Developing Geospatially Enabled Property Maps

As a first step in identifying suitable areas for site establishment for landfills in Georgia, property maps that could be available electronically and/or geospatially enabled format were developed for this section of using ArcGIS. An electronic property map would display information pertaining to landfill configurations, clearance, parcel area, and general features related to the landfills. In addition, the electronically available property maps would facilitate analyses of potential sites for biomass production within the Dean Forest Landfill based in Savannah, GA. The process behind developing a map involved accessing a series of open-source datasets containing imagery from the National Agriculture Imagery Program (NAIP). The NAIP program is administered by the U.S. Department of Agriculture (USDA) Farm Service Agency (FSA). NAIP imagery is available for distribution within 60 days of the end of a flying season and is intended to provide current information of agricultural conditions such as vegetation canopy analysis, hydrology, land-use change, and green space in support of USDA farm programs. For USDA-FSA, the 1 m and ½ m GSD product provides an ortho image base for Common Land Unit boundaries and other data sets.

The 1 m and ½ m NAIP imagery is generally acquired in projects covering full states in cooperation with state government and other federal agencies that use the imagery for a variety of purposes including land use planning and natural resource assessment.

Mowable Area for Pilot Study

Following results from the preliminary meetings, it was decided that the pilot study should be established in the Dean Forest Landfill. To facilitate continuous access to the sampling sites, site selection was chosen based on access to the site and proximity to Georgia Southern University. In. Bulloch, Candler, and Emanuel counties were selected for secondary sites.

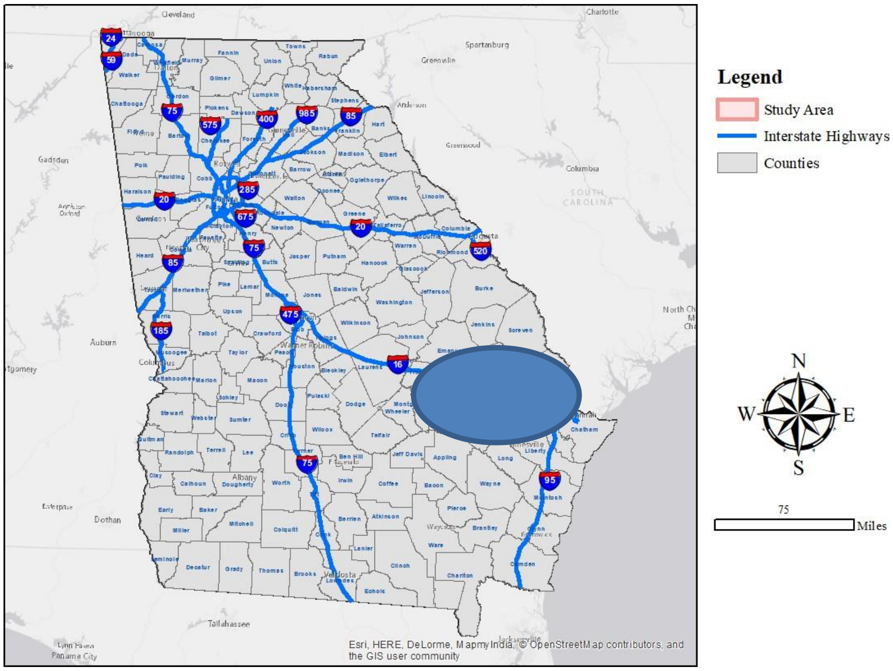


Figure 7. Map. Georgia's interstate highway system with study area.

High-resolution imagery of fenced landfills and tree lines separating government from private property was incorporated into ArcGIS to determine boundaries throughout the study area. The highway imagery was derived from a series of datasets provided by USDA's FSA 2015 Orthoimagery. These downloaded images of land boundaries were used to digitize the available areas in ArcGIS 10.4 (figure 8). The parcel size throughout this section of I-16 was derived from the digitized imagery within ArcGIS 10.4. The major steps for obtaining the electronic property map for this section of I-16 were downloading the Orthoimagery datasets, projecting them to North American Datum of 1983 (NAD 83), and digitizing in ArcGIS to produce an electronically available landfill property map for this section.

The property map would be made available to GDOT administrators to incorporate for future studies on the site.

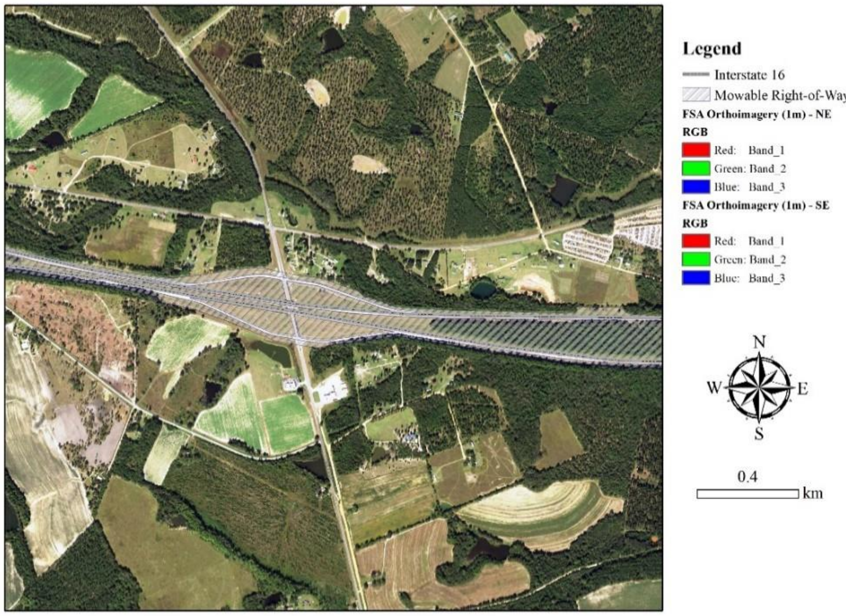
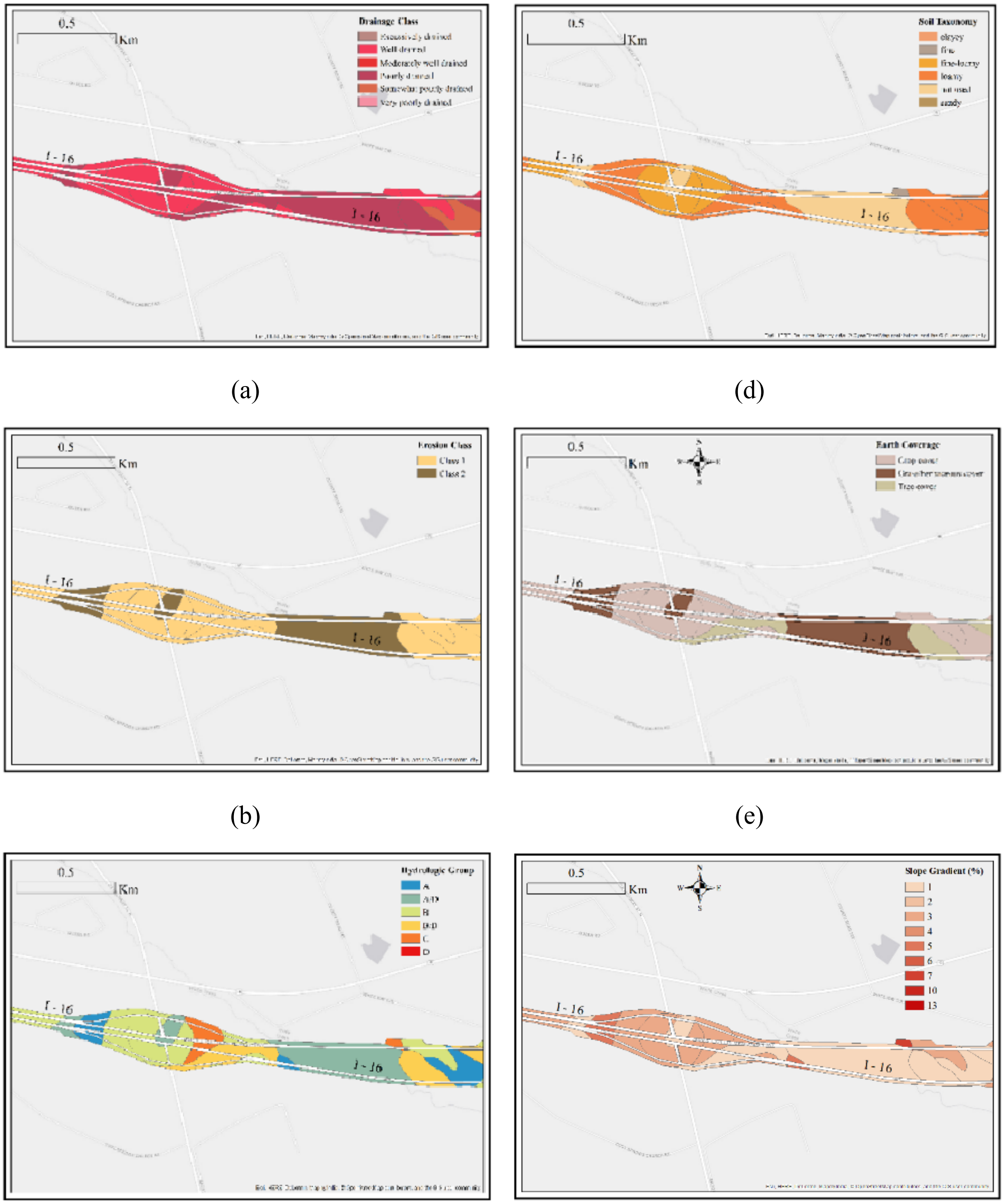


Figure 8. Image. A high-resolution aerial image of site with cross-hatched polygons superimposed on mowable right-of-way.

Combining the electronic property map with the Soil Survey Geographic (SSURGO) database allowed for delineation of the soil types and topography along the highway sites. SSURGO is a readily available database designed by the USDA and the Natural Resources Conservation Service (NRCS) for natural resource planning and management of farms, ranches, townships, and counties. The SSURGO database is comprised of geo-referenced spatial polygon data collected through intensive soil surveys over a given area (soil map unit [SMU). These SMUs function as the basic geographic unit of the SSURGO and delineate the extent of different soils in the digitized soil map at a scale of 1:24,000 (USDA-NRCS 2017) resulting in high quality descriptions of soil, biological, climate, hydrology, and production properties of soils. Some of these properties that can be found in SSURGO include plasticity, taxonomy, flooding frequency, organic matter, bulk density, and pH level. A series of electronic maps were created that depict relevant landfilling conditions (parameters).

Subsequent steps involved performing a spatial intersection of the digitized sites and SSURGO data representing landfilling conditions (parameters) anticipated. This process would map areas based off the following parameters: drainage, erosion, hydrologic group, soil taxonomy, earth coverage, and slope (figure 9). These parameters were selected based on their expected effects on feedstock productivity and were incorporated into a GIS to electronically delineate suitable feedstock-specific areas of production for this section. The mapped parameters and their associated SSURGO attribute field names are described in the section below.



(a) (d)

(b) (e)

(c) (f)

Figure 9. Map. Each parameter incorporated for geoprocessing site selection model: (a) Drainage Class; (b) Erosion Class; (c) Hydrologic Group; (d) Soil Taxonomy; (e) Earth Coverage; (f) Slope Gradient (percentage).

Parameter – Drainage Class

Figure 9(a) is a map of Drainage Class for this section of landfill. This parameter can be categorized by the relative rate and length of periods when soil is absent of saturation in seven classes ranging from poorly to excessively drained. Drainage class was incorporated into the site selection model due to it being associated with natural drainage conditions of the soil and refers to the frequency and duration of wet periods. Identifying areas with minimal periods of wetness would provide areas that are not hazardous. In addition, areas with wet soils can reduce field access and cause rutting.

Parameter – Erosion Class

Figure 9(b) is a map of Erosion Class for this section. Soil erosion is the detachment and movement of soil material. The process may be natural or accelerated by human activity. Erosion class was incorporated into the site selection model due to the site being exposed to construction activities which can cause the removal of original soil. Over time erosion can cause the removal of topsoil containing important nutrient compositions such as organic matter and organic carbon. This parameter can be categorized by classes of soil loss in the top soil layers in five classes: None (area of soil deposition); Class 1 (1 to 25 percent of original topsoil has been removed by erosion); Class 2 (1 to 25 percent of the original topsoil has been removed by erosion); Class 3 (75 to 99 percent of the original topsoil has been removed by erosion); Class 4 (all of the original topsoil has been removed by erosion). SSURGO attribute field name: erocl

Parameter – Hydrologic Group

Figure 9(c) is a map of Hydrologic Groups for the soils along this section. This parameter can be categorized in seven classes that depict the rate that the soil absorbs rainfall: Group A (soils comprised of deep, well drained sands or gravelly sands with high filtration and low runoff rates); Group B (soils comprised of deep well drained soils with a moderately fine to moderately coarse texture and a moderate rate of infiltration and runoff); Group C (soils with a layer that impedes the downward movement of water or fine textured soils and a slow rate of infiltration); Group D (soils with a very slow infiltration rate and high runoff potential); Group A/D (soils naturally have a very slow infiltration rate due to a high water table but will have high infiltration and low runoff rates if drained); Group B/D (soils have a very slow infiltration rate due to a high water table but will have a moderate rate of infiltration and runoff if drained); Group C/D (soils naturally have a very slow infiltration rate due to a high water table but will have a slow rate of infiltration if drained). Hydrologic Group was incorporated into the site selection model to grade soils in the LANDFILL under wet conditions. This is important to plant development when considering that establishing plants require access to water in the soils. However, too much water is not ideal as this can potentially landfill out newly establishing plants in the LANDFILL. SSURGO attribute field name: hydgrp

Parameter – Soil Taxonomy

Figure 9(d) is a map of Soil Taxonomy for this section of landfill. This parameter can be categorized by particle-size classes used as family differentiae. Particle-size refers to grain-size distribution of the whole soil and is not the soil texture. Knowing soil texture is essential for estimating the available water-holding capacity (AWHC) and cation exchange capacity (CEC) of a soil. The CEC is directly related to the amount of clay and organic matter present in the soil—the higher the clay or organic matter content, the higher the CEC The CEC is the capacity of a soil to hold positive ions (referred to as bases or cations). A soil with a high CEC holds a much greater number of cations, such as calcium and magnesium, than a soil with low CEC. Figure 5.11 shows some typical available water-holding capacities for various soil textures. SSURGO attribute field name: taxpartsize

Parameter – Earth Coverage

Figure 9€ is a map of Earth Coverage for this section. This parameter can be categorized by different descriptions of ground cover based on a set of vegetal and non-vegetal classes. Descriptions range from herbaceous plants such as forbs and graminoids to nonherbaceous plants. Determining which areas long the section contain low-lying herbaceous plants helps with identifying soils with higher levels of organic matter. Most herbaceous plants contribute to organic matter concentrations in nearby soils due to decaying plant material decomposing into the soils. SSURGO attribute field name: earthcovkind2

Parameter – Slope Gradient

Figure 9(f) is a map of Slope Gradient for this section. This parameter can be categorized by elevation differences between two points which is expressed as a percentage of the distance between those points. This SSURGO database attribute column displays the slope gradient of the dominant component of the map unit based on composition percentage. This parameter was included into the site selection process due to its relevance with accessibility for farm equipment. In addition, areas with steeper slopes may present erosion and excess runoff hazards to new plants. SSURGO attribute field name: slopegraddcp

SELECTING SUITABLE SITES USING ARCGIS

The selected site parameters were incorporated into the site selection. In addition, it would provide information on dredged material adaptability to different conditions. As a result, ArcGIS was used to facilitate the landfill site selection process for the pilot study by developing an automated workflow of geoprocessing tools (operations) for the site selection. Geoprocessing tools perform analysis, data management, editing, and other operations on an input dataset and usually produce a new output dataset. Many GIS workflows involve running several tools in a particular order. The output of one tool becomes the input to another. The Modelbuilder application embedded within ArcGIS contains a visual programming language for building geoprocessing workflows. Geoprocessing models allowed for expediting and documenting our spatial analysis and data management processes.

Using ArcGIS Modelbuilder, the plant parameters described in section 3.2.2 were incorporated into a series of geoprocessing (GIS operation used to manipulate data) steps to develop a site selection model for each feedstock used in this study. The geoprocessing operations used for the site selection model are illustrated in sections 3.4.1 and 3.4.2. The resulting product was a GIS-based model that can easily be used to generate a spatial representation of areas that are suitable for the establishment of future sites. In addition, the model is presented as a site selection service that can be easily reused or repurposed with different criteria tailored toward specific applications regarding future projects established with landfills. Depending on the inputs provided by the user, the geoprocessing model can also be applied to alternative applications of interest to GDOT such as the "wildflower program" as the site suitability methodology behind the model would be the same.

Preliminary Data Collection for Geoprocessing Model

Input data sets (road, hydrology and counties) for this study were collected from a host of publicly accessible open source data. Major road data were obtained from the U.S. Census

Bureau, Geography Division as was incorporated into the site selection model to provide context on the generated map. Surface waters such as lakes and ponds were obtained from the National Hydrography Dataset (USDA, NRCS) and were incorporated into ArcGIS to illustrate locations of nearby water surfaces and to facilitate the creation of a safe zone (buffer) around nearby wetlands to separate them from potential areas of feedstock production. County boundaries used to delineate the study area was obtained through the U.S. Census Bureau, Geography Division. Information pertaining to soil parameters was collected by accessing the SSURGO database and was used to delineate various soil types and characteristics on the site. Data pertaining to soil characteristics such as area of adaption and suitable soils were obtained from the USEPA and DNR fact sheets.

Geoprocessing Site Selection Model – Part 1

The selection of suitable geographic locations for bioenergy crops can be difficult due to the various environmental factors involved in the process, such as, topographic, hydrologic, and soil conditions. A geographic information systems is a robust geographic engine that is powerful in performing spatial analysis and modeling. Geoprocessing models were employed using a GIS to identify representative sampling zones to study the impacts of replacing roadside vegetation with alternative crops that are used for bioenergy production. Soil and hydrologic parameters, variable throughout the study area, were incorporated in the GIS Modelbuilder application to select the best areas where sites could be established.

The site selection model allows for the depiction of different landfilling conditions set by the user to facilitate decision-making for site establishment. The end-result of the site selection model is to map areas of land that comply with criteria developed for different feedstocks. The data sets needed for the site selection model was incorporated into a model using the Modelbuilder application within ArcGIS 10.4. The Modelbuilder application embedded within ArcGIS contains a visual programming language for building geoprocessing workflows. Using ArcGIS Modelbuilder, the data sets described in section 3.4.1 and site parameters described in section 3.2.2 were incorporated into site selection model. Each input for each geoprocessing operation within the site selection model is highlighted in blue, the geoprocessing operations are shown in yellow, and the generated outputs from each geoprocessing operation is highlighted in green (figure 10). The “Make Feature Layer” operation (yellow) generated a feature layer (green) from the SSURGO database (blue) for each parameter of interest. The generated feature layer from this operation is created through a SSURGO database query SSURGO for attributes corresponding to the parameters of interest.

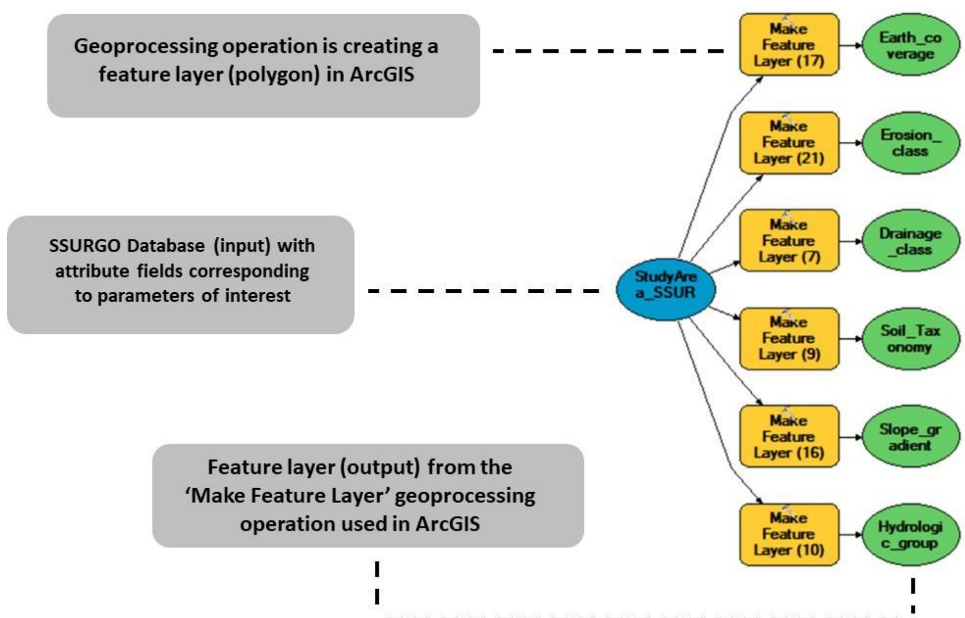


Figure 10. Diagram. Geoprocessing site model performing spatial queries on selected SSURGO attributes (i.e., site variables) within the Modelbuilder application in ArcGIS 10.4.

Geoprocessing Site Selection Model – Part 2

The next geoprocessing operation used in the model was an “Intersect” operation which computed a geometric intersection of each feature layer generated by the previous operation. The “Buffer” geoprocessing operation was used next to delineate a 500-foot clearance from wetlands nearby I-16. The polygon representing a clearance of 500 ft around all ponds and lakes generated by the buffer was combined with the digitized areas for the “Erase” operation.

This geoprocessing step omitted areas of L that were located within the wetland buffer. Finally, a “Clip” operation was utilized to ensure that the delineated suitable sites for the energy crop is within the study area.

SELECTING SITES FOR PILOT STUDY

Based on the input data sets incorporated into the site selection model end-result of the model was a map of landfill with highlighted areas that represent suitable sites for bioenergy feedstocks. As a result, three sites were selected for the pilot study with each site spaced approximately 10 miles apart (Figure 6a and b). The selected sites would be prepared as establishment sites for assessing the use if dredged materials in landfills in southeast Georgia. There was an interest in evaluating the effects of establishing sites within different configurations. The selected sites were identified as the best zones to transplant the material being used for the study due to the geoprocessing model outputs. Each site selected had soil properties that changed when moved from east to west on site. The fact that these sites represented different landfill configurations guaranteed that the sites were representative of west- and eastbound landfill.

. As part of a preliminary site assessment, each site was visited with landfill personnel to verify that there was enough space and initial conditions to establish the pilot study. The geographic coordinates for each site were obtained using a Geographic Positioning System (Leica GS14).

CONDUCTING BASELINE SURVEY OF SITES

Performing an assessment of soils was crucial to determine the precise location of the landfill site. Measuring the soil quality of land previously affected by refuse was critical because of the nature of the facility. Thus, it necessary to properly evaluate the success of the transportation study. Soil quality can be deduced by changing the topsoil with soil types or aggregates containing low organic matter content, by soil compaction, which diminishes soil volume and increasing soil density, which directly affect water and oxygen penetration and by changing soil slopes.

These earth movement activities take place near the natural (original) grounds that are adjacent to constructed cut and fill slopes that support the highway. Conversely, the natural grounds within the landfill to represent the terrain that existed prior to disturbance and/or road construction. Because the selected sites for the pilot study were positioned on these natural grounds there was an interest in establishing a baseline evaluation of the soil quality for the selected areas.

Each site evaluation was incorporated into a baseline survey conducted prior to the monitoring and evaluation of the bioenergy feedstocks to help determine the impact on soil quality from dredged material.

Soil Quality Indicators

The site evaluation for the demonstration was established using a series of common soil quality indicators. These indicators were chosen based on the literature review preformed in which publications related to the importance of soil quality parameters such as soil organic carbon, pH, phosphorus, bulk density, potassium, soil texture, soil N, magnesium, and calcium and their effects on plant establishment were used. The Dean Forest Landfill provided lab services for this part of the study due to their ongoing sampling program. The use of the following

Soil Organic Carbon

Soil organic carbon (SOC) provides a viable energy source for healthy soil microbial activity. The presence of SOC in soils stabilizes and helps bind soil particles, which can help minimize adverse effects from erosion hazards. Plant health is influenced by the level of SOC in soils as the water holding capacity of a soil medium can be improved with increasing levels of SOC. In addition, SOC presence in soils increases storage and nutrient availability (e.g., nitrogen, phosphorus, and sulfur) to developing plants and soil organisms that are beneficial to soil health.

pH

pH has an effect on solubility and availability of plant nutrients and soil organic matter decomposition. Studies have shown that pH is able to influence nutrient availability to plants due to its influence on a soil's cation exchange capacity (McCauley, Jones, and Jacobsen 2009). A soil's ability to hold and supply nutrients is related to its cation and anion exchange capacities, thus a high CEC indicates that a soil can capture additional cations (i.e., calcium and potassium) more efficiently.

Phosphorus

Phosphorus is an essential macronutrient for life in general. It plays a role in energy transfer in plant cells and is required for plant in relatively large quantities as its presence helps with flowering and root development (Gliessman 2006).

Bulk Density

Bulk density in soils serves as an indicator of soil porosity and compaction. A higher bulk density can stunt root and limit root penetration which can result in limited water and nutrient uptake. Bulk density can be altered by crop and land management practices (i.e., cultivation) that affect soil cover, organic matter, soil structure, and porosity (NRCS 2008).

Potassium

Studies have shown that potassium is acquired by plants in greater quantity than all other mineral elements apart from nitrogen and calcium. Potassium serves several functions ranging from cell division and to form starch and sugar within the plant.

Soil Texture

Soils are composed of minerals of varying sizes, ranging from clay (smallest) to stone (largest). The mineral element supports plant health, and its presence minimizes disease susceptibility (Gliessman 2006). Each mineral particle in a soil sample can be grouped into six categories depending on its size: clay < silt< sand< gravel< cobble < stone. The fine soil fraction is composed of a combination of sand, silt, and clay size particles. The proportion of these size groups in a soil is called the soil texture. Soil texture is an important function of soil water storage because the unique arrangement of pores created in each texture class holds differing quantities of moisture (Steinfeld et al. 2007).

Soil N

Nitrogen is an important component of proteins and plays an integral role in enzymatic activity. Studies have highlighted that in most terrestrial ecosystems, plant development is N-limited. As a result, for most herbaceous species, N resorption efficiency will be used to help determine nutrient use efficiency (NUE) of plants.

CHAPTER 6. PROCEDURES FOR PILOT STUDY

ESTABLISHING SITES FOR PILOT STUDY

At this stage of the pilot study a second meeting was scheduled with GDOT to review the updated pilot study and define the preliminary tasks to be completed before starting the second phase of the project. Landfill operators met with GDOT and the Georgia Southern University research team. Topics addressed during the meeting included: selected sites and soil composition types to be deposited in landfill areas, safety priorities in areas, pilot study site location approval, assistance during the site preparation, and other related aspects.

Site Preparation

Site preparation activities included performing a visual inspection of the sites chosen prior to implementing the pilot study. These meetings culminated with the Dean Forest Landfill preparing the selected sites and assisting with soil sampling for the materials described in earlier sections. The soil was tilled at each of the selected sites. Climate data at each site (i.e., temperature and precipitation) was obtained by matching each site's coordinates with climate data (Monthly Summaries) recorded at weather stations within the Georgia Automated Environmental Monitoring Network. Within ArcGIS the coordinates associated with the surrounding weather stations were used to generate precipitation and temperature surfaces across the study area. Pictures of the sites are included in Appendix A.

Using the coordinates from the selected sites, mean precipitation and temperature data from the weather (raster) surface were summarized within each site using zonal statistics in ArcGIS. The zonal statistics tool summarizes the values of a raster within a zone (area) of another spatial dataset (raster or polygon). This process would be used to obtain monthly climate data throughout the upcoming seasons.

Evaluating the year-to-year variability in dredged material under normal weather and landfill conditions was important to the study as this information would aid decision-making regarding the feasibility of using the dredged material in landfill over long-term periods (>5 years). As a result, all observations in this study were analyzed for significant differences in their interactions over two cycles spanning 1999–2021 using a repeated measured split-plot arrangement. The term "split plot" derives from agriculture, where fields may be split into plots and subplots. In agronomic experiments using split plot designs, whole plot experimental units can be individual feedstock groups. Since the LANDFILL areas were large enough, they were used as blocks for two levels of feedstock treatments. Each field is composed of six whole plots, each comprised with up to three subplots. Feedstocks are assigned to whole plots using randomized complete block design (RCBD) (blocked by field) while fertilizer (FR) and installation method (IM) are assigned to subplots using RCBD (blocked by feedstock). Split plot designs were used for the pilot study because it is allowed for the administering of different treatments simultaneously. This type of design is also useful for cases when the GDOT wishes to expand the scope of the experiment: an additional group (factor) can be added at the whole plot level without sacrificing sensitivity in the subplot factor.

. The identified plants were incorporated into Simpson's diversity index (SDI) to calculate a diversity score for vegetation communities present at each right-of-way site. It is based on both the number of different species in the community and the number of individual plants present for each of those species. The higher the score, the more diverse the community is considered to be. The SDI was determined with the equation below:

$$\text{Simpson Diversity Index (D)} = 1 - \frac{\Sigma n(n-1)}{NN(NN-1)} \qquad (3)$$

Where

Σ = sum of (total)

n is the number of individuals of each different species

N is the total number of individuals of all the species.

Production Budget Assumptions

The economic model used for this study is based on unit production budgets associated with the establishment, harvest, and transportation of perennial feedstocks produced for bioenergy purposes. Machinery prices, schedules, and baseline inputs were provided by crop budgets from The University of Georgia Extension (Smith 2017). Machinery associated with capital recovery, maintenance, and fuel prices associated with typical farm situations were also referenced by the University of Georgia Extension (Smith 2017). Assumptions common to the establishment and harvest budgets were the use of a 120-hp tractor to power farm implements, labor rate of $8.5/hr, and a nominal interest rate of 8 percent. The assumptions used for the production budgets can be changed to reflect different production scenarios encountered in feedstock development programs. The model is capable of adjusting to these changes and producing accurate results pertaining to the expected costs and profits associated with producing biomass feedstocks under varying conditions.

Model Inputs and Definitions

Based on the inputs and outside assumptions associated with each unit production budget (e.g., establishment, harvest, storage, and transportation) an economic model was developed from this study **(**figure 11**)**. The production scenarios illustrated in the model were developed to show the different costs and revenues involved in landfilling SW and BB. A spreadsheet using these scenarios of costs and revenues and breakeven payback periods was developed at Georgia Southern University to fit specific production conditions.

Producers can change the quantity of inputs, respective prices, and assumptions, allowing for costs and revenue adaptation for various scenarios.

	Financial Aspects of Landfill Operations	Unit
Landfill characteristics	Total Landfill Volume (CY)	CY
	Landfill's footprint (AC)	AC
	Final surface grades needing cap (AC)	AC
	Bottom Area of landfill - Leachate System (AC)	AC
	Total acres of landfill construction (AC)	AC
Local Waste Disposal	Total waste disposal market ($ per year)	$ per year
	Average tipping fee ($ per ton)	$ per ton
	Landfill Annual disposal rate (tons per year)	tons per year
Construction & Operations	Projected operational lifetime (years)	years
	Support facilities & Ancillary Structures ($)	$
	Landfill's Cost of Construction	$ per Lined Acre
	Surveying	$ per acre
Landfill Closure Costs	1st Layer: Gas management layer ($ per CY)	$ per CY
	2nd layer: Compacted Clay ($ per CY)	$ per CY
	3rd layer: Geosynthetic component ($ per sqft.)	$ per sq ft
	Smooth geomembrane	$ per sq ft
	Textured geomembrane	$ per sq ft
	Geocomposite drainge layer ($ per sqft.)	$ per sq ft
	Cover soil layer ($ per CY)	$ per CY
	Vegetation (seeding, mulch and fertilizers) ($ per acre)	$ per acre

Figure 11. Table. Economic model inputs and outputs.

Calculation Metrics for Model

The additional formulas for economic feasibility model shown in figure 11 are outlined above. The formulas are developed to illustrate cost/profit per acre and are presented under their respective production budget:

$$\text{Machinery Fuel} = (\text{Fuel Gallon/acre}) \times \text{Price of Fuel per Gallon} \tag{1}$$

$$\text{Machinery Labor} = 1.25 \times [\text{Machinery Throughput Rate (hrs per acre)}] \tag{2}$$

$$\text{Staging} = \text{Yield (tons)} * 2000 \text{ (lbs)}/ \text{ lbs per Bailing Method (Rectangular or Round)} \tag{3}$$

Sensitivity Analysis

A sensitivity analysis was performed on the breakeven even payback period for a 10-yr contract. The breakeven even payback associated with three scenarios to establish the operation would be the baseline for the sensitivity analysis as this level of input represents a realistic amount operators can expect.

CHAPTER 7. FINDINGS FROM PRELIMINARY STUDY

DEVELOPING GEOSPATIALLY ENABLED PROPERTY MAPS

The results of digitizing the site throughout the study area revealed the site spans approximately 5 miles.

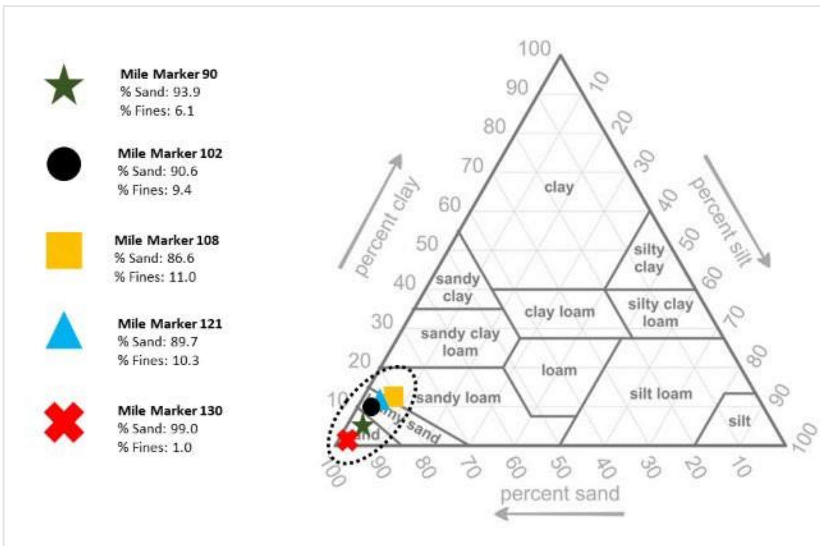


Figure 12. Diagram. Soil texture classifications for right-of-way sites.

The plot shows the soil texture classification associated with the five right-of-way sites in relation to the soil textural triangle defining the 12 textural classes based on the percentage of sand, silt, and clay in a soil sample (figure 12). When assessing the location of the five right-of-way sites within the soil textural triangle the soil at mile markers 90 and 130 is classified as sand, the soil at MM108 and 121 is classified as sandy loam and the soil at MM102 is classified as a loamy sand. When considering the soil textures dominating these sites (e.g., sandy loam, loamy sand, and sand) these soils are not able to hold much water due to the low surface area associated with sand particles.

Chronology of Site Observations Over Time

Soil Nutrient Composition

Nutrient concentrations were measured in parts per million (PPM) throughout the pilot study by analyzing soil samples collected at the onset of the pilot study. These initial soil samples were compared with additional samples analyzed at the first and second (last) harvest period. The results showed that biomass feedstocks established along the site had an impact on soil nutrient compositions over subsequent seasons. When comparing soil samples collected over the duration of the pilot study, it was observed that calcium (Ca), potassium (K), magnesium (Mg), manganese (Mn), phosphorus (P), and zinc (Zn) concentrations depleted over the annual period.

Vegetation Taxonomy

The vegetation taxonomy produced the identification of 55 roadside species along Bulloch, Candler, and Emanuel counties. The results show that Bahiagrass (*Paspalum notatum*) is the most prevalent roadside species while Partridge pea (*Chamaecrista fasciculata*), Petiteplant (*Lepuropetalon spathulatum*), Southern Dewberry (*Rubus trivialis*), Mexican petunia (*Ruellia simplex*), Muscadine (*Vitis rotundifolia Michx.*) and Carolina canarygrass (*Phalaris caroliniana*) represented the smallest percentages (<1%) of roadside vegetation (figure 13).

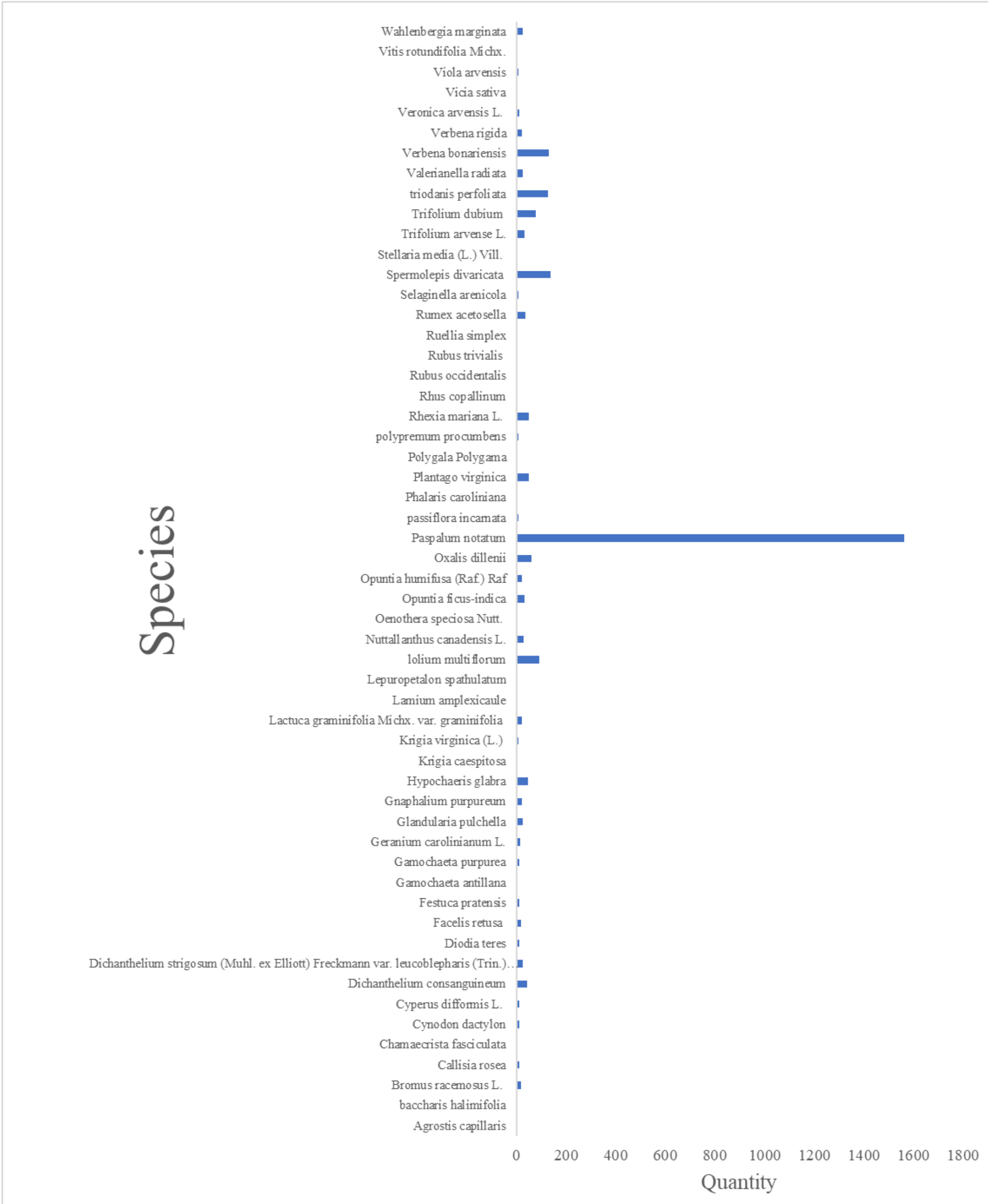


Figure 13. Bar Chart. Vegetation taxonomy of sites.

The most prevalent roadside vegetation throughout the study area are presented in table

Table 9. Top 10% most abundant vegetation: description and applications.

Paspalum notatum  By: Harry Rose	Family: Poaceae Genus: Paspalum Common Name: Bahiagrass Duration: Perennial Glandfillth Habit: Graminoid Applications: Erosion Control; Turf/Lawn in areas requiring low-maintenance and heavy foot traffic; Use for livestock as a source of hay Percentage of observed vegetation: 54.2 %
Spermolepis divaricata  By: Russ Kleinman & Richard Felger. Apr. 20, 2010	Family: Apiaceae Genus: Spermolepis Common Name: Roughfruit scaleseed Duration: Annual Glandfillth Habit: Forb/herb Applications: N/A Percentage of observed vegetation: 4.75 %
Verbena bonariensis  Source: http://flowers3.la.coocan.jp. July 2006	Family: Verbenaceae Genus: Verbena Common Name: Purpletop vervain Duration: Annual/Biennial/Perennisl Glandfillth Habit: Forb/herb Applications: N/A Percentage of observed vegetation: 4.47 %

Source: http://www.missouriplants.com. May 6, 2005

Family:

Campanulaceae

Genus: Triodanis

Common Name: Clasping venus's looking glass

Duration: Annual

Glandfillth Habit: Forb/herb

Applications: N/A

Percentage of observed vegetation: 4.33 %

Lolium multiflorum

By: Trevor James

Family:

Poaceae

Genus:

Lolium

Common Name: Italian Rye

Grass Duration:

Annual/Perennial Glandfillth

Habit: Graminoid

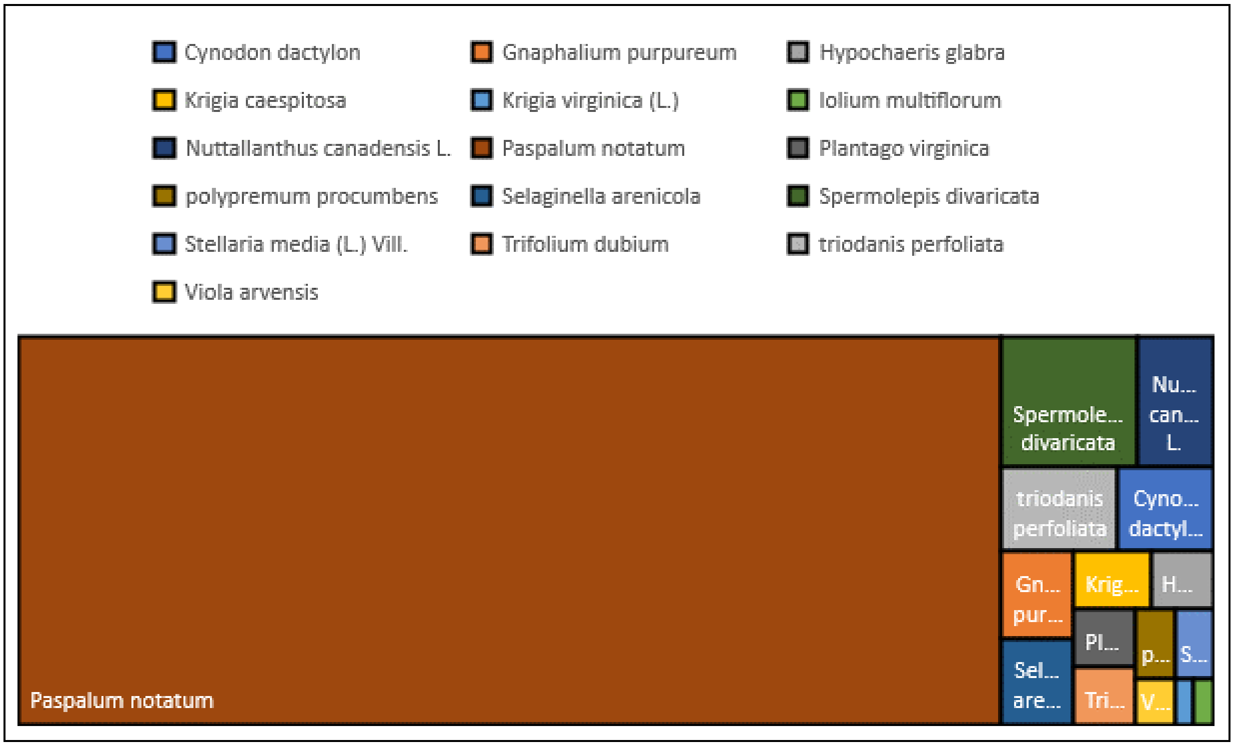
Applications: N/A

Percentage of observed vegetation: 3.19 %

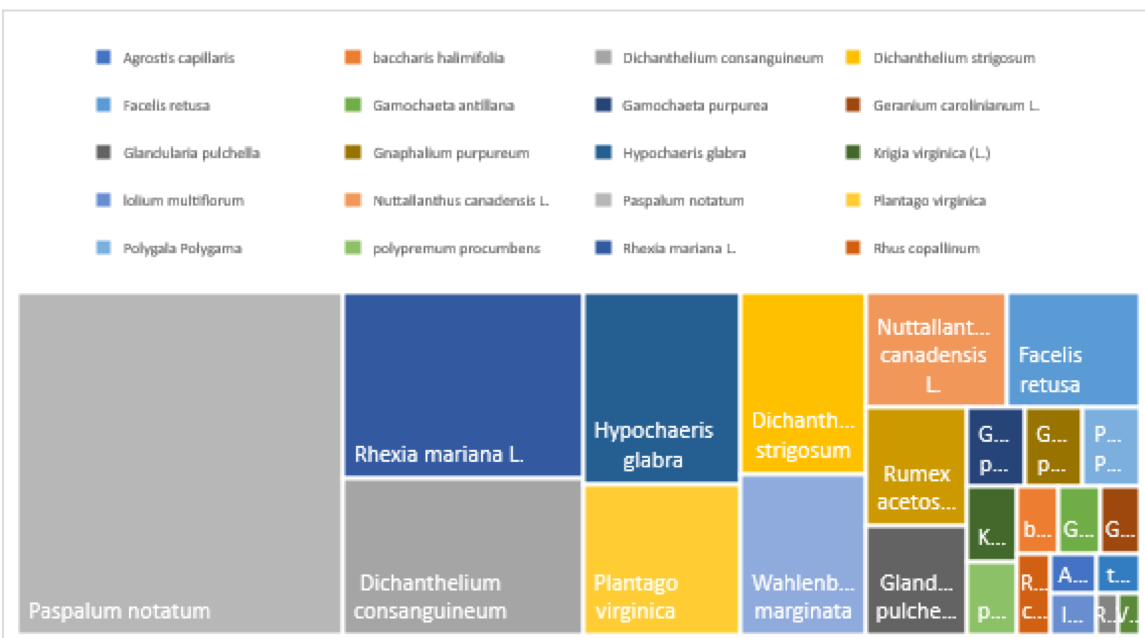
These results show that landfilling capping contains relatively diverse roadside plant communities as evident by the Simpson's diversity index score. Bahiagrass is the most prominent plant along the right-of-way of Bulloch, Candler, and Emanuel counties. While Bahiagrass is serviceable as a livestock feed that can provide forage for cattle, *Verbena bonariensis* (Purpletop vervain), *Triodanis perfoliate* (Clasping venus's looking glass), *Spermolepis divaricata* (Roughfruit scaleseed) and *Lolium multiflorum* (Italian Rye Grass) present no applications of interest and are considered common weeds.

Simpson's Diversity Index

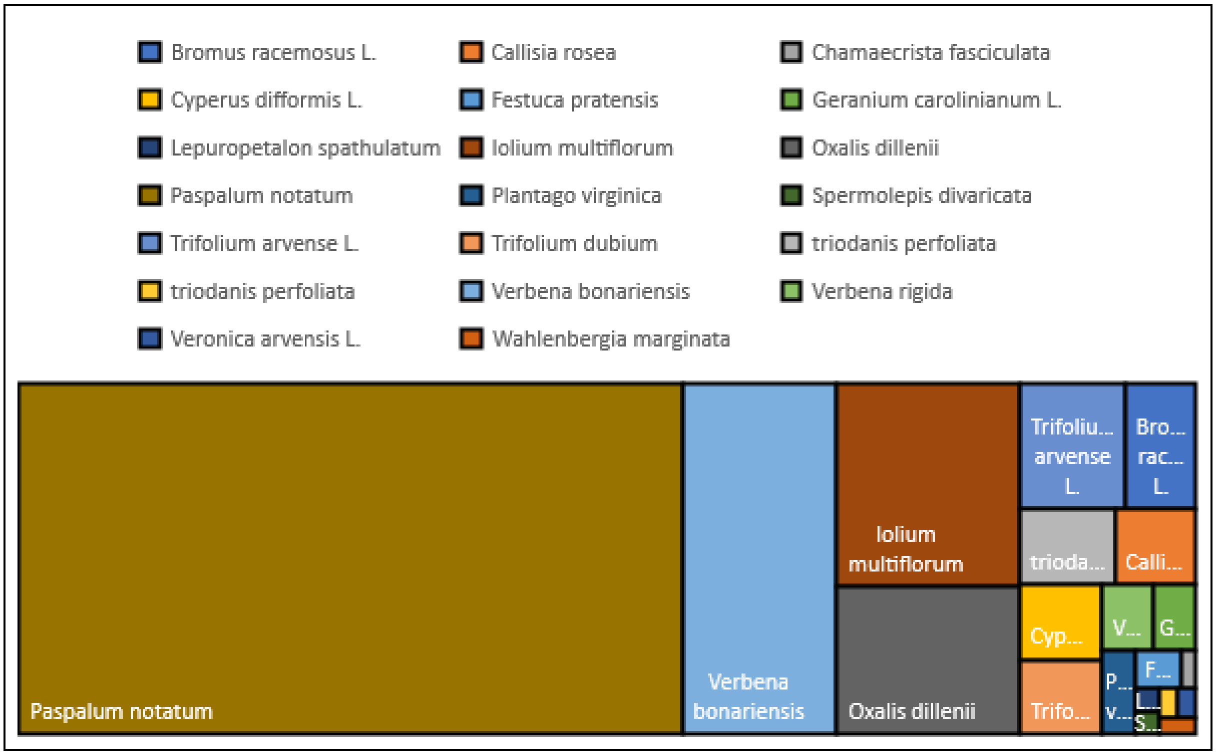
The Simpson's diversity indexes reported for each determined for each site were 0.32, 0.87, 0.65, 0.88, and 0.51 for MM90, 102, 108, 121, and 130, respectively. The SDIs suggest there is a small number of distinct species making up the plant community at the site. Alternatively, the higher diversity indexes reported for MM102 through 130 suggest the plant communities populating these locations are rich with diverse species. The observed diversity indexes for these sites could be attributed to factors such as soil type and configuration.


Cynodon dactylon
Gnaphalium purpureum
Hypochaeris glabra
Krigia caespitosa
Krigia virginica (L.)
lolium multiflorum
Nuttallanthus canadensis L.
Paspalum notatum
Plantago virginica
polypremum procumbens
Selaginella arenicola
Spermolepis divaricata
Stellaria media (L.) Vill.
Trifolium dubium
triodanis perfoliata
Viola arvensis
Paspalum notatum
Spermole... divaricata
Nu... can... L.
triodanis perfoliata
Cyno... dactyl...
Gn... pur...
Krig...
H...
Pl...
p...
S...
Sel... are...
Tri...
V...

(a)


Agrostis capillaris
baccharis halimifolia
Dichanthelium consanguineum
Dichanthelium strigosum
Facelis retusa
Gamochaeta antillana
Gamochaeta purpurea
Geranium carolinianum L.
Glandularia pulchella
Gnaphalium purpureum
Hypochaeris glabra
Krigia virginica (L.)
lolium multiflorum
Nuttallanthus canadensis L.
Paspalum notatum
Plantago virginica
Polygala Polygama
polypremum procumbens
Rhexia mariana L.
Rhus copallinum
Paspalum notatum
Rhexia mariana L.
Dichanthelium consanguineum
Hypochaeris glabra
Plantago virginica
Dichanth... strigosum
Wahlenb... marginata
Nuttallant... canadensis L.
Facelis retusa
Rumex acetos...
Gland... pulche...

(b)



Bromus racemosus L.
Callisia rosea
Chamaecrista fasciculata
Cyperus difformis L.
Festuca pratensis
Geranium carolinianum L.
Lepuropetalon spathulatum
lolium multiflorum
Oxalis dillenii
Paspalum notatum
Plantago virginica
Spermolepis divaricata
Trifolium arvense L.
Trifolium dubium
triodanis perfoliata
triodanis perfoliata
Verbena bonariensis
Verbena rigida
Veronica arvensis L.
Wahlenbergia marginata
Paspalum notatum
Verbena bonariensis
lolium multiflorum
Oxalis dillenii
Trifoliu... arvense L.
Bro... rac... L.
trioda...
Calli...
Cyp...
V...
G...
Trifo...
P... v...
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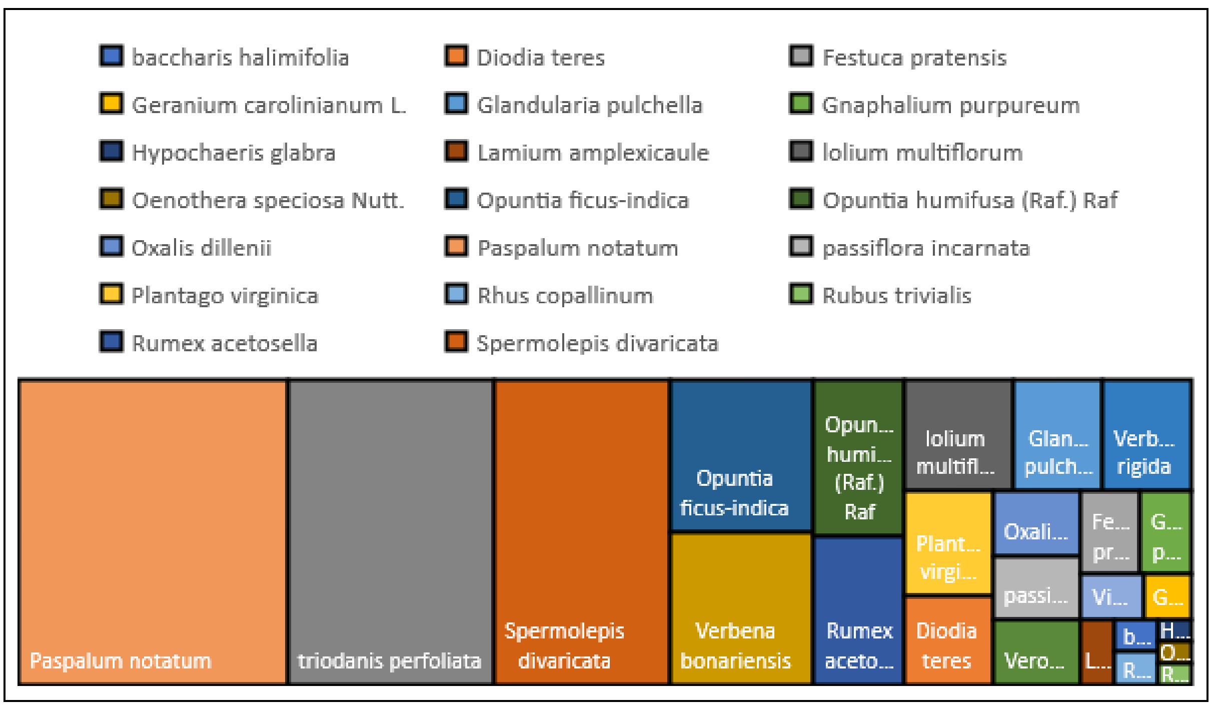
L...
S...

(c)



baccharis halimifolia
Diodia teres
Festuca pratensis
Geranium carolinianum L.
Glandularia pulchella
Gnaphalium purpureum
Hypochaeris glabra
Lamium amplexicaule
lolium multiflorum
Oenothera speciosa Nutt.
Opuntia ficus-indica
Opuntia humifusa (Raf.) Raf
Oxalis dillenii
Paspalum notatum
passiflora incarnata
Plantago virginica
Rhus copallinum
Rubus trivialis
Rumex acetosella
Spermolepis divaricata
Paspalum notatum
triodanis perfoliata
Spermolepis divaricata
Opuntia ficus-indica
Verbena bonariensis
Opun... humi... (Raf.) Raf
Rumex aceto...
lolium multifl...
Glan... pulch...
Verb... rigida
Plant... virgi...
Oxali...
Fe... pr...
G... p...
passi...
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Diodia teres
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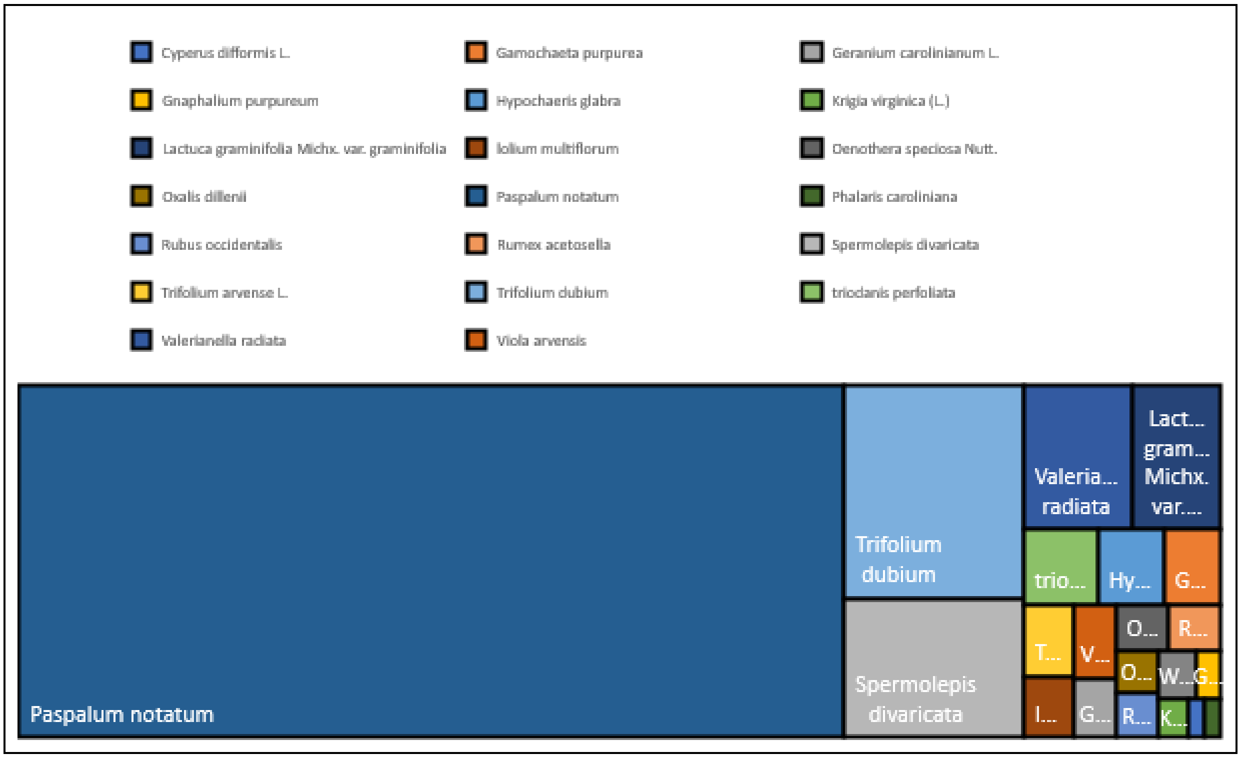
(d)



(e)

Figure 14. Treemaps. Distribution of plant communities present at sites.

Potential of Vegetative Output for Biomass

The treemaps presented in figure 14 illustrate the distribution of plant communities along the landfill sites. Most of the identified vegetation along the sites contain no biomass potential as the specimens collected for this taxonomy were comprised of weedy vegetation. There were some notable specimens identified in the sites taxonomy that may present value to the sites if properly managed. Partridge pea (*Chamaecrista fasciculata*) found at MM108 has been used as a root medicine to prevent fatigue from sports players. Purple passionflower (*Passiflora incarnata L.*), which populated MM121 has ethnobotany applications as Native Americans used the poultice root for boils, cuts, earaches, and inflammation. In addition, dried leaves boiled with water have been used to treat insomnia. *Opuntia ficus-indica*, commonly known as the prickly pear cactus, is a drought-resistant plan t that also has drawn interest from researchers due to it potentially being used as a second-generation carbohydrate feedstock. A feasibility study was recently done on using an enzymatic hydrolysate to pretreat the stems prior to fermentation. These results suggest that the use of dredge material contains some high-diversity sites that offer high-value vegetation for GDOT to investigate.

Table 10. 10-yr production life span with outdoor storage environment: Break even payback period for Big Bluestem and Switchgrass glandfilln as a bioenergy crop using seeded and plug methods of installation (BB = Big Bluestem, SW = Switchgrass).

			Annualized Unit Production Cost				
			$/ac				
Species	Method	Fertilizer N treatment	Establishment	Harvest	Storage	Transportation	Breakeven Period (years)
BB	Seed	0 lb N/ac	$21.48	$72.66	-	$34.32	2.2
		54 lb N/ac	$32.60	$117.66	-	$61.41	2.62
		107 lb N/ac	$43.52	$119.96	-	$62.79	2.73
	Plug	0 lb N/ac	$1344.94	$72.66	-	$34.32	20.52
		54 lb N/ac	$1356.06	$117.66	-	$61.41	12.86
		107 lb N/ac	$1366.98	$119.96	-	$62.79	12.74
SW	Seed	0 lb N/ac	$17.23	$106.01	-	$54.40	2.94
		54 lb N/ac	$28.36	$108.49	-	$55.89	3.08
		107 lb N/ac	$39.28	$150.14	-	$80.96	3.63
	Plug	0 lb N/ac	$1747.00	$106.01	-	$54.40	21.46
		54 lb N/ac	$1758.13	$108.49	-	$55.89	21.11
		107 lb N/ac	$1769.05	$150.14	-	$80.96	16.08

Owing to tremendous interest from landfill operators, in a scenario where the harvested biomass would be stored in an indoor facility near the highway for a given period the economic model reflects this scenario in the annualized unit production cost as shown in Table 21. The assumptions for this scenario involve the use of a 1-acre indoor structure with an assumed cost of $12 per square foot. In addition, a yearly ownership cost at 12 percent of the storage structure cost is assumed. Table 21 illustrates the same concept as Table 20, with the exception of the use of an indoor storage facility, rather than an outdoor storage environment. After accounting for the cost of an indoor storage facility breakeven payback periods for the production scenario increase by 43 percent overall.

Table 10 incorporates the calculation metrics listed to generate the enterprise budget for establishing Switchgrass using seed and high inputs of fertilizer. The average revenue stream from delivering switchgrass to an end-user during consecutive landfilling season is $640 for year two, followed by $1,069 from the third year onwards. With an assumed market value of $84 per ton of biomass, the profits associated with producing switchgrass over a 10-year period are shown to be $244 per acre of harvested biomass in year two, followed by $545 from the third year of production onwards. The enterprise budget can display cost/profits associated with different production scenarios.

CHAPTER 8. FINAL CONCLUSIONS AND RECOMMENDATIONS

There are many acres of dredged materials that could be used for successful implementation in landfills. Continuous and consistent use of significant amounts of this material would greatly reduce the amount spent by landfills. The results of this study show that the dredged material from Section 2A possess suitable geotechnical characteristics and meets all national and state requirements for capping. Monitoring over a two-year cycle shows dredge material performs as well as regular mixed soil typically used or imported for daily cover and capping.

It was also observed that a significant amount of vegetation on the capping possessed some potential for alternative use as mulch. Most of the identified vegetation contained no biomass potential as the specimens collected for this taxonomy were comprised of weedy vegetation. There were some notable specimens identified in the taxonomy that may present value to the landfill if properly managed. Some areas have poor nutrient compositions due to the pH levels associated with the soils. In addition, soils for this study were classified as some variant of sand, resulting in low water holding capacity, poor soil structure and lack of chemical properties (fertility). Most of these limitations have no impact on the suitability of dredged materials for landfill use.

Implementation is highly dependent on the willingness of the stakeholders to engage in a mutually beneficial agreement. Factors contributing to this decision are transportation costs, facility equipment, distance to DMCA and expertise. For ease, a questionnaire for potential GDOT personnel is below to determine whether it may be a good match.

CHECKLIST FOR ALTERNATIVE USES OF THE ROW

The following checklist includes questions that GDOT administrators might consider should they decide to assess whether a program to accommodate renewable energy production in the state highway ROW is viable. The checklist is not meant to communicate roles and responsibilities or imply that these are the only considerations necessary

PROJECT FEASIBILITY QUESTIONAIRE

Yes? No?

1. Does GDOT have leadership support to explore the accommodation of renewable this type of project? ___________

A committed project champion within GDOT leadership is vital in overcoming barriers and keeping projects on the paths forward.

2. Does the GDOT have an encroachment policy or other policy that might discourage some alternative uses of the dredge material? ___________

If so, the GDOT should assess whether the policy pertains to all potential alternative uses and/or whether the policy still aligns with current priorities. GDOT could consider the development of an ***interdisciplinary team*** *to identify and address the unique issues—including those related to design and construction—that alternative uses of the ROW present in that state.*

3. Are the GDOTs property maps available electronically and/or geospatially enabled format(s)?

Having electronically available property maps would likely facilitate analyses of potential sites for dredge material usage. Electronically accessible property maps that could be incorporated into a G.I.S system would facilitate the development of a site suitability model for feedstock establishment as was observed in this study.

4. **Does GDOT have staff qualified and available (likely GIS staff) to review data on natural resource location(s)? Does the state have natural resource data that the GDOT can use/leverage?**

If no, is the GDOT in a position to hire a consultant to perform analyses of natural resource location data in relation to GDOT property maps? For potential projects, not all suitable locations from a transportation perspective will necessarily be in locations with suitable natural resource (e.g., soil resources) availability. Open-source natural resource information would be available through the Soil Survey Geographic (SSURGO) Database. In a scenario where suitable locations are being scouted for a project, SSURGO would be a source of spatial information pertaining to available natural resource distributions over a given area of land where GDOT may be considering the establishment of a site.

5. Does GDOT legal staff have experience working with agreements related to similar projects?

____

Dredge material projects can involve complex legal documents that GDOT may not be able to develop given current areas of in-house expertise. Therefore, the GDOT may need to utilize outside legal counsel or consultants to help guide the

POTENTIAL PARTNERS FOR PROJECT COLLABORATIONS

The following section includes information on potential partners for GDOT to collaborate with for beneficial use. This section is meant facilitate the connection of GDOT and end-users. It is expected that these end-users would be capable of utilizing the dredged material for capping and daily cover in the state of Georgia. Table 32 illustrates various facilities in Georgia capable of transporting and utilizing this material. It is assumed that these facilities would assume the cost of transportation. These facilities are located across the state and would provide additional outlet for dredge material generated from the Savannah Harbor Expansion across the state of Georgia.

Table 11: Potential partners for GDOT to collaborate with on future projects

Landfill Name	*Physical Address*	*County*	*Ownership Type*	*Contact Person*
Athens-Clarke County Landfill	5700 Lexington Road, Winterville	Clarke	Public	Brad Rickard
Atkinson County - SR 50 MSWL	64 Author Davis Drive, Willacoochee	Atkinson	Public	
Bartow County MSWLF	40 Allatoona Dam Road between Hwy 41 & S.R. 293, Cartersville	Bartow	Public	
Button-Gwinnet Landfill	70 Arnold Road, Lawrenceville	Gwinnett	Private	Carolyn Callihan
Camden County SR 110 MSW Landfill	5395 Hwy 110 (SR 110 & Russell Road) 12 miles SW of Woodbine, Silco	Camden	Public	Kevin Barkley
Carroll County - Carrollton	439 Simonton Mill Road, Carrollton	Carroll	Public	Jacqueline Dost
Cascade Road Landfill	4047 Cascade Road S.W., Atlanta	Fulton	Public	Amy Williams
Catoosa County MSW Landfill	912 Shope Ridge Road, Ringgold	Catoosa	Public	
Cedar Grove Landfill	172 Roger Brown Drive, Barnesville	Lamar	Public	
Cherokee County - Blalock Road	Blalock Road 2 mi SE of Holly Springs, Canton	Cherokee	Unknown	Troy Brazie
Chesser Island Road Landfill	Highway 121 S. (SR 23) at Chesser Island Road, Folkston	Charlton	Private	
City of Forsyth-Old Brent Road	Old Brent Road, Forysth	Monroe	Public	
City of LaGrange Landfill	2233 Greenville Road, LaGrange	Troupe	Public	Chris Bradley
City of Thomasville	88 Landfill Road off Sunset Drive, Thomasville	Thomas	Public	Jimmy Smith, Jr
City of Tifton	445 Mitchell Store Road, Tifton	Tift	Public	Chad Mallow
Clayton County Lovejoy Landfill	11678 Hastings Bridge Road, Lovejoy	Clayton	Public	Jeff Metarko
Columbus Pine Grove	7900 Pine Grove Way, Columbus	Muscogee	Public	Matthew Dolan
Crisp County Landfill	3354 U.S. Highway 41 S, Cordele	Crisp	Public	Carl Gamble

Deans Bridge Road	4330 Deans Bridge Road, Blythe	Richmond	Public	
Decatur County Solid Waste Facility	104 Mine Loop Road, Attapulgus	Decatur	Public	Andrew Jones
Dougherty County Fleming/Gaissert Road	900 Gaissert Road, Albany	Doughtery	Public	Campbell Smith
Eagle Point Landfill LLC	8880 Old Federal Road, Ball Ground	Forsyth	Private	Scott Mann
Evergreen Landfill LLC	2995 Wetherington Lane, Valdosta	Lowndes	Private	
Fort Benning LF	1st Division Road, Fort Benning	Chattahoochee	Public	
Fulton County Merk Miles Road	3225 Merk, College Park	Fulton	Public	
Gordon County Redbone Ridges LF	1224 Pleasant Hill Road Extension NE & Red Bone Ridge Road, Ranger	Gordon	Public	Jim Ledbetter
Grady Road Landfill	316 Grady Road, Rockmart	Polk	Public	Michael Birch
Gun Club Road landfill	1401 Gun Club Road N.W., Atlanta	Fulton	Public	
Hall County Allen Creek Landfill	2665 Allen Creek Road, Gainesville	Hall	Public	Ken Rearden
Heard County Landfill	off Frolona Road 5.6 miles NW, Franklin	Heard	Public	
Hickory Ridge Landfill	3330 Moreland Avenue, Conley	DeKalb	Private	
Jefferson County CR-138 MSWL	1619 Mennonite Church Road, Louisville	Jefferson	Public	Steven Green
Laurens County - Old Macon Road MSWL	1645 Old Hawkinsville Road, Dublin	Laurens	Public	Michael Snipes
Liberty County LF	Limerick Road, Midway	Liberty	Public	Johnny Schaadt
Live Oak LF	1189 Henrico Road, Conley	DeKalb	Private	
Macon Bibb Walker Road MSWL	920 11th Street, Macon	Bibb	Public	
Marble Top Road Landfill	N. Marble Top Road, Chickamauga	Walker	Public	
Morgan Falls	Morgan Falls Road, Dunwoody	Fulton	Public	
Murray County Landfill	6585 Highway 411 S, Chatsworth	Murray	Public	

Newton County Landfill	205 Lower River Road, Covington	Newton	Public	
Oak Grove Landfill	967 Carl Bethlehem Road 3 mi SW of Winder, off SR 324, Winder	Barrow	Private	
Old Dixie Highway MSW Landfill	4189 Old Dixie Highway S.E., Dalton	Whitfield	Public	
Paulding County Landfill	end of Grants Chapel Road off Seven Hills Road, Dallas	Paulding	Public	
Pine Bluff Landfill	13809 East Cherokee Drive, Ball Ground	Cherokee	Private	
Polk County Landfill #1	Highway 278 ~1 mile from Grady Road LF, Cedartown	Polk	Public	
R & B (Banks) Landfill	610 Bennett Road, Homer	Banks	Private	
Richland Creek Road Landfill	5691 South Richland Creek Road, Buford	Gwinnett	Public	
Roberts Road Landfill	180 Roberts Road, Fayetteville	Fayette	Public	
Savannah-Dean Forest Road SL	1327 Dean Forest Road, Savannah	Chatham	Public	
Seminole Road MSW Landfill	4203 Clevemont Road, Ellenwood	DeKalb	Public	
Southern States-Bolton Road	2236 Bolton Road, N.W., Atlanta	Fulton	Private	
SR247 MSW Landfill	2080 GA Hwy 247, Kathleen	Houston	Public	
Superior Landfill & Recycling Center	3001 Little Neck Road, Savannah	Chatham	Private	
Swift Creek Environmental Landfill	4200 Davis Road, Macon	Bibb	Private	
Toombs County-S1898, PH 3 MSWLF	2974 Lyons Center Road, Lyons	Toombs	Public	
Turkey Run Landfill	7144 Lone Oak Road, Hogansville	Meriwether	Private	
Union Hill Church Road MSWLF	154 Union Hill Church Road S.W., Gordon	Gordon	Public	
Walker Mountain Landfill	433 Walker Mountain Road, Rome	Floyd	Public	
Watts Road LF	1144 Field Road NW, Atlanta	Fulton	Private	

WI Taylor County Disposal, LLC	33 Stewart Road, Mauk	Taylor	Private	
WMI-Rolling Hills	870 Sullivan Road at Lees Mill Road, College Park	Clayton	Private	
Wolf Creek Landfill, LLC	911 Landfill Road off Hwy 80 (Jeffersonville Road), Dry Branch	Twiggs	Private	

APPENDIX A: PICTURES FROM THE PILOT STUDY SITES

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