Honeywell

Honeywell
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March 29, 2013

VIA EMAIL AND REGULAR MAIL

Mr. Galo Jackson
US EPA Region IV
Waste Management Division
Superfund Program
61 Forsyth Street, SW
Atlanta, Georgia 30303

Re: Draft Feasibility Study Report for OU1 (Estuary) − LCP Chemicals Site, Brunswick, Georgia

Dear Mr. Jackson,

The LCP Chemicals site responsible parties are pleased to submit to the US Environmental Protection Agency (EPA) the draft Feasibility Study for Operable Unit 1 (OU1) of the LCP Chemicals Site, Brunswick, Georgia. This FS report is being submitted in accordance with the 1995 Administrative Order on Consent (AOC) (EPA Docket No. 95-17-C) regarding the LCP Chemicals Site.

Today's electronic submittal via email will be followed by hard copies that will be sent to EPA and the Georgia Environmental Protection Division (EPD) next week (Monday, April 1), along with compact disks (CDs) that include the report PDF file and electronic data.

Although the report itself is complete, we have not yet prepared an Executive Summary. We plan to prepare an Executive Summary for EPA and EPD to review. The Executive Summary will be sent to you Friday, April 5.

Please feel free to call me at 973-722-1656 if you have any questions.

Sincerely,

Prashant K. Gupta
Remediation Manager

Enclosure

cc: Jim Brown, GAEPD
Jim McNamara, GAEPD
Brett Mitchell, Georgia Power
Paul Taylor, Atlantic Richfield Company
Victor Magar, ENVIRON

DRAFT

FEASIBILITY STUDY
LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:

Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:

ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

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Acronyms and Abbreviations

%	percent
AET	apparent effects threshold
AOC	Administrative Order on Consent
AQ	Anchor QEA
ARAR	Applicable or Relevant and Appropriate Requirement
ARCO	Atlantic Richfield Company
BERA	Baseline Ecological Risk Assessment
BMP	best management practice
ccc	criterion continuous concentration
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter(s)
cm/sec	centimeter(s) per second
COC	chemical of concern
CSF	cancer slope factor
CSM	conceptual site model
CTE	central tendency exposure
CY	cubic yards
DoD	Department of Defense
DMCF	dredged material containment facilities
EEV	ecological effects value
ELCR	excess lifetime cancer risk
ENVIRON	ENVIRON International Corporation
ER-L	effects range-low
ER-M	effects range-medium
FCGs	Fish Consumption Guidelines
FDA	Food and Drug Administration
FFDA	former facility disposal area
FS	feasibility study
ft/sec	feet per second
GADNR	Georgia Department of Natural Resources
GAEPD	Georgia Environmental Protection Division
GPS	global positioning system
GRA	general response action
GRC	Georgia Regional Council
HHBRA	Human Health Baseline Risk Assessment
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
Honeywell	Honeywell International Inc.

kW	kilowatt
LCP	LCP Chemicals of Georgia, Inc.
LiDAR	light detection and ranging
LOAEL	lowest observed adverse effect levels
LOE	lines of evidence
MHHW	mean high high water
mg/kg	milligram(s) per kilogram
mg/kg-day	milligrams per kilograms per day mg/kg BW-daymilligram per kilogram body weight per day
MLLW	mean low low water
µg/kg	microgram(s) per kilogram
µg/L	microgram(s) per liter
MNR	monitored natural recovery
MSL	mean sea level
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
ng/L	nanogram(s) per liter
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NRWQC	National Recommended Water Quality Criteria
NOAEL	no observed adverse effects levels
O&M	operations and management
ODMDS	Ocean Dredged Material Disposal Sites
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PEL	probable effects level
PRP	potentially responsible party
RM	river mile
PTI	PTI Environmental Services
QA/QC	quality assurance/quality control
RAGS	Risk Assessment Guidance for Superfund
RAO	remedial action objective
RfD	reference dose
RGO	remedial goal options
RI	remedial investigation
RME	reasonable maximum exposure
ROD	Record of Decision
RSL	regional screening level
SEC	sediment effect concentrations
SHEP	Savannah Harbor Expansion Project
SMA	sediment management areas

SWAC	surface-weighted average concentrations
TBC	to be considered guidance
TEL	threshold effect levels
TIE	toxicity identification evaluation
TOC	total organic carbon
TRBE	Turtle River/Brunswick Estuary
TRV	toxicity reference value
T&E	Threatened and Endangered species
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USDOE	United States Department of Energy
USFWS	United States Fish and Wildlife Service
WQS	water quality standards

1 Introduction

In 1995, Honeywell (formerly AlliedSignal, Inc.), the Atlantic Richfield Company (ARCO), and the Georgia Power Company entered into an Administrative Order on Consent (AOC) (USEPA Docket No. 95-17-C) with the United States Environmental Protection Agency (USEPA) regarding the LCP Chemicals Site located in Brunswick, Georgia (Site). This Feasibility Study (FS) Report has been prepared by ENVIRON International Corporation (ENVIRON) and Anchor QEA (AQ) in accordance with the requirements of the AOC. The Site is being managed as three Operable Units (OUs). The estuarine setting constitutes Operable Unit 1 (OU1) and is the focus of this FS.

Building on historical information, ecological and human health risk assessments (Black & Veatch 2011; EPS 2011a), and information presented in the OU1 Remedial Investigation (RI) Report (EPS and ENVIRON 2012), this FS relies on analyses of hydrological, ecological, and sediment conditions within OU1 to support the evaluation of potential remedial measures. Consistent with USEPA *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (1988), this report:

- Identifies remedial action objectives (RAOs).
- Considers the range of available remediation technologies.
- Evaluates technologies considered relevant to remediation of OU1 sediments.
- Compares remediation alternatives against National Oil and Hazardous Substance Pollution Contingency Plan (NCP) criteria to evaluate remedy effectiveness and to provide USEPA with the information needed to identify a preferred remedy.

1.1 Objectives

The work embodied in the FS is based on the following two primary objectives:

- Identify and screen sediment technologies that address the occurrence of elevated concentrations of chemicals of concern (COCs) in the Site surface sediments.
- Evaluate viable remedial alternatives against the RAOs and against the NCP criteria.

This FS focuses on remedial alternatives that manage the potential risks associated with the presence of elevated concentrations of COCs in OU1 sediments in a cost effective manner while minimizing, to the extent practicable, the incidental impacts to the existing marsh ecosystem associated with remediation. Screening and evaluation are conducted according to criteria that weigh long-term reduction of ecological and human health risks against preserving the existing habitat to the extent practicable.

1.2 Report Organization

This introduction to the FS (**Section 1**) is followed by a summary of the background information for OU1 of the Site (**Section 2**). **Section 3** identifies RAOs and remedial goals for OU1 and **Section 4** presents a screening of available remedy technologies and process options. Site-specific remedy alternatives developed for OU1 sediments are presented in **Section 5** and evaluations of the remedial alternatives using the criteria established by the NCP are provided in **Section 6**. **Section 7** summarizes key findings and conclusions of the FS. References are provided in **Section 8**.

The FS also includes the following appendices: **Appendix A** presents the groundwater evaluation; **Appendix B** describes the hydrodynamic model; **Appendix C** provides an analytical data summary for sediment investigations conducted in August and October of 2012; **Appendix D** provides a detailed view of the 50 meter by 50 meter area averaging used in the Western Creek Complex and Purvis Creek; **Appendix E** describes the methods used to evaluate remedy effectiveness; **Appendix F** provides a graphical summary of contaminants in fish tissues over time; **Appendix G** presents cost estimates for the remedy alternatives; and **Appendix H** presents preliminary chemical transport modeling used to evaluate the long-term performance of the chemical isolation caps.

2 Site Background

2.1 Site and Facility Information

This section includes details on the Site location, historical site uses, and adjoining land uses. It provides a summary of the available Site information.

2.1.1 Site Area Description

The Site property is located in Glynn County, Georgia, immediately northwest of the City of Brunswick (**Figure 2-1**). The Site consists of approximately 760 acres of estuary (OU1), and 121 acres of upland area (OU3), east of the estuary, where former plant operations took place.

OU1 consists of approximately 662 acres of flat, heavily vegetated tidal marsh and approximately 98 acres of tidal creeks within the Turtle River/Brunswick Estuary (TRBE). The marsh elevation is low (approximately 2 to 3 feet above mean sea level [MSL]), and the numerous channels and creeks traversing the marsh are under tidal influence from the nearby Turtle River (EPS and ENVIRON 2012). As illustrated on **Figure 2-1**, the marsh is discussed in terms of four domains (Domain 1, Domain 2, Domain 3, and Domain 4):

- Domain 1 is bounded by the uplands to the east, LCP Ditch to the north and Eastern Creek to the west. A marsh removal action conducted in 1998-1999 addressed sediments in the eastern portion of this domain. The western portion, adjacent to Eastern Creek, is referred to as Domain 1a.
- Domain 2 is bounded on the east by Domain 1, in the south by uplands not part of the LCP property, in the west by Purvis Creek, and north by Purvis Creek and LCP Ditch. Domain 2 includes Western Creek Complex.
- Domain 3 is bounded to the south by LCP Ditch, by uplands to the east, and the west and north by Purvis Creek. Dillon Duck is the easternmost portion of Domain 3.
- Domain 4 is the area west of Purvis Creek and is bounded to the southwest by Turtle River and northwest by uplands not part of the LCP property. Domain 4 is divided into eastern and western portions by the flow divide between creek and river.

Figure 2-1 also identifies the key features of the uplands portion of the Site, east of the tidal marsh, which are described in detail in the OU1 RI (EPS and ENVIRON 2012). The eastern boundary of the uplands portion is at an elevation of approximately 15 feet MSL and slopes gently to an elevation of 5 feet MSL along the west border with OU1. The east-west entrance road (B Street) divides this area of the Site roughly in half. Chlor-alkali process operations were conducted primarily in the former cell buildings south of B Street, the area of the boiler house north of B Street, and the smaller isolated waste disposal areas dispersed over the northern half of the Site. The area of the former chlor-alkali plant south of B Street is fenced in and covered with a soil cap (EPS and ENVIRON 2012).

A land disposal unit known as the Former Facility Disposal Area (FFDA) is located in the southern portion of the Site (see **Figure 2-1**). The FFDA contained elevated concentrations of Site-related constituents and spent graphite anodes (EPS and ENVIRON 2012).

Refinery operations were present over most of the upland areas until 1935, after which portions of the refinery footprint were demolished and sold for scrap and other portions were used for petroleum storage. Power generation facilities constructed by Georgia Power were located primarily north of B Street and the Dixie paint operations were South of B Street.

2.1.2 Facility Operating History

The Site was operated as a petroleum refinery from 1919 to the mid-1930s by the Atlantic Refining Company, a predecessor of the Atlantic Richfield Company. In 1922, oil replaced coal as the refinery fuel, until 1935 when operations ceased. Remnants of these operations exist at the Site including concrete storage tank supports and many buildings. During World War II much of the steel was salvaged for scrap or moved to other locations (GAEPD 1990).

In 1937, 1942, and 1950 Georgia Power purchased portions of the Site, including two parcels of land and two 750 kilowatt (kW) electric generators from Atlantic Refining. Georgia Power increased the power generation capacity of the Site from 1500 to 5500 kW by 1941. The source of fuel for the power plant was Bunker C oil (GAEPD 1990).

From 1941 to 1951, the Dixie Paint and Varnish Company operated a paint and varnish manufacturing facility in an area south the Georgia Power parcel. The Dixie Paint and Varnish Company became the Dixie O'Brien Corporation and eventually a wholly owned subsidiary of the O'Brien Corporation (GAEPD 1990).

In 1955, Allied Chemical and Dye Corporation (now Honeywell) acquired most of the land now referred to as the Site. They established a chlor-alkali facility at the Site producing chlorine gas, hydrogen gas, and caustic solution using the mercury cell process. This involves passing a concentrated brine solution between a stationary graphite or metal anode and a flowing mercury cathode. A second reaction is used to produce sodium hypochlorite (bleach) (EPS and ENVIRON 2012).

In 1979 the property, including the chlor-alkali plant, was purchased by LCP Chemicals – Georgia, Inc., a division of the Hanlin Group (LCP). While the chlor-alkali facility continued to run, some modifications were implemented. These included the production of hydrochloric acid by reacting chlorine and hydrogen. Operations terminated in 1994 when LCP shut down the plant (EPS and ENVIRON 2012). Honeywell repurchased the property in 1998 and currently owns the property. Presently, the Site is mostly vacant, though it contains several building remnants.

2.1.3 Land Use

Predominantly industrial and commercial property surrounds the Site. A county land disposal facility and a pistol firing range border the Site to the north (**Figure 2-1**). A tidal marsh and the Turtle River lie to the west, and the Georgia-Pacific Cellulose facility is to the South. Commercial property borders the property to the East.

The area is designated as industrial use according to the Glynn County Planning Commission Land Use Maps. These maps zone the "useable" areas of the Site, the tidal marsh from the eastern bank of Purvis Creek, and the Georgia-Pacific Cellulose site as "Basic Industrial." The former SIC code for the property is 2812 (Chemical and Allied Products, Alkalies and Chlorine), which falls within the Georgia Environmental Protection Division's (GAEPD) regulatory definition of non-residential property (391-3-19-02(2)(i)).

2.2 Geology and Hydrology

This section discusses the Site's hydrogeological setting and details the groundwater flow into the estuary. It also includes details on the hydrology and the sediment transport processes in the estuary. The section closes with an overview of site surface uses, including vessel traffic patterns and maintenance dredging activities in the vicinity of the Site.

2.2.1 Hydrogeology

The hydrogeologic conceptual site model is presented on **Figure 2-2**. This figure is taken from the 1997 RI report (Geosyntec 1997) and illustrates the Site stratigraphy, and indicates hydraulic conductivities of the hydrogeologic units. The Site is underlain by the Satilla Formation, which is Holocene to Pleistocene in age. Beneath the Satilla Formation are the Coosawhatchie Formation and the Berryville Clay Formation, which forms the regional confining layer.

The Satilla Formation is approximately 55 feet thick in the vicinity of the Site and is divided into two general layers. The upper Satilla sand is the local aquifer and extends to a depth of approximately 45 feet. The lower Satilla sand is approximately 10 feet thick and, in the vicinity of the marsh and upland areas of the Site, is variable in texture ranging from sand to dense clayey sand.

In areas to the west of the Site, marsh sediments overlie the Satilla Formation and locally provide confined conditions for groundwater flow, having a median hydraulic conductivity on the order of 10^{-7} centimeters per second (cm/sec). Marsh sediments in the vicinity of the Site are typically 7 to 8 feet thick, though locally they may be thicker, and near the upland areas they may be thinner. The upper Satilla sand is composed of uniform very fine to medium sand with thin, discontinuous layers of clay. The thin clay layers result in an anisotropic hydraulic conductivity for the formation where the vertical permeability of the unit is significantly lower than the horizontal permeability. Slug tests conducted in the upper and lower Satilla sand indicate a horizontal hydraulic conductivity on the order of 10^{-2} cm/sec. The upper Satilla sand primarily discharges to Purvis Creek, which ultimately discharges to Turtle River; some seep discharges also occur, allowing direct discharge into the marsh (which is discussed further in **Section 2.2.2**). The water in the Satilla Formation at the Site is non-potable due to naturally occurring high dissolved mineral content.

The Coosawhatchie Formation is Miocene in age and is approximately 180 feet thick. It can be divided roughly into two water-bearing units and two confining layers. The uppermost layer of the Coosawhatchie is approximately 3 to 15 feet of cemented sandstone, which acts as a confining layer between the Satilla sand and the Coosawhatchie A/B aquifers (**Figure 2-2**). The cemented sandstone has an approximate hydraulic conductivity of 10^{-5} cm/sec. The Coosawhatchie A/ B aquifers are approximately 50 feet thick and have an approximate hydraulic conductivity of 10^{-2} cm/sec. On-site pump tests conducted across the cemented sandstone have verified that the cemented sandstone is an effective confining layer hydraulically separating the two water-bearing units. The Coosawhatchie C consists of an approximately 30 foot thick dolomitic marlstone and acts as a confining layer between the Coosawhatchie A/B aquifers and the Coosawhatchie D aquifer.

The Coosawhatchie D aquifer is approximately 50 feet thick and is composed of variably cemented sandstone. It is the main water-bearing unit in the "rock aquifer" in the vicinity and many of the potable residential wells in the Brunswick and the Blythe Island areas of Glynn County are completed in this unit.

The Coosawhatchie Formation is underlain by the Berryville Clay, an approximately 80 foot thick clay layer that forms a regional confining unit. This clay layer separates the surficial water-bearing units from the deeper Brunswick Aquifer and Floridan Aquifer.

2.2.2 Local Groundwater Flow to the Estuary

Local groundwater flows from the uplands into the salt marsh along four types of flow paths (**Figure 2-3**). COCs that are transported along each flow path encounter a sequence of geochemical conditions that affect the fate of the COCs as they are transported.

Shallow groundwater in the Satilla Aquifer, down to the cemented sandstone, migrates towards the marsh, approximately perpendicular to the marsh boundary. Groundwater migrating to the marsh from upland areas must cross a vertical plane parallel to the marsh boundary. The groundwater COC contribution across this vertical plane flows through four groundwater pathways as follows from longest to shortest:

- Flow Path to Purvis Creek and Beyond (Flow Path 1): The longest flow path is from upland areas to Purvis Creek and beyond. This path is dominated by water that begins near the bottom of the Satilla Sand aquifer at the marsh boundary and is transported more than 1,000 feet within the Satilla Sand. The groundwater enters the marsh sediments from below and discharge may occur as diffuse flow through the marsh sediments or through focused seeps that emanate in Purvis Creek.
- Flow Path to Marsh Flats and Intertidal Channels (Flow Path 2): This flow path begins with groundwater at depth along the marsh boundary. The groundwater is transported within the aquifer and enters the marsh sediments from below. Discharge may diffuse discharge through the marsh sediments or release in focused seeps.
- Flow Path to Restored Marsh Area (Flow Path 3): This flow path begins at shallow depths along the marsh boundary. Groundwater is transported less than 500 feet within the aquifer from upland areas. The groundwater then enters the marsh sediments from below and discharge diffuse through the marsh sediments or release in focused seeps.
- Flow Path to Near-Shore Seeps (Flow Path 4): The shortest flow path between upland groundwater and the marsh leads to nearshore seeps, such as those that have been identified and sampled by lysimeters. This transport flow path is dominated by the shallowest groundwater in the aquifer along the marsh boundary. The groundwater may be expressed at the surface after intense rainfall events. The distance of transport within the aquifer is short and the discharge to the surface may be in an area where the marsh sediment layer is thinnest.

Each of these flow paths encompasses lithologic and biogeochemical zones that affect the fate of the COCs being transported. The major differences between the flow paths are related to the residence time of the groundwater in the various lithologic and biogeochemical zones. Along each flow path, the zones encountered include:

- The aquifer
- The marsh sediments below the root zone
- The marsh sediments within the root zone

Upon discharge to the surface, direct mixing with tidal surface water occurs. The more focused the discharge (i.e., as a seep), the higher the potential COC concentration, but also the greater the influence of surface water dilution at the point of discharge to surface water and the smaller the area of marsh that is impacted by groundwater flow. Conversely, diffuse discharges upwelling through the sediment bed are subject to more attenuation within the sediments resulting in lower potential COC concentrations at the point of discharge. Like focused discharges, diffuse discharges are also subject to dilution at the point of discharge to surface water.

The potential for groundwater transport to result in recontamination of the marsh sediments was evaluated in the OU1 RI using a transect analysis method (EPS and ENVIRON 2012). In May 2012, the upland wells along the plume transect were resampled and supplemental groundwater wells were installed and sampled to update the transect analysis. The updated groundwater transport analysis is presented in **Appendix A**, and indicates that the potential for sediment recontamination by groundwater transport of COCs is minimal and insignificant.

2.2.3 Estuary Hydrology

The Site consists of an interconnected complex of tidal creeks and vegetated marshes, with an areal extent of approximately 760 acres, which is part of the saltwater TRBE that flows eastward into St. Simons Sound. Purvis Creek is the primary tidal channel that connects the Site to the Turtle River, and divides the marsh areas within the Site approximately in half (**Figure 2-1**). Several secondary channels (i.e., Eastern Creek, the Western Creek complex, LCP Ditch, Domain 3 Creek) are directly or indirectly connected to Purvis Creek. Numerous small channels provide hydraulic connections between the primary/secondary tidal channels and the intertidal marsh areas. No significant freshwater tributaries flow into the Site.

Tidal hydrodynamics have a significant effect on the transport of waterborne substances (e.g., suspended sediment, chemicals) within the Site. A preliminary modeling study was conducted to evaluate estuarine hydrodynamic processes within the Site (**Appendix B**). The model predicted a typical tidal range of about 7 to 8 feet, which produces strong vertical mixing in the water column and relatively long horizontal excursion of water. Density-driven circulation was minimal because there are no significant freshwater inflows to the Site estuary.

Water flows from the Turtle River into Purvis Creek during flood tide and is then conveyed to intertidal marsh through the system of secondary creeks and smaller channels. Tidal flows are mostly confined to the creeks and smaller channels at the beginning of flood tide. Current velocities are relatively high within the tidal creeks during flood tide. Water flows into the vegetated marsh once the tidal elevation reaches the bank elevation. The elevation of the marsh is about 2 to 3 feet MSL. Thus, the marsh is only inundated with water during high tide. Current velocities are relatively low within the marsh area due to increased storage area and high drag induced by plants.

As the maximum tidal elevation is reached at high tide, current velocities are very low throughout the estuary during slack water conditions. During ebb tides, water drains from the intertidal marsh into the tidal channels and creeks and eventually back to the Turtle River. During this ebbing stage, the current velocities are relatively high in the creeks.

The relatively large tidal range within the Site causes nearly complete exchange of water between the intertidal marsh areas and the creeks during each tidal cycle (i.e., marsh areas are filled and drained during one tidal cycle). Dense vegetation has a significant effect on hydrodynamics in the marsh, with relatively low current velocities in those areas.

Historical development within the Site altered marsh drainage patterns, which likely affected local tidal hydrodynamics. These alterations include the construction of causeways, landfills, and the marsh removal action during 1998 and 1999. The marsh removal action included backfill to pre-excavation elevations and replanting, so hydrologic changes were temporary. Construction of the causeway, which runs parallel to the northern bank of LCP Ditch, permanently separated the northern and southern marshes, so that the only surface-water connection between these two areas is now Purvis Creek. These major alterations occurred more than 10 years ago, and the Site is currently assumed to be in a state of geomorphologic equilibrium.

2.2.4 Estuary Sediment Transport Processes

Sediment transport processes within the Site are controlled by tidal circulation and rare storm events (**Appendix B**). The dominant source of suspended sediment to the estuary is the Turtle River because no tributaries flow directly into the estuary. The sediment bed in the tidal creeks is composed predominantly of cohesive sediment. Sediment erosion is expected to occur in some portions of the tidal creeks during spring tide conditions because peak current velocities are high enough (i.e., about 2 feet per second [ft/sec]) to exceed the critical shear stress of surface sediments (generally about 0.1 to 0.5 Pascals). However, bed scour is expected to be minimal (i.e., about 1 to 2 millimeters) because of bed armoring processes in the cohesive sediment bed. Deeper bed scour may occur in some localized areas of the creek channels during rare storms (e.g., hurricane storm surge).

Suspended load transport is the primary mechanism for sediment movement within the estuary. The transport of suspended sediments is controlled by tidal hydrodynamics, which will cause movement of suspended sediment between the intertidal marsh areas and creek channels. The intertidal vegetated marshes are a net depositional zone for suspended sediments due to the low current velocities and presence of vegetation within those areas. Sediment deposition occurs in the marsh during flood tide and slack water before ebb tide; sediment is not remobilized by tidal currents after initial deposition in the marsh because most flow conveyance occurs in the channels and not on the vegetated marsh areas. Consistent with observations in similar saltwater vegetated marshes (Stumpf 1983; Wang et al. 1993; Leonard et al. 1995), relatively higher sedimentation rates are expected along channel banks in the vegetated marshes. Various physical processes influence the spatial distribution of net sedimentation rates within the marsh areas, including tidal elevation, current velocity, sediment supply, and vegetation characteristics (i.e., species, biomass, plant density and height).

2.2.5 Site Uses: Vessel Traffic Patterns, Maintenance Dredging History

Recreational and navigational use of OU1 is infrequent due to the difficulty in navigation of small crafts; the effects of remedial actions on those types of uses do not need to be evaluated. The Turtle River, which is adjacent to the Site, is subject to this type of use.

Information on waterway traffic was obtained from the Port of Brunswick, the US Army Corps of Engineers (USACE), and correspondence with other marine service providers. Two private recreational marinas are located in the Turtle River. Most recreational boat passage in the Turtle River is due to access to or from St. Simons Sound. The primary route of large commercial vessels traffic is from the Atlantic Ocean to the Port of Brunswick, which is located about five miles downstream of the Site. Occasional commercial ship traffic that passes by the Site in the Turtle River consists of oil barges in transit to the oil-fired power plant located upstream. Large recreational boats cannot enter the Site due to the narrow, shallow tidal creeks. Small recreational boats (i.e., less than about 14 feet long) can access the Site during high tide but this type of boat traffic is reported to be very rare, perhaps because of the risk of being stranded at low tide.

No active maintenance dredging has occurred to create and maintain a navigational channel in the Site. Maintenance dredging has been limited to the navigation channel from the upper limits of the Brunswick harbor at river mile (RM) 12.76 in the Turtle River to the entrance of St. Simon Sound, with the navigation channel dimensions maintained at a depth of 30 feet and width of 400 feet. However, in 1998 to 1999, approximately 13 acres of marsh near the sources of historical discharge including a portion of Eastern Creek and LCP Ditch were excavated, backfilled, and restored.

2.3 Existing Habitat Conditions

This section presents information on the habitat and ecology of the Site. It includes an overview of biological characteristics of the marsh and its associated wildlife with detailed discussions of invertebrate, fish, bird, and mammal communities. This section closes with an overview of the physical characteristics of the Site and a summary of past restoration efforts.

2.3.1 OU1 and Associated Wildlife

The Site is a tidal estuary that comprises approximately 4 percent (%) of the TRBE (**Figure 2-4** and **Table 2-1**). Approximately 13% of the Site is composed of tidal creeks, with approximately 87% of the marsh composed of indigenous marsh grasses, predominantly smooth cordgrass (*Spartina alterniflora*).

An undisturbed plant community and species diversity are characteristics of a healthy marsh. Based on visual observations from a January 2012 site visit, the Site appears to be a functioning habitat with an undisturbed plant community of *S. alterniflora* and occasional patches of black needle rush (*Juncus roemerianus*) (see photos 2-5A, B, C, D, E, F, G, and H in **Figure 2-5**). The productivity of the marsh is especially apparent in areas adjacent to Eastern Creek and LCP Ditch (see photos 2-5A, B, D, and E in **Figure 2-5**) and Domain 1 and 2 (see photos 2-5 C and F in **Figure 2-5**). *S. alterniflora* is prevalent in the low marsh with plant diversity increasing towards the upland area such as the Dillon Duck area (see photos 2-5I and J in **Figure 2-5**).

Benthic, Epibenthic, and Epiphytic Community Structure

The benthic salt marsh invertebrate community at the Site includes those organisms that live in the sediment of a salt marsh (benthic fauna) and on the sediment (epibenthic fauna). It also includes those organisms that live on the plants of a salt marsh community, also known as epiphytic fauna. Tidal influences and inundation are often key factors that govern community structure. Site-specific invertebrate surveys and studies have described the critical components of the invertebrate community as follows:

- Fiddler crabs are ubiquitous in salt marshes. Three species of fiddler crabs inhabit the Site: *Uca minax, U. pugilator,* and *U. pugnax.* These crabs appear to have a mutually beneficial interaction with marsh vegetation as crab burrows increase plant production by moderating soil conditions. In turn, marsh plants facilitate crab burrows by stabilizing the substrate (Norman and Pennings 1998).
- Grass shrimp (*Palaemonetes pugio*) are a major source of food for crabs and fish and facilitate nutrient cycling.
- Other macroinvertebrates are present at the Site. The benthic community is composed of barnacles, mysids (*Mysidopsis bahia*), penaeid shrimp, ribbed mussel (*Geukensia demissa*), marsh periwinkle (*Littorina irrorata*), mud snail (*Illynassa obsolete*), eastern oyster (*Crassostrea virginica*), blue crab (*Callinectes sapidus*), and amphipods. Horne et al. (1999) reported that polychaetes and oligaetes dominated the benthic community composition in OU1 and reference area. Horne et al. (1999) also noted the low representation (less than 3% of the total community) of amphipods in both the Site and a reference area. Another benthic community survey of the Site conducted in 2000 did not identify any amphipods at the Site or reference locations (Black & Veatch 2011).

Fish Community

Fish inhabit the LCP salt marsh, generally entering into the marsh area with incoming tides. Fish indigenous to the estuary include the mummichog (*Fundulus heteroclitus*), red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), silver perch (*Bairdiella chrysoura*), spotted seatrout (*Cynoscion nebulosus*), striped mullet (*Mugil cephalus*), Atlantic croaker (*Micropogonias undulates*), southern kingfish (*Menticirrhus americanus*), spot (*Leiostomus xanthurus*), and sheepshead (*Archosargus probatocephalus*) (Black & Veatch 2011). Smaller fish, like mummichog, do not migrate and are a key component of the food web. Many other fish species migrate from the Site to nearby areas.

Bird Community

Birds indigenous to the estuary include grebes, cormorants, herons, bitterns, ibises, geese, marsh ducks, mergansers, vultures, hawks, ospreys, falcons, rails (including the clapper rail (*Rallus longirostris*)), stilts, plovers, sandpipers, gulls, terns, pelicans, skimmers, kingfishers, and songbirds. The wood stork (*Mycteria americana*), an endangered species, has been observed foraging in tidal creeks of the salt marsh and breeding at several colonies in the vicinity of Brunswick. The upland bird fauna is likely to consist mostly of species adapted to abandoned industrial sites, but may also include hawks that forage in the grassy areas of the upland (USDOI 1995).

Mammal Community

Despite highly variable environmental conditions in salt marshes (related to tidal inundation and salinity), mammals use the habitat for food and shelter. At the Site, resident mammal species likely include shrews, bats, raccoon (*Procyon lotor*), mink (*Mustela vison*), river otter (*Lutra canadensis*), marsh rice rat (*Oryzomys palustris*), and marsh rabbit (*Sylvilagus palustris*). The West Indian manatee (*Trichechus manatus*) and the Atlantic bottle-nosed dolphin (*Tursiops truncatus*), both of which are protected under the Marine Mammal Protection Act, have been observed in Purvis Creek. Resident upland mammals that likely inhabit the margins of the marsh include raccoons, various shrews and rodents, Eastern cottontails (*Sylvilagus floridanus*), opossums (*Didelphis marsupialis*), and nine-banded armadillos (*Dasypus novemcinctus*) (USDOI 1995).

Reptile Community

The most common reptile in Atlantic coast salt marshes is the diamondback terrapin (*Malaclemys terrapin*). Several species of threatened or endangered Atlantic sea turtles, including the green turtle (*Chelonia mydas*), Kemp's ridley turtle (*Lepidochelys kempi*), hawksbill turtle (*Eretmochelys imbricata*), loggerhead turtle (*Caretta caretta*), and leatherback turtle (*Dermochelys coriacea*) may visit the estuary but there is no historical record of occurrence or nesting (Black & Veatch 2011).

2.3.2 Estuary Aquatic Habitat Characteristics

As described in **Section 2.2.3**, the Site is only inundated during high tide. Fish and shellfish predominantly reside in the creeks and make use of the marsh areas only during high tide conditions when the marsh is inundated. However, the use of different areas of the marsh by aquatic organisms (e.g., fish, shellfish, grass shrimp) depends on the proportion of time that each area is inundated. The location and duration of inundation depends on bank elevation, which is variable and is illustrated using light detecting and ranging (LiDAR) mapping of mean high high water (MHHW) and mean low low water (MLLW) (**Figures 2-6A** and **2-6B**). During MLLW vegetated marsh areas and creeksare predominantly exposed; water is present only in portions of the creeks. Photos 2-5A and 2-5B in **Figure 2-5** depict LCP Ditch at low and high tide, respectively. This exposed marsh area is used by non-aquatic organisms such as fiddler crabs which emerge from their burrows to forage on organic carbon and algae (Photo 2-5K in **Figure 2-5**). The LiDAR data, along with field observations, and hydrologic estimations were used to characterize the inundation cycle. Based on the model and an understanding of tidal fluctuations, Domain 1 may only be inundated 5% to 20% of the time, which equates to approximately 1 to 4 hours a day, depending on the elevation at any particular point in Domain 1 (**Table 2-2**). This is particularly relevant to understand the types of ecological exposures that occur for wildlife in the marsh, as aquatic organisms readily move into and out of the marsh with the ebb and flood tides.

As summarized in **Section 2.2.2** and described in **Appendix A**, groundwater seeps are located along the upland portion of the Site (Figure A7 in **Appendix A**). Groundwater seeps typically flow only after heavy rainfall events, and are diffused across the marsh with relatively small discharge.

2.3.3 Marsh Dieback

Although most of the Site has high plant productivity, there are some areas where *Spartina* growth is sparse. From 2001 to 2002, Georgia and parts of South Carolina experienced a widespread coastal marsh dieback event in which approximately 2,000 acres of marsh were adversely affected. Symptoms of dieback included color change and complete rhizome failure in affected plants (Hurley n.d, Mackinnon 2006). Onset was rapid (one to two growing seasons), but growth impacts were transitory, as indicated in a 2003 study by Ogburn and Alber (2006), which found no significant difference in growth in transplanted *Spartina* between vegetated marshes with and without dieback. However, rhizomes from dieback marshes could not be re-sprouted when transplanted from affected areas and watered (Mackinnon and Huntington 2005).

To date, no definitive cause of the marsh dieback has been determined (Mackinnon and Huntington 2005). Georgia Regional Council (GRC) continues to monitor eight sites (with and without dieback) quarterly for biological, physical, and chemical parameters (Mackinnon and Huntington 2005). Although plant densities have increased in dieback areas (Mackinnon and Huntington 2005, Alber 2008), new areas of dieback were reported in both Georgia and South Carolina in 2007. One of the GRC's monitoring stations is near the Site, and areas within the Site and outside the Site were observed to be impacted by the dieback during a January 2012 Site visit (See photo 2-5L in **Figure 2-5**). Another potential source of stress to the Site may be a former county landfill that is located within Domain 3. Along the margins of the landfill, *Spartina* is sparse and debris is scattered (See photo 2-5M in **Figure 2-5**). Although the landfill is no longer operational, it does not appear that closure has occurred and areas of exposed waste are visible.

2.3.4 Overview of Restoration and Recovery

Thirteen acres of the Site in Domain 1 were remediated in 1998 and 1999 (**Figure 2-7**). The remediation included the eastern portion of the LCP Ditch. Prior to remediation, a temporary sheet pile wall was erected to isolate the area. The area was excavated and subsequently backfilled with clean sediment to restore the area to pre-removal elevations that were within the range for *Spartina* regrowth. *Spartina* sprigs were planted in the remediated area three to five days after the temporary piling wall was removed to ensure that tidal fluctuations were well established over the area to aid in regrowth (See photo 2-10A on **Figure 2-8**). As a result of the temporary sheet pile wall, the portion of Eastern Creek located near the southern end of the remediated area adjusted its course. In addition, tidal tributaries to Eastern Creek that extended landward were shortened. These modified natural features and the footprint of the marsh removal are visible in aerial photographs (See photo 2-10B on **Figure 2-8**).

Case studies indicate that salt marshes can become completely revegetated within 2 to 15 years depending on the elevation and tidal regime (Minello n.d.; Able et al. 2008; Broome et al. 1986, 1988; Webb and Newling 1985; Woodhouse et al. 1976; Leonard et al. 2002; LaSalle et al. n.d.; Edwards and Proffitt 2003; Craft et al. 2002; 2003). Within two years after remediation, *Spartina* filled the remediated area of the Site (See photo 2-10C on **Figure 2-8**). After three to four years, the area was indistinguishable from the surrounding marsh (see photo 2.5E in **Figure 2-5**). These site-specific restoration time frames are consistent with the other observations noted for created salt marsh sites. Other recovery metrics include the amount of organic carbon (TOC) in sediment and nitrogen recycling, both of which can take from 5 to more than 10 years to fully recover. This delay relative to *Spartina* regrown is evident at the remediated area at the Site, as TOC is low (below 2.5 %) when compared to other areas of the marsh (**Figure 2-9**). The percent of fine materials in the sediment of the remediated area is also low relative to other areas of the marsh; percent fines influence the benthic community habitat (**Figure 2-10**).

The baseline ecological risk assessment (BERA) (Black & Veatch 2011) found no evidence that the function of marsh grasses and the microbiotic community at the Site differs from that of similar marsh habitats along the southeast coast. This lack of evidence of a difference in function is supported indirectly by studies that demonstrate that mercury and Aroclor 1268 have no significant effect on microbes found on *Spartina*, which are important biotic components in a healthy salt marsh ecosystem as they aid in the breakdown of vegetation (Wall et al. 2001, Newell et al. 2000). Furthermore, the BERA reported no concerns related to salt marsh function, and instead focused on concerns related to potential toxicity to fish and wildlife.

2.4 Summary of Remedial Investigation Results

This section summarizes the results of prior environmental investigations related to:

- Delineation of chemicals in sediment
- Evaluation of potential human health risks
- Evaluation of potential risks to ecological receptors

This summary focuses on the four COCs addressed in the BERA (Black & Veatch 2011): mercury, Aroclor 1268, lead, and total polycyclic aromatic hydrocarbons (PAHs).

The human health baseline risk assessment (HHBRA) (EPS 2011a) and BERA (Black & Veatch 2011) estimated current risks to human and ecological receptors in the absence of remediation (i.e., baseline). Baseline risks are typically evaluated to determine the need for remedial action. Risk assessment is a framework that uses information about the toxicity of COCs to estimate a theoretical probability of adverse health effects in humans and ecological receptors potentially exposed to site-related chemicals. This process determines whether concentrations of chemicals in environmental media (i.e., soil, water, sediment, biological tissue) pose an unacceptable risk as defined by regulatory benchmarks. When reviewing the results of any risk assessment it is important to recognize that the risk estimates are intended to facilitate those determinations, but are not necessarily predictive of adverse health effects for any person or ecological receptors. For example, given that the current rate of cancer in the US is between one-in-two and one-in-three (ACS 2011), predictions of cancer risks associated with chemical exposures within the acceptable range of one-in-ten-thousand to one-in-one-million are not discernible from the background incidence of cancer.

2.4.1 OU1 – Delineation of Chemicals in Sediment and Surface Water

The delineation of chemicals in sediment was conducted by USEPA in 1995, Geosyntec in 1995-1999, PTI Environmental Services (PTI) in 1996, the National Oceanic and Atmospheric Administration (NOAA) in 1997, and CDR Environmental in 2000 to 2007. Additional surface sediment investigations were performed by ENVIRON and Anchor QEA in August and October 2012 as part of the development of this FS. The August and October 2012 sampling events were conducted in accordance with the approved Sediment Investigation Work Plan and the Sediment Investigation Work Plan Addendum (ENVIRON and Anchor QEA 2012a, 2012b). The 2012 sampling locations, analytical data, laboratory reports, and data validation reports are provided in Appendix C. Results from these investigations were used to delineate sediment concentrations of the four COCs: mercury, Aroclor 1268, lead, and total PAHs. This section summarizes COC concentrations in the surface and subsurface sediments, for investigations from 1995 through 2012.

Surface Sediment COC Concentrations

Surface sediment samples are defined as those collected from the interval of 0 to 1 foot below the sediment surface in order to be consistent with the BERA sampling. When mapping and analyzing surface-sediment data, the following guidelines were followed:

- Data management for individual sampling events
  - Data from the 0 to 0.5-foot interval was preferentially used from every location, when available, as this was the sample interval identified in BERA monitoring 2003 to 2007.
  - Data from the 0 to 1-foot interval was used when the 0 to 0.5-foot interval was not available, as this was the case for BERA monitoring in 2000 and 2002.
  - Data were averaged over the upper 0 to 0.5-foot interval when multiple samples were collected, as was the case in 1995 and 1996 when, for example, samples were collected over 2-inch intervals at several locations (note that an occasional sample started in the 0 to 0.5-foot interval and slightly extended below 0.5 feet, such as a sample from 0.39 to 0.59 feet).[1]
- Data management for multiple sampling events at a single location over time
  - Data were averaged at each location for any sample available in the upper 0 to 0.5-foot interval and 0 to 1-foot interval, providing these samples were identified for inclusion based on the guidelines for individual sampling events above.

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[1] Only 8 locations sampled in 1995 and 1996 samples were collected between the intervals of 0.5-to-1-foot. This interval was not included because at each of these locations, the interval above it was also sampled (i.e., the upper 0-to-0.5 foot interval was available and was preferentially selected in accordance with the BERA 2003 to 2007 monitoring interval).

- Three historical locations were resampled in 2012 (one location in Domain 3 and two locations in south Purvis Creek); the 2012 surface chemistry results replaced the historical values at these locations.

Figures 2-11 through **2-14** present the distribution of OU1 surface sediment concentrations for mercury, Aroclor 1268, lead, and total PAHs, respectively. Where neighboring data points overlap in **Figures 2-11** through **2-14**, the mapping algorithm was programmed so that samples with higher concentrations always overlay samples with lower concentrations—this approach prevents lower-concentration sample locations from obscuring the presence of higher-concentration sample locations.

Mercury

Average surface sediment mercury concentrations in OU1 are shown in **Figure 2-11**. Mercury concentrations greater than 10 milligrams per kilogram (mg/kg) are typically found in Eastern Creek and LCP Ditch. Higher concentrations are found in portions of Eastern Creek and LCP Ditch where limited or no sediment removal was conducted during the remediation of Domain 1 in 1998 to 1999. Mercury concentrations greater than 10 mg/kg also are observed in surface samples collected from the marsh, near the boundary of Eastern Creek and LCP Ditch. Concentrations are lower throughout the rest of the estuary, and typically range from 1 to 5 mg/kg, except for isolated areas in the Western Creek Complex and Domain 3 Creek. Mercury concentrations are even lower in Domain 4 West which is located west of a tidal divide between Turtle River and Purvis Creek.

Aroclor 1268

Surface sediment Aroclor 1268 concentrations exhibit a spatial pattern generally consistent with that of mercury, with the highest sediment concentrations observed in LCP Ditch and Eastern Creek (**Figure 2-12**). The Aroclor 1268 concentrations in these areas are generally greater than 10 mg/kg. Similar to mercury, Aroclor 1268 concentrations are lowest in the vegetated marsh areas and in Domain 4 West.

Lead

Surface sediment locations with elevated lead concentrations occur in the Dillon Duck feature, in the nearby Domain 3 Creek, and in isolated portions of Domain 2 (**Figure 2-13**). The lead concentrations in these areas are greater than 100 mg/kg in some locations. Surface concentrations of lead are generally less than 50 mg/kg in other areas of OU1, except for isolated areas in Domain 4 East, Eastern Creek and Western Creek with concentrations greater than 50 mg/kg.

Total PAHs

Total PAH sediment concentrations were determined by summing the concentrations of the 18 individual PAHs[2] analyzed during the remedial investigation sediment sampling. For non-detect results, half the detection limit was used. During the 1995-1999 sampling events, elevated

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[2] Total PAH compounds include acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, 1-methynaphthalene, 2-methynaphthalene, naphthalene, phenanthrene, and pyrene.

detection limits greater than 400 micrograms per kilogram (µg/kg) were frequently reported; these non-detect results were not included in the total PAH summation.[3]

The distribution of surface sediment total PAH concentrations are shown in **Figure 2-14**. In general, surface concentrations are less than 5 mg/kg in the majority of the marsh and tidal channels. Concentrations greater than 10 mg/kg are located in isolated locations of LCP Ditch, Domain 3 Creek, Eastern Creek, and the westernmost segment of the Western Creek Complex (headwater portion of the channel).

Subsurface COC Concentrations

The vertical distribution of mercury, Aroclor 1268, lead, and total PAHs in the upper few feet of marsh sediment was evaluated by PTI as part of the 1994 and 1996 sampling investigations. Cores were collected from Domains 1, 2, and 3, Purvis Creek and LCP Ditch. Cores analyzed for mercury and Aroclor 1268 found that higher concentration were typically found in the 0 to 0.8 foot interval with lower concentrations approaching non-detect below 0.8 feet (0.8 to 1.2 feet and 0.8 to 1.6 feet). Cores collected for lead and total PAHs typically contained concentrations below 40 mg/kg and 4 mg/kg in these intervals, respectively.

Additional depth profiling was performed as part of the marsh exploration sampling in 1997. During this investigation, sampling was performed to depths of up to 8 feet in the Domain 1 Remediation Area. Beyond depths of 1 foot, Aroclor 1268 concentrations were typically non-detect, and mercury concentrations were below 10 mg/kg, except for core locations directly adjacent to LCP Ditch and the FFDA. While lead vertical profiles were confined to a depth of 3 feet, at depths greater than 1 foot lead concentrations were less than 50 mg/kg. Cores from this investigation were not analyzed for total PAHs. Vertical profiles are shown in the OU1 RI report (EPS and ENVIRON 2012).

COC Concentrations in Surface Water

Surface water concentrations for dissolved (total) mercury and dissolved (methyl) mercury are summarized and compared to the USEPA (2013a) National Recommended Water Quality Criteria (NRWQC) and GAEPD (2013) Water Quality Standards (WQS) on **Figure 2-15A**. This figure identifies that dissolved (total) mercury and dissolved (methyl) mercury do not exceed either the NRWQC or the Georgia WQS. The USEPA NRWQC identifies that dissolved phase data (total mercury or methyl mercury) are the appropriate values for comparison to NRWQC, when available. The Georgia WQS do not state that dissolved phase data are the appropriate values for comparison but rather identifies that total phase data should be used for the comparison. Therefore, the total mercury values for surface water are compared to the Georgia WQS (**Figure 2-15B**). **Figure 2-15A** identifies that some detections of total mercury exceed the

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[3] The approach for summing total PAH concentrations with non-detect results was reviewed with the Agencies during a conference call on August 2, 2012. Non-detect samples with elevated detection limits (greater than 400 µg/kg) were not included in the summation, because if half the detection limits were used, it could result in the exceedance of the total PAH Remedial Goal, even though no PAH compounds were actually detected. An uncertainty analysis related to this topic is considered with regard to Remedy Effectiveness. Results showed that this uncertainty had no significant impact on the characterization of PAHs, because locations with elevated PAHs were sampled in subsequent events and at nearby locations with lower detection limits.

Georgia WQS, including at least one detected concentration from Troop Creek, a reference location. None of the detected concentrations exceed the NRWQC. Furthermore, **Figure 2-15B** identifies that the NRWQC (940 nanograms per liter [ng/L]) is more than an order of magnitude greater than the Georgia WQS (25 ng/L). Whereas the toxicity studies that are the basis of the NRWQC are readily available, the basis of the Georgia WQS is not readily available. Therefore, the exceedances of the Georgia WQS are difficult to interpret.

The surface water data for Aroclor 1268 are compared to the NRWQC and Georgia WQS for polychlorinated biphenyls (PCBs) on **Table 2-3**. As indicated on **Table 2-3,** the NRWQC and Georgia WQS are the same value. In addition, **Table 2-3** indicates that the majority of data to date for PCBs in surface water reflect non-detected values where the detection limits exceed the NRWQC and the Georgia WQS. In 2006 and 2007, lower detection limits were achieved and some areas showed detections of the NRWQC and Georgia WQS.

2.4.2 Human Health Risk Assessment

The final OU1 HHBRA (EPS 2011) was approved by USEPA in a letter dated November 30, 2011 (USEPA 2011), and was conducted in a manner consistent with the risk assessment framework outlined in USEPA's *Risk Assessment Guidance for Superfund (RAGS), Volume I, Part A* (USEPA 1989) including updates and supplemental guidance. The overall goal of the HHBRA was to evaluate whether COCs detected in post-removal action sediment and consumable biota present potential exposure and health risks to future Site trespassers or consumers of biota in order to determine the need for remedial action. The HHBRA was a four-part process consisting of the following components: data analysis and COC selection; exposure assessment; toxicity assessment; and risk characterization.

Data Analysis and COC Selection

USEPA (2010a) used analytical data from surface sediment and biota samples (fish and clapper rail) collected from the Site to identify COCs and to evaluate human exposure to those COCs (**Table 2-4**). Sediment samples from Purvis Creek and the Turtle River were excluded as these areas remain inundated at low tide and afford no opportunity for human exposure. The biological dataset used in the HHBRA included samples of finfish and shellfish likely to be consumed by humans (e.g., red drum, spotted seatrout), as well as those less likely to be consumed (e.g., spot, striped mullet). The biological dataset also included samples of breast tissue from clapper rail, a small game bird inhabiting coastal marshes, which were collected from the estuary adjacent to the Site in 1995 (i.e., prior to the remediation of Domain 1).

Sediment and biota COCs were identified by comparing the maximum detected concentration of each constituent with the appropriate USEPA Regional Screening Levels (RSLs) (USEPA 2010b, c). The maximum detected concentrations of the inorganic constituents in sediments were also compared with twice the mean site-specific background concentrations.

Exposure Assessment

For risk assessment purposes, the term "exposure" is defined as contact with constituents in environmental media at the outer boundaries of the body, such as the gastrointestinal tract (for ingestion route) and skin (for the dermal route). Both reasonable maximum exposure (RME) and central tendency exposure (CTE) were evaluated. The following human receptors were evaluated:

- Marsh trespasser – an adolescent or adult who visits marsh areas adjacent to the Site for up to 52 days per year for a total of 30 years in an RME scenario and for 6 days per year for 8 years in a CTE scenario. More accessible areas were included in this evaluation.
- Recreational fish consumer – consumes fish from areas proximate to the Site (e.g., 26 meals per year for 30 years for adults). This scenario uses data on the amount of recreationally-caught fish consumed by children, adolescents, and adults in the southeastern US (USEPA 1997a) and makes the very conservative assumption that all of this consumption occurs at the Site.
- High quantity fish consumer – consumes more locally-caught fish than the typical recreational angler (e.g., 40 meals per year for 30 years for adults) (DHHS 1999). Similarly, this is based on the very conservative assumption that all fish consumption occurs at the Site.
- Shellfish consumer – consumes shellfish (white shrimp and blue crab) directly from the Site (e.g., 19 meals per year for 30 years for adults); estimates are based on the amount of shellfish consumed by children, adolescents, and adults in the US (USEPA 1997a). Again, this is based on the very conservative assumption that all of this consumption occurs at the Site.
- Clapper Rail consumer – consumes clapper rail. In order to estimate consumption rates for clapper rail, the risk assessment used USEPA consumption rate data for all kinds of wild game ingestion for children, adolescents, and adults (USEPA 1997a) as a starting point. The risk assessment then derived a clapper rail consumption rate by assuming that people might eat clapper rail at a rate that was 10% of the total game consumption rate. The risk assessment also assumed that 100% of clapper rail that people might consume would come from the Site. Coupled with the fact that clapper rail is not commonly consumed (Geraghty & Miller 1999) and is unlikely to be hunted at this location due to the proximity of more desirable and accessible areas, this is a very conservative risk approach.

Toxicity Assessment

The toxicity assessment provides a description of the relationship between a dose of a chemical and the potential for an adverse health effect. For risk assessment purposes, potential effects of constituents are separated into two categories: cancer and noncancer. With the exception of Aroclor 1268, cancer slope factor (CSF) and reference dose (RfD) values specific to each COC were obtained from the December 2010 edition of USEPA's RSL Table (USEPA 2010b). USEPA has not developed CSFs or RfDs specific to Aroclor 1268. In this assessment the high end CSF of 2 milligrams per kilograms per day (mg/kg-day) was applied consistent with USEPA guidance for evaluation of PCBs in biota soil and sediment. For evaluation of noncancer endpoints the RfD for Aroclor 1016 was applied to evaluate Aroclor 1268 because mammalian studies on Aroclor 1268 were not available at the time of the HHBRA and it was assumed that Aroclor 1016 was more similar to Aroclor 1268 than other Aroclors.

Risk Characterization

The risk characterization integrates the exposure estimates for Site receptors with the representations of the potential toxicity derived for each COC. This integration yields quantitative estimates of theoretical excess lifetime cancer risks and noncancer hazard quotients for COCs. These estimates provide a quantitative representation of the relationship between hypothetical exposures and potential toxic responses.

Theoretical excess lifetime cancer risk (ELCR) estimates for receptors are expressed as an upper-bound probability of additional lifetime cancer risk due to exposure to site-related chemical constituents. These estimates do not reflect an individual's existing lifetime risk of developing cancer—which is, without site exposure, already between one-in-two (2×10^{-1} or 2E-1) and one-in-three (3×10^{-1} or 3E-1) (ACS 2011)—but only the additional incremental risk that is theoretically related to exposure to Site COCs. Cancer risk estimates were compared with the USEPA target range of 10^{-4} (1 in 10,000) to 10^{-6} (1 in 1,000,000) for incremental cancer risk identified under the NCP (40 CFR Part 300). Calculated upper-bound ELCR estimates less than 1×10^{-6} are considered to be insignificant, and ELCR estimates greater than 1×10^{-4} may require further characterization, but not necessarily remedial action or other risk reduction measures (USEPA 1991).

Potential noncancer risks for individual COCs are expressed as hazard quotients (HQs) and a hazard index (HI) which is the sum of HQs (USEPA 1989). For each receptor scenario, HQs are calculated as the ratio of the estimated daily intake of each COC to the corresponding RfD for that COC. Where the average daily dose estimated for the COC exceeds the RfD, the HQ exceeds 1. HQ or HI of 1 is typically considered a threshold requiring further evaluation since it indicates that exposure could be higher than the no effect dose represented by the RfD. However, because of the conservative nature of RfDs and the uncertainties surrounding the RfD, HQ values greater than one do not necessarily indicate that harm will occur from this exposure level.

Risk / Hazard Summary

The theoretical cancer risks and potential noncancer hazards estimated for each receptor are summarized below **(Table 2-5**[4]**)**:

Carcinogenic effects:

- Only the RME high-quantity fish consumer scenario has an ELCR estimate that exceeds USEPA's target risk range of 10^{-6} to 10^{-4} and that estimate is 2×10^{-4}.
- The RME recreational fish consumer and clapper rail consumer scenarios both have ELCR estimates equal to 1×10^{-4} and so are equal to the upper-end of USEPA's target risk range.
- All of the receptor scenarios have CTE ELCR estimates below the upper end of USEPA's target risk range and all marsh trespasser RME or CTE ELCR estimates are below the upper end of USEPA's target risk range.

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[4] This table is a reproduction of Table 22 of the OU1 HHBRA Report (EPS, 2011).

Noncancer effects:

- The marsh trespasser is the only RME scenario with a cumulative HI estimate below the threshold value of 1.
- All of the RME seafood and wild game consumption scenarios have cumulative HI estimates above 1; however, since all COCs do not share same mode of action, summing across all COCs is very conservative.
- The high-quantity fish consumer scenario is the only receptor scenario with CTE HI estimates above 1.

Characterization of Uncertainties

Uncertainties are inherent in the quantitative risk assessment process due to environmental sampling results, assumptions regarding exposure, and the quantitative representation of chemical toxicity. In virtually all cases, conservative assumptions are built into the HHBRA to compensate for unavoidable uncertainty, such that resultant risk estimates are more likely to overestimate risks than to underestimate risks. Examples of uncertainty in the OU1 HHBRA where conservative assumptions were made relate to the exposure assumptions used to characterize the RME receptor scenarios, the concentrations of COCs in biota tissue used to estimate receptor intake, and the surrogate toxicity values used to characterize the potential cancer risks associated with Aroclor 1268. These assumptions are:

- An individual trespasser would walk through the Site once a week for 30 years (a total of 1,560 separate events), each time getting nearly a quarter of his body covered in sediment.
- 100% of the fish and shellfish eaten by any individual would come from the areas in the immediate vicinity of the Site, particularly when the Georgia Department of Natural Resources (GADNR) 2012 Fish Consumption Guidelines (FCGs) and posted signage generally serve to discourage the consumption of significant amounts of seafood from the area.
- A hunter would eat clapper rail obtained from the Site such that this source of clapper rail comprises 10% of the wild game that he eats.
- The potential carcinogenicity of Aroclor 1268 should be evaluated using the upper-bound CSF for high risk/persistence PCBs such as Aroclor 1254, when the tumorigenic potency of Aroclor 1268 may be at least 10-times lower (Warren et al. 2004).

The consistent application of conservative assumptions to address areas of uncertainty in the OU1 HHBRA should be considered when evaluating the need for remedial actions to address human health risks that exceed the USEPA targets.

2.4.3 Summary of the Baseline Ecological Risk Assessment

The BERA describes the likelihood, nature, severity, and spatial extent of adverse effects to ecological receptors resulting from exposure to chemicals released to the environmental media (i.e., sediment, surface water, biological tissue) in the estuary as a result of past Site activities. This information provides a basis for decisions regarding the need for remedial actions. USEPA established a general framework for conducting ecological risk assessment (USEPA 1998), which is an iterative process in which risk questions are asked, data with which to address the questions are collected and analyzed, and additional study is conducted if warranted. Ecological analyses of the Site estuary have been conducted at various stages of the process with the first assessment submitted to USEPA in 1997 (PTI and CDR 1997), followed by analyses submitted in 2001 (CDR and GeoSyntec 2001) and 2009 (CDR and EPS 2009). The final BERA Report was issued in April 2011 and encompasses approximately 1,000 pages of text, figures, tables, and appendices (Black & Veatch 2011). The following summary focuses exclusively on the 2011 BERA.

2.4.4 Data Used in the BERA

The data used quantitatively in the OU1 BERA report (Black & Veatch 2011) were generated in the post-removal action ecological monitoring event in 2000 and subsequent annual monitoring events that occurred between 2002 and 2007. The decision to use the entire post-removal action dataset, rather than just the most contemporary data, was based on an evaluation of temporal characteristics of COC concentrations in surface sediment collected from sentinel monitoring stations sampled repeatedly over that period. The BERA concluded that, with a few possible exceptions, there were no discernible concentration trends for the COCs at these sentinel stations. The BERA also concluded that there were no apparent temporal COC concentration trends in biota.

The experimental design for the OU1 BERA was established in the work plan for the 2000 monitoring event (Honeywell 2000), and with the exception of several unique amphipod toxicity studies conducted in 2006 to address specific risk questions, remained fairly consistent for the 2000 to 2007 monitoring events. The experimental design is summarized in **Table 2-6.**[5]

Problem Formulation

Problem formulation is a planning step that identifies the major questions to be addressed in an ecological risk assessment, along with the basic approaches that will be used to characterize the potential ecological risks.

Chemicals of Potential Concern

The BERA focuses on the four major Site COCs: mercury (including methyl mercury), Aroclor 1268, lead, and total PAHs. Information on the ecological toxicity of the COCs is provided in Section 3.6 of the OU1 BERA (Black & Veatch 2011). Mercury and Aroclor 1268 are of potential concern for both direct toxicological effects to lower trophic level organisms in the sediment and water column (i.e., invertebrates) and upper-trophic-level ecological receptors via bioaccumulation within the food web. Lead and PAHs are of potential toxicological concern only to lower trophic level organisms in the sediment and water column.

These four chemicals remain the primary COCs evaluated quantitatively in the BERA. However, based on subsequent rounds of sampling, the COC screening process was updated to identify other COCs in sediment and surface water samples that could potentially contribute

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[5] This table is a reproduction of Table 3-1 of the OU1 BERA Report. Additional detailed information about the specific analyses conducted at each monitoring station for each monitoring event is provided in Tables 3-2 and 3-3 of the OU1 BERA Report. The locations of the ecological monitoring stations in the Site are shown in Figures 3-3, 3-4, and 3-5 of the OU1 BERA (Black and Veatch 2011).

to ecological risks. This updated screening process involved comparing maximum detected concentrations of all target analytes to conservative screening-level ecological effects values (EEVs) recommended for this purpose by USEPA. No additional COCs were identified. Detailed information related to the updated COC screening is provided in Appendix B of the OU1 BERA (Black & Veatch 2011).

Assessment and Measurement Endpoints

Assessment endpoints are the valued attributes of ecological resources or receptors upon which risk management actions are focused. USEPA defines an assessment endpoint as “an explicit expression of the environmental value to be protected, operationally defined as an ecological entity and its attributes” (USEPA 1998). Measurement endpoints are ecological characteristics that can be measured, interpreted, and related to the valued ecological attributes selected as the assessment endpoints (USEPA 1997b, 1998a). The following assessment and associated measurement endpoints were identified for the OU1 BERA:

- *Assessment Endpoint 1 – Viability of the benthic estuarine community.* This assessment endpoint is evaluated by three measurement endpoints: 1) comparisons of concentrations of COCs in surface sediment to site-specific effects levels; 2) results of toxicity tests conducted with sensitive life stages of benthic biota exposed to surface sediment; and 3) evaluation of the indigenous benthic community.
- *Assessment Endpoint 2 – Viability of omnivorous reptiles using the estuary.* This assessment endpoint is evaluated by HQs derived from food web exposure models for diamondback terrapins (*Malaclemys terrapin*).
- *Assessment Endpoint 3 – Viability of omnivorous avian species using the estuary.* This assessment endpoint is evaluated by two basic measurement endpoints: 1) HQs derived from food web exposure models for red-winged blackbirds (*Agelaius phoeniceus*); and 2) HQs derived from food web exposure models for clapper rails.
- *Assessment Endpoint 4 – Viability of piscivorous avian species using the estuary*. This assessment endpoint is evaluated by HQs derived from food web exposure models for green herons (*Butorides striatus*).
- *Assessment Endpoint 5 – Viability of herbivorous mammalian species using the marsh*. This assessment endpoint is evaluated by HQs derived from food web exposure models for marsh rabbits (*Sylvilagus palustris*).
- *Assessment Endpoint 6 – Viability of omnivorous mammalian species using the estuary*. This assessment endpoint is evaluated by HQs derived from food web exposure models for raccoons.
- *Assessment Endpoint 7 – Viability of piscivorous mammalian species using the estuary.* This assessment endpoint is evaluated using HQs derived from food web exposure models for river otters.
- *Assessment Endpoint 8 – Viability of finfishes using the estuarine system.* This assessment endpoint is evaluated by five measurement endpoints: 1) comparisons of concentrations of COCs in surface water to general literature-based effects levels; 2) results of toxicity tests conducted with early (and sensitive) life stages of aquatic biota

exposed to COCs in surface water; 3) HQs derived from residue-based toxicity reference values (TRVs) and finfish bioaccumulation models; 4) HQs derived from residue-based TRVs and finfishes collected on-site in Purvis Creek; and 5) evaluation of the benthic community as a food source for juvenile and adult fishes.

Ecological Exposure and Effects Evaluation

The OU1 BERA describes temporal trends of COCs in surface sediment of the estuary at the Site between 2000 and 2007; the presence of chemicals in various environmental media of the Site; and describes the laboratory-, field-, and modeling-based analyses that form the basis for the risk characterization for benthic and aquatic invertebrates, fish, and wildlife receptors.

Analytical Chemistry Results for Sediment, Surface Water, and Biota

The OU1 BERA presents data on the concentrations of COCs in surface water, sediment, and biological tissue over the 2000 to 2007 monitoring period. Tables 4-1 through 4-12 of the OU1 BERA provide detailed summaries of these data. The BERA concludes that there were no discernible temporal COC concentration trends for sediment, surface water, or biota in the Site over the extended monitoring period.

Surface Water Toxicity Tests

Chronic toxicity tests with surface water from the Site were conducted in 2000 and included eight replicate measurements of survival and growth in mysid shrimp (*Mysidopsis bahia*) and four replicate measurements of survival and growth in sheepshead minnows from four stations in the Site and two reference stations. For the mysids, the mean survival and growth was similar to the control and reference stations. However, for the sheepshead minnows, only the tests conducted with water collected from Station C-33 in Domain 3 had a mean growth rate that was statistically lower than the control and Crescent River reference station. Two out of the four replicates from this station also exhibited survival less than 80%, which is the minimum acceptable survival for control organisms. The results of the surface water toxicity tests are summarized in Tables 4-13 and 4-14 of the OU1 BERA (Black & Veatch 2011).

Sediment Toxicity Tests with Laboratory-Cultured Invertebrates

Sediment toxicity tests with the amphipod *Leptocheirus plumulosus* were conducted during each monitoring event between 2000 and 2006. Measurement endpoints were survival, growth, and reproductive response. Table 4-14 of the OU1 BERA summarizes the results of the amphipod toxicity tests by year and Tables 4-15 through 4-19 of the OU1 BERA summarize the results of the amphipod toxicity tests conducted in 2006, when the potential causes of sediment toxicity were evaluated by a comprehensive set of amphipod studies that included a site-specific toxicity identification evaluation (TIE), equilibrium partitioning study for metals, and an Apparent Effects Threshold (AET) study.

Sediment toxicity tests with the grass shrimp were conducted during each monitoring event between 2000 and 2005. Measurement endpoints included embryo development rate, embryo hatching rate, ovary maturation rate, survival, and DNA strand damage in embryos. Table 4-21 of the OU1 BERA Report summarizes the results of the grass shrimp toxicity tests by year.

Using all valid toxicity test data, a variety of site-specific sediment effect concentrations (SEC) were calculated separately for each of the assessment endpoints for amphipods and grass shrimp based on common approaches presented in the scientific literature (Long and Morgan 1990, MacDonald et al. 1996, Cubbage et al. 1997). The SEC metrics included AETs, threshold effect levels (TELs), probable effects levels (PELs), effects range-low (ER-L), and effects range-medium (ER-M). These SECs, shown in Tables 4-20 and 4-22 of the OU1 BERA, provided a range of benchmarks to assess potential toxicity.

Sediment Toxicity Tests with Indigenous Grass Shrimp

Sediment samples from the Site also were evaluated in chronic toxicity tests using grass shrimp indigenous to the Site and Blythe Island. These tests were limited to two measurement endpoints (embryo hatching rate and DNA strand damage in embryos), and conducted during each monitoring event between 2002 and 2007. Statistically significant reductions in these measurement endpoints (as compared with reference sediments) were only observed in tests of sediment samples from LCP Ditch, the bank of LCP Ditch, and Eastern Creek. The results of these studies are summarized in Table 4-24 of the OU1 BERA (Black & Veatch 2011).

Benthic Community Studies

Field-based studies of the benthic community structure and function were limited. Benthic community surveys conducted at four stations in the Site during the 2000 monitoring event revealed reduced number of taxa, individual organisms, and density at two of the four Site stations as compared with two reference stations. These two stations were both in areas characterized by relatively high concentrations of COCs in the sediment. Polychaetes were the dominant species in the reference locations and Site stations. The results of this study are summarized in Table 4-25 of the OU1 BERA (Black & Veatch 2011).

Fiddler crab abundance in the Site was sampled in a single-season study at a single location characterized by relatively high body burdens of COCs (Black & Veatch, 2011). Exposure to COCs was not quantified in the BERA. Abundance of fiddler crabs at the Site was similar to that reported more than 30 years ago at the relatively pristine Duplin Estuary Marsh in Georgia (Wolf et al.1975).

Development of Hazard Quotients for Fish

Exposures of finfish to COCs and the potential for adverse effects as a result of those exposures were evaluated in the BERA using two different approaches. In the first approach, concentrations of COCs in finfish tissue (in units of mg/kg wet weight) via surface water and prey items, were calculated using models published in the scientific literature (Evans and Engle 1994, Clark et al. 1990, Bergen et al. 1993, Gobas 1993) and compared with tissue residue-based TRVs based on no observed adverse effects levels (NOAELs) and lowest observed adverse effect levels (LOAELs) to generate HQs. In the second approach, measured COCs concentrations in the tissue of finfish collected from the Site were compared with the same tissue residue-based NOAEL and LOAEL TRVs to generate HQs. Using both approaches, HQs were developed for red drum, silver perch, black drum, spotted seatrout, and striped mullet.

The exposure assumptions and tissue residue-based TRVs used in the finfish exposure models are shown in Tables 4-26 and 4-27, respectively, of the OU1 BERA. The calculated HQs based on modeled and empirically-measured fish tissue concentrations are provided in Tables 4-28 and 4-29, respectively, of the OU1 BERA Report.

Development of Hazard Quotients for Wildlife

Exposures of wildlife receptors to COCs and the potential for adverse effects as a result of those exposures were evaluated in the BERA by calculating daily intakes of COCs (in units of milligrams per kilogram body weight per day [mg/kg BW-day]) and comparing these calculated intakes with dietary TRVs based on NOAELs and LOAELs to generate HQs. Using this approach, HQs were developed for diamondback terrapin, red-winged blackbird, clapper rail, green heron, marsh rabbit, raccoon, and river otter.

The exposure assumptions and dietary TRVs used in the wildlife exposure models are shown in Tables 4-26 and 4-27, respectively, of the OU1 BERA Report. The calculated HQs for wildlife receptors are provided in Table 4-30 of the OU1 BERA Report (Black & Veatch 2011).

Risk Characterization for Assessment Endpoints

Risk characterization involves the integration of exposure and effects data to evaluate the likelihood of adverse effects. The BERA for the Site evaluates potential risk pertaining to eight assessment endpoints using one or more measurement endpoints to evaluate each of the assessment endpoints. The results associated with these measurement endpoints serve as lines of evidence (LOE) to support the risk characterization.

Benthic Estuarine Community (Assessment Endpoint 1)

Three basic measurement endpoints were employed to evaluate the viability of the structure and function of the benthic estuarine community at the Site. These endpoints were:

- Comparisons of concentrations of COCs in surface sediment with site-specific effects levels
- Results of toxicity tests conducted with sensitive life stages of benthic biota exposed to surface sediment
- Evaluation of the indigenous benthic community

Concentrations of total mercury, Aroclor 1268, lead, and total PAHs in creek and marsh surface sediment exceeded their site-specific SECs. Potential causes of sediment toxicity were evaluated in 2006 by a comprehensive set of amphipod studies that included a site-specific TIE study, an equilibrium partitioning study for metals, and an AET study. The AET study evaluated survival, growth, and/or reproduction of lab-cultured amphipods exposed to surface sediment samples collected from 150 locations in Eastern Creek, LCP Ditch, and Western Creek Complex. Endpoints were often significantly reduced relative to controls and some reference areas. The OU1 BERA concluded that the observed toxicity appeared to be caused by COCs and, to a limited extent, other metals but also acknowledged that there were no discernible COC exposure-response relationships of high predictive value, and toxicity was substantially influenced by other factors including TOC, sulfide, and grain size.

Sediment toxicity test results with lab-cultured grass shrimp suggest that grass shrimp may be more sensitive than amphipods. For example, reproductive TELs for embryo development and hatching success from exposure to mercury in sediments ranged from 1.4 to 3.9 mg/kg, while the reproductive TEL for amphipods exposed to mercury was 4.9 mg/kg.

Hatching success and DNA strand damage of embryos produced from indigenous grass shrimp throughout the 2002 to 2007 study period deviated statistically (and adversely) from control conditions in LCP Ditch, the bank of LCP Ditch, and Eastern Creek. An evaluation of the indigenous benthic community at the Site suggested HQ values less than that predicted by laboratory-based studies. In a single field evaluation conducted in 2000, the differences in metrics of the macrobenthos community between Site and reference areas included a lesser number of taxa, individuals, and density of individuals at two of the four Site stations. These stations included C5 (at the mouth of LCP Ditch) and C33 (at the marsh/upland border in Domain 3). The stations in Purvis Creek and Eastern Creek were within the range seen in reference areas for total taxa and above the range seen in the reference areas for total individuals and mean density, as enumerated on Table 4-25 of the BERA. Dominance by polychaetes was characteristic of all Site and reference stations.

The OU1 BERA concluded that these LOE for collectively evaluating the viability of the structure and function of the benthic estuarine community at the Site indicate that the potential for risk associated with COCs and non-COCs is evident, particularly in LCP Ditch and Eastern Creek.

Omnivorous Reptiles (Assessment Endpoint 2)

One LOE was used to evaluate the viability of omnivorous reptilian species using the Site: HQs derived from food web exposure models for diamondback terrapins. Because all HQs derived for diamondback terrapins were substantially below 1, the OU1 BERA concluded that there is no potential risk to the viability of omnivorous reptiles using the Site.

Omnivorous Birds (Assessment Endpoint 3)

Two LOEs were used to evaluate the viability of omnivorous avian species using the Site: 1) HQs derived from food web exposure models for red-winged blackbirds and 2) HQs derived from food web exposure models for clapper rails. The following is a summary of the findings:

- All food web HQs (NOAEL and LOAEL) for inorganic mercury, Aroclor 1268, and lead were below 1 for both red-winged blackbirds and clapper rails, indicating no significant risk.
- For red-winged blackbirds, modeled NOAEL and LOAEL HQs for methyl mercury were at or below 1 in all domains.
- For clapper rails modeled for exposure to methyl mercury all LOAEL HQs were less than 1. NOAEL HQs were slightly greater than 1 in Domain 1 (3.0), Eastern Creek (2.6), and LCP Ditch (1.7).

Based on these findings, the OU1 BERA concluded that the overall potential for risk to omnivorous birds at the Site is minimal.

Piscivorous Birds (Assessment Endpoint 4)

One LOE was used to evaluate the viability of piscivorous avian species using the Site: HQs derived from food web exposure models for green herons. The following is a summary of the findings:

- All food web HQs (NOAEL and LOAEL) for inorganic mercury, Aroclor 1268, and lead were below 1 for green herons, indicating no potential for risk.
- All NOAEL HQs generated by the green heron modeled for exposure to methyl mercury exceeded 1 (1.4 to 10.6).
- LOAEL HQs for green herons modeled for methyl mercury exposure at the Site exceeded 1 in Domain 1 (2.8), Eastern Creek (3.5), and LCP Ditch (1.5).

Based on these findings, the OU1 BERA concluded that potential risk to the viability of piscivorous avian species at the Site from mercury is moderate.

Herbivorous Mammals (Assessment Endpoint 5)

One LOE was used to evaluate the viability of herbivorous mammalian species using the Site: HQs derived from food web exposure models for marsh rabbits. The following is a summary of the findings:

- All NOAEL and LOAEL HQs for inorganic mercury, methyl mercury, and lead were below 1 for marsh rabbits, indicating no potential for risk.
- For marsh rabbits modeled for exposure to Aroclor 1268 (based on a TRV for Aroclor 1254), all LOAEL HQs were less than 1. The NOAEL HQ was slightly greater than 1 in Domain 1 (3.0).

Based on these findings, the OU1 BERA concluded the potential for risk to herbivorous mammals foraging within the Site is minimal.

Omnivorous Mammals (Assessment Endpoint 6)

One LOE was used to evaluate the viability of omnivorous mammals foraging within the Site: HQs derived from food web exposure models for raccoons. The following is a summary of the findings:

- All NOAEL and LOAEL HQs for inorganic mercury, methyl mercury, and lead, were below 1 for raccoons, indicating no potential for risk.
- For raccoons modeled for exposure to Aroclor 1268 (based on a TRV for Aroclor 1254), all LOAEL HQs were less than 1. NOAEL HQs were slightly greater than 1 in Domain 1 (2.6) and Domain 2 (1.1).

Based on these findings, the BERA concluded that the potential for risk to the viability of omnivorous mammals using the Site is minimal.

Piscivorous Mammals (Assessment Endpoint 7)

One LOE was used to evaluate the viability of piscivorous mammals foraging within the Site: HQs derived from food web exposure models for river otters. The modeling study for river otters generated Site NOAEL HQs for Aroclor 1268 (based on a TRV for Aroclor 1254) that ranged from 0.1 to 3.9. No LOAEL-based HQ for Aroclor 1268 exceeded 1. In addition, no risk of adverse effects was predicted for mercury or lead exposures.

Based on these findings, the BERA (Black & Veatch 2011) concluded that the potential risk to the viability of piscivorous mammalian species using the Site is minimal.

Finfish (Assessment Endpoint 8)

Five LOEs were used to evaluate the viability of finfish inhabiting the Site:

1) Comparisons of concentrations of COCs in surface water to general literature-based effects levels

2) Results of toxicity tests conducted with sensitive life stages of aquatic biota exposed to COCs in surface water

3) HQs derived from food web exposure models for upper trophic level fish

4) HQs derived from measured residues in field-collected fish

5) Evaluation of the benthic macroinvertebrate community (as a food source for juvenile and adult fishes)

The following is a summary of the findings:

- The highest concentration of total mercury measured in surface water of the Site (188 ng/L) in Eastern Creek in 2000) is less than the criterion continuous concentration (CCC) of 940 ng/L. The highest concentration of dissolved lead in water (2.5 micrograms per liter (µg/L) in LCP Ditch during 2000) is below the CCC of 8.1 µg/L. No criteria have been developed specifically for Aroclor 1268.
- Laboratory toxicity tests designed to evaluate chronic toxicity of “whole” surface water from the Site to mysid shrimp and sheepshead minnows generated similar results. Mean survival of mysids exposed to surface water from the Site and two reference locations ranged from 92.4% to 100%, which was greater than the minimum acceptable survival for control organisms (80%). Mean growth (measured as weight) of mysids exposed to surface water from the Site and from reference locations exceeded the weight of control organisms. Survival of sheepshead minnows exposed to the same surface water ranged from 80% to 100%, which was at least equal to the minimum acceptable survival for control organisms (80%). Mean growth of fish exposed to Site surface water was statistically similar to weight observed for at least one reference location.
- The mean LOAEL HQ derived using a fish bioaccumulation model for methyl mercury was 2.9. Using three different fish bioaccumulation models for PCBs, mean LOAEL HQ values for Aroclor 1268 ranged from 0.5 to 1.4. The modeled tissue concentrations on which these HQs are based are generally higher than the measured concentrations in most species of fish collected from the Site.
- When HQs were derived based on measured concentrations in field-caught fish from the Site, mean LOAEL HQs for methyl mercury slightly exceeded 1 in silver perch (1.3), black drum (1.1) and spotted seatrout (1.9). Mean LOAEL HQs for Aroclor 1268 slightly exceeded 1 in silver perch (1.1), black drum (1.1), and stripped mullet (2.5).

- Evaluation of the benthic macroinvertebrate community in the Site did not identify a limitation of this source of food to fishes, although toxicity to benthic organisms may limit food for fish in portions of LCP Ditch, Eastern Creek, and Western Creek Complex.

Based on an overall evaluation of these five measurement endpoints, the OU1 BERA (Black & Veatch 2011) concluded that that there is no risk to fish in the Site from direct exposure to COCs in the water column. However, the bioaccumulation modeling and field data for finfish suggest that chronic risk from mercury and Aroclor 1268 to viability of finfish indigenous to the Site is of concern.

Uncertainty Analysis

The OU1 BERA (Black & Veatch 2011) examined a variety of uncertainties associated with the components of the BERA process and considers whether these uncertainties tend to over or underestimate risks. It also presents findings from several independent studies conducted in the Site and evaluates whether those studies lend additional support to, or conflict with, the conclusions of the BERA. The most significant sources of uncertainty in the OU1 BERA are briefly described below. The application of conservative assumptions and interpretations to each of these sources of uncertainty generally results in an overestimation of risks for the assessment endpoints evaluated in the BERA.

- The evaluation of potential adverse effects to the benthic invertebrate community relied on hundreds of site-specific toxicity test measurements using both indigenous and laboratory-cultured organisms. The results of these tests suggest that Site COCs can contribute to chronic toxicity of benthic invertebrates at high COC concentrations, but toxicological responses observed at low COC concentrations also suggest the influence of other unknown factors. As such, the OU1 BERA notes that the development of remedial goal options (RGOs) for the protection of benthic invertebrates is “highly uncertain with poor accuracies” and that “only conservative assumptions were used” for this purpose.
- The evaluation of potential adverse effects to mammalian receptors from Aroclor 1268 is based on a TRV for Aroclor 1254. Appendix J of the OU1 BERA contains a detailed discussion of the relative toxicities of these two PCB mixtures and concludes that representing the toxicity of Aroclor 1268 with Aroclor 1254 TRV overestimates the potential for adverse effects to the mammalian assessment endpoints considered in the OU1 BERA.
- The evaluation of potential adverse effects to upper-trophic level fish from Aroclor 1268 is based on a tissue residue TRV derived though an extremely conservative interpretation of a toxicity study for that PCB mixture by USEPA. This TRV is based on a study published by Matta et al. (2001), in which a statistically significant growth increase was observed in mummichogs with a measured tissue level of 1.3 mg/kg (wet weight) Aroclor 1268. USEPA determined that this concentration represented an LOAEL rather than NOAEL, resulting in an overestimation of the potential for adverse effects to this assessment endpoint.
- The evaluation of potential adverse effects to upper-trophic-level fish, birds, and mammals is based on the calculation of HQs. While this has become routine in the realm of regulatory risk assessment, the practice has been criticized by Tannenbaum (2005, 2007) and others. The HQ is simply the ratio of a conservative exposure estimate and a conservative TRV, and is not a measure of the probability that an adverse effect will occur.

Furthermore, the HQ relates to the response of an individual organism, rather than the population. The HQ methodology involves the implicit assumption that as exposures and HQs increase, an increasing number of individuals could experience adverse effects, and that the higher the number of individuals affected, the greater the risk to the population. In reality, density-dependent biological processes, such as competition for limited food resources, can offset reductions in the reproductive output of individual organisms. In addition, it is well documented that wildlife can acclimate and adapt to elevated levels of chemicals in the environment, thereby mitigating adverse population-level effects.

2.5 Conceptual Site Model

This section discusses the conceptual site model (CSM), which identifies the physical setting of the Site; the distribution of the COCs; and COC sources, fate, and transport. The section closes with a discussion of current and likely future risks.

2.5.1 Physical Setting

OU1 includes numerous tidal channels, including the man-made LCP Ditch, Eastern Creek, the Western Creek Complex, and Domain 3 Creek, hydraulically connected to the Turtle River (**Figure 2-1**). These channels, which are described below, subdivide the Site into domains or areas of similar physical setting.

- Turtle River is tidally influenced and is considered saltwater in the vicinity of Brunswick and the Site. The water depth in the Turtle River can vary in excess of 9 feet during a tidal cycle.
- The prevailing feature of OU1 is Purvis Creek, which divides the marshlands roughly in half. Purvis Creek has a maximum depth of approximately 11 feet and a maximum width of 500 feet (GAEPD 1990).
- LCP Ditch runs adjacent to the man-made causeway extending from the LCP upland to Purvis Creek. Eastern Creek feeds into LCP Ditch at its approximate midpoint and drains the eastern half of the Site south of the causeway road (**Figure 2-1**).
- Approximately 500 feet downstream from where LCP Ditch enters Purvis Creek is the mouth of the Western Creek Complex. The Western Creek Complex is comprised of three secondary channels and drains the western half of the Site below the causeway.
- The Domain 3 Creek borders the County Landfill at the northern portion of the Site, and is near the Dillon Duck feature.

2.5.2 Chemical Distribution

This section reviews the delineation of Site COCs, as previously outlined in **Section 2.4.1**, and discusses their distributions in relation to the CSM for the Site.

Mercury and Aroclor 1268

The distribution of surface sediment mercury and Aroclor 1268 concentrations are shown in **Figures 2-11** and **2-12**, respectively. As discussed in **Section 2.4.1**, the elevated mercury and Aroclor 1268 concentrations are primarily located in Eastern Creek and LCP Ditch. These distributions are consistent with the surface water CSM. Mercury, Aroclor 1268, and other Site-related constituents associated with the FFDA and untreated discharge from upland operations typically entered the estuary as particulate-bound chemicals, which fell out of suspension in the nearshore channels causing the higher surface sediment concentrations in LCP Ditch and Eastern Creek areas. Once in the estuary, the cycle of flood and ebb tides also contributed to the upstream and downstream transport of particulates and associated COCs within the channels.

Elevated mercury concentrations were also observed in the marsh near the banks of LCP Ditch and Eastern Creek and are consistent with the surface water CSM discussed in **Section 2.5.3**. During high tide, suspended contaminated particles can be transported over the banks into the marsh. However, once out of the channel, the rapid increase in cross-sectional area and resistance to flow caused by the marsh grasses lowers the water velocity and limits the transport distance of chemicals into the marsh. In Domains 2, 3, and 4, typically the highest COC concentrations were found in creeks and much lower concentrations were measured in the vegetated marshes. An exception to this observation is the Domain 1 marsh area that underwent remediation in 1998 to 1999. Dillon Duck, which has high lead concentrations, is another exception and is discussed below. Because of its proximity to the point of release, surface sediment concentrations in the 13-acre remediated marsh area were significantly elevated compared to the rest of the marsh.

Lead

Elevated surface sediment concentrations of lead occur in the Dillon Duck feature and the nearby Domain 3 Creek and in isolated areas of Domain 1, Domain 2, Eastern Creek and LCP Ditch (**Figure 2-13**). The distribution of elevated concentrations observed in Domain 1, Domain 2, Eastern Creek and LCP Ditch is similar to mercury and Aroclor 1268 and consistent with the surface water CSM as described below.

The elevated concentrations in Dillon Duck and Domain 3 Creek correspond with the former refinery facility process outfalls located in the northern upland portion of the Site. Elevated concentrations are present in Domain 3 Creek both north and south of the process outfall, and concentrations typically decrease away from this source. Again, these distributions are consistent with the CSM, as the flood and ebb tides lead to an upstream and downstream transport of these COCs within Domain 3 Creek.

Total PAHs

The distribution of total PAHs in surface sediment is provided in **Figure 2-14**. As discussed in **Section 2.4.1**, total PAH concentrations are typically low throughout the estuary with isolated areas of total PAHs greater than 10 mg/kg found in LCP Ditch, Eastern Creek, Domain 3 Creek, and Western Creek. PAHs were introduced to the estuary by many of the historic sources identified in **Section 2.5.3**. The relatively low PAH concentrations are likely due to lack of significant current sources and weathering/biodegradation since refinery and power production operations ceased (EPS and ENVIRON 2012). Conditions favorable to PAH biodegradation, including oxygen, nutrients, and warm temperatures, exist in the surface sediments of the Site.

2.5.3 Upland Sources, Fate, and Transport

Upland historical industrial activities dating back to the early 1900s contributed to the current COCs observed in the sediments of tidal creeks and vegetated marshes of the Site. The upland facilities that were in operation over that period of time included a petroleum refinery, power plant, paint manufacturer, chlor-alkali plant, landfill, and adjacent shooting range.

Overland Sources

The distribution and extent of COCs within the Site is attributed to tidal estuarine processes that redistributed the contaminants from the source areas where they were discharged by historical industrial practices in upland facilities, extending as far back as the early 1900s. The contaminant sources primarily consisted of point and non-point sources including direct discharge of contaminants from the process and storm sewer lines, seepage and surface runoff from the FFDA, and groundwater seepage. It is believed that some of the major sources were the result of wastewater discharges from the process and storm sewer lines servicing the chlor-alkali plant and the areas in the former ARCO community (**Figure 2-16**). COC sources included the following:

- Untreated processes and storm sewer discharges from the on-site operations during early industrial operations (up to the early 1970s) entered the nearshore marsh through the outfall pond and API separators located along the shore.
- Two process sewer lines associated with the chlor-alkali plant were directly connected to the canal and outfall pond.
- Overflow from the pond directly entered into LCP Ditch.
- Two of the sewer lines were connected to the API Separator tanks located at south and north shore. These separator tanks contained thick sludge with high concentrations of COCs. The sludge was removed from the tank during the upland removal action that was completed in 1997.
- COCs also spread by surface runoff and soil erosion processes from the FFDA. Particularly, the southern portion of shoreline was once rip-rapped using the waste disposal materials. Surface runoff processes and routine tidal inundation washed out the contaminated sediments into the nearshore marsh.

Source control and mitigation activities from the early 1970s through 1997 removed the potential for recontamination from upland sources (EPS and ENVIRON 2012).

Groundwater Transport Evaluation

The potential for sediment recontamination due to groundwater diffusion through the marsh clay layers was evaluated using a transect analysis as indicated in the OU1 RI (EPS and ENVIRON 2012). Local, sporadic groundwater seepages were observed along the marsh edge where the marsh clay was absent and the underlying sand exposed. The transect analysis was performed to quantify the flux of groundwater contaminant transport toward the marsh and to determine whether groundwater chemical transport is a significant source of sediment contamination.

A transect of shoreline/nearshore groundwater wells was identified along the length of the Site. In May 2012, groundwater was sampled from the upland and offshore wells along transect, as well as from wells outside of the transect. Groundwater sampling followed methods outlined in the groundwater monitoring work plan (EPS 2012); sample locations were identified in consultation with USEPA and GAEPD.

The analysis concluded that the potential for sediment recontamination due to groundwater transport is minimal and that the observed concentrations of COCs found in the restored marsh area sediments were not the result of groundwater transport. The detailed analysis is provided in **Appendix A**.

2.5.4 Marsh Hydrodynamics

A generalized conceptual model of the marsh hydrodynamics and sediment transport is central to the discussion of contaminant transport and understanding of observed COC distributions across the Site sediments. **Figure 2-16** presents a generalized conceptual model of the tidal hydrodynamics and potential effects on contaminant fate and transport within the Site sediments.

A unique feature of intertidal marsh areas is the complex network of tidal creeks that provide preferential pathways for flooding and draining the marsh areas during a tidal cycle.

During flood tide, water flows from the Turtle River into the Purvis Creek and is then conveyed to intertidal marsh through the system of secondary creeks and smaller channels. At the beginning of flood tide, flows are mostly confined to the creeks and smaller channels. Once the tidal elevation reaches the bank elevation, water flows into the marsh, where current velocities are relatively low due to increased storage area and high drag induced by plants. During ebb tide, water drains from the intertidal marsh into the tidal channels and creeks, and eventually back to the Turtle River. The relatively large tidal prism within the Site causes nearly complete exchange of water between the intertidal marsh areas and the creeks during each tidal cycle (i.e., marsh areas are filled and drained every tidal cycle). Thus, the larger creek channels play an important role in the exchange of water and sediment between intertidal vegetated marshes and the Turtle River during the tidal cycle.

Spatial patterns of chemical concentrations in surface sediments suggest some redistribution of contaminants over time from past sources areas. Mercury, Aroclor 1268, lead, and PAHs are relatively insoluble chemicals that preferentially adsorb to sediment particles. Thus, the fate and transport of these chemicals is dependent on sediment transport processes within the estuary. The sediment bed in the creeks is predominantly composed of clayey silts (i.e., cohesive sediment bed). Due to bed armoring processes in these cohesive sediment beds (**Sections 2.2.1** and **2.2.4**), minimal erosion is expected to occur during typical tidal conditions within the creek channel. Bed scour may occur in some localized areas of the creek channels during rare storms (e.g., hurricane storm surge).

The transport of suspended sediments is significantly affected by the tidal hydrodynamics within the estuary, which cause movement of suspended sediment between the intertidal marsh areas and creek channels. The intertidal vegetated marshes are a depositional zone for suspended sediments due to the low current velocities and presence of vegetation within those areas. Salt marshes are net depositional coastal features and, thus, act as sediment “sinks,” particularly when viewed on larger spatial scales and over multiyear periods.

2.5.5 Current and Likely Future Risk

Sections 2.4.2 and **2.4.3** provided a detailed description of current risks as estimated in the HHBRA and the BERA. Likely future risks are discussed in more detail in **Section 6** of this FS with regard to the evaluation of remedy effectiveness.

3 Potentially Applicable or Relevant and Appropriate Requirements and Sediment Management Areas

This section provides information regarding the potentially applicable or relevant and appropriate requirements (ARARs) considered in developing this FS (**Section 3.1**). In addition, RAOs are identified and discussed (**Section 3.2**). The basis for RGOs is summarized, and RGO values are identified (**Section 3.3**). Finally, this section identifies sediment management areas (SMAs) and the basis for the development of the SMAs (**Section 3.4**).

3.1 Potentially Applicable, or Relevant and Appropriate Requirements

In accordance with federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance, consideration must be given to ARARs and to other relevant information when planning a response action. Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. ARARs, while not specifically applicable to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, are those requirements that address problems or situations sufficiently similar to those encountered at the CERCLA site, such that their use applies to the particular site. Guidance that may or may not be legally enforceable, but may contribute to the development and implementation of effective and protective sediment remedy alternatives, is to be considered (TBC) in the FS and remedy selection process.

ARARs and TBC guidance information that may contribute to defining remedial alternatives for the Site are summarized in **Tables 3-1** through **3-3** and grouped into chemical-specific, location-specific, and action-specific categories. Chemical-specific ARARs specify concentration limits for environmental media defined by State of Georgia or federal regulations. Location-specific ARARs place constraints on or define requirements for remedial activities that occur in environmentally sensitive areas (e.g., wetlands, floodplains), manage the disposal of sediment-derived wastes, navigational constraints, and define siting and permitting requirements for treatment and disposal facilities (e.g., landfills). Action-specific ARARs govern the design, performance, or operational aspects of contaminated materials management and may be used to establish safe concentration levels for discharge of materials during implementation of a remedial action.

3.2 Remedial Action Objectives

The following are the RAOs identified for this project:

RAO 1**:** *Mitigate potential COC releases of contaminated in-stream sediment deposits and prevent such releases from entering Purvis Creek.*

> This RAO applies to sediment COCs in Eastern Creek, LCP Ditch, the Domain 3 Ditch and areas within Domains 1, 2, 3, and 4 that may contribute COCs into Purvis Creek. The goal of this RAO is to achieve, in the future, lower concentrations of COCs throughout the Site, particularly in Purvis Creek.

RAO 2: *Reduce exposure to piscivorous bird and mammal populations from ingestion of COCs in prey exposed to contaminated sediment in the estuary to acceptable levels considering spatial forage areas of the wildlife and movement of forage prey.*

This RAO addresses ecological exposures based on COCs in sediment. Therefore, the NCP criteria that address remedy short-term and long-term effectiveness as well as reductions in toxicity, mobility, and/or volume of sediments impact this RAO. Remedy evaluation should consider not only long-term risk reduction associated with reduced human and ecological exposure to chemicals in sediment, but also short-term risks introduced by implementing a remedy alternative (USEPA 2005).

Evaluation of this RAO includes monitoring of surficial sediment, biological organisms, and ecological recovery following remedy implementation.

RAO 3: *Reduce human exposure to COCs, through the ingestion of fish and shellfish, that could result in a cumulative HI greater than 1 or exceed the acceptable range for cancer risk, defined as an added health risk between 1 in 10,000 (1×10^{-4}) and 1 in 1,000,000 (1×10^{-6}).*

Sediment remedies will be evaluated for their ability to reduce long-term human health risk at the Site with regard to the ingestion of fish and shellfish. The remedies also will consider the uncertainties associated with the various conservative assumptions used in the HHBRA to quantify potential health risks.

GAEPD issues advisories on eating fish and shellfish because some of these contain chemicals at levels that may be harmful to health. When reviewing fish contaminant data to derive fish advisories, GAEPD considers the fish contaminant levels and fish physical characteristics, health risks and health benefits, populations at greater potential risk, US food marketplace standards, and risk communication issues. This FS assumes that the current fish advisories will be used in conjunction with other remedial actions. The most recent fish consumption advisories for the Turtle River/Brunswick Estuary were updated in 2012. **Table 3-4** summarizes fish consumption advisory improvements since 1995, including the most recent updates in 2012 (GADNR 2004, 2012).

Evaluation of this RAO includes monitoring of fish and shellfish following remedy implementation to assess changes in residual fish chemical concentrations.

RAO 4: *Reduce ecological risks to benthic organisms exposed to contaminated sediment to levels that will result in self-sustaining benthic communities with diversity and structure comparable to that in appropriate reference areas.*

This RAO addresses ecological exposures to all four COCs in sediment, including PAHs, lead, mercury, and Aroclor 1268. Therefore, the NCP criteria that address remedy short-term and long-term effectiveness as well as reductions in toxicity, mobility, and/or volume of sediments impact this RAO. Remedy evaluation should consider not only long-term risk reduction associated with reduced human and ecological exposure to chemicals in sediment, but also short-term risks introduced by implementing a remedy alternative (USEPA 2005).

Evaluation of this RAO involves monitoring biological communities following remedy implementation.

RAO 5: *Reduce finfish exposures from ingestion of COCs in food items exposed to contaminated sediment in the estuary to support conditions within OU1 that do not pose unacceptable adverse effects on fish.*

Like RAO 2, this RAO addresses ecological exposures to mercury and Aroclor 1268 in sediment. The NCP criteria that address remedy short-term and long-term effectiveness as well as reductions in toxicity, mobility, and/or volume of sediments will impact this RAO. Remedy evaluation should consider not only long-term risk reduction associated with reduced human and ecological exposure to chemicals in sediment, but also short-term risks introduced by implementing a remedy alternative (USEPA 2005a).

Evaluation of this RAO, like that described for RAO 2, would include monitoring of surficial sediment and fish for mercury and Aroclor 1268.

RAO 6: *Meet and sustain the applicable USEPA and State of Georgia Water Quality Standards for protection of aquatic life in the estuary, using total or dissolved phase mercury and PCB measures.*

This RAO applies to sediment COCs that may be suspended in the water column in a biologically active, dissolved phase. Current conditions have demonstrated that dissolved phase water concentrations meet the USEPA NRWQC and Georgia WQS for chronic and acute exposures for mercury. The current conditions meet the Georgia WQS criteria when measured dissolved phase results are considered. As was described previously, the current conditions do not meet the Georgia WQS when total mercury is compared to the Georgia WQS. The RAOs have not consistently met the PCB standards for either the USEPA NRWQC or the Georgia WQS, or the results have been unclear, primarily because laboratory detection limits routinely exceed the criterion.

RAO 7: *Implement a remedy that balances human and ecological risk reduction with sustaining and protecting existing habitat and wildlife.*

The Georgia Marshland Protection Act (O.C.G.A. § 12-5-280) empowers the state to ensure the protection of coastal marshlands. Coastal marshlands of Georgia comprise a vital natural resource system, and coastal marshlands are “costly, if not impossible, to reconstruct or rehabilitate once adversely affected by man (*sic*) related activities and is important to conserve for the present and future use and enjoyment of all citizens and visitors to this state.”

USEPA (1999) *Ecological Risk Assessment and Risk Management Principles for Superfund Sites* recommends that risk managers ask the question: “*Will the cleanup cause more ecological harm than the current site contamination?*” That is, the likelihood of the response alternatives to achieve success and the time frame for a biological community to fully recover should be considered in remedy selection. At some sites, especially those that have sensitive habitats, removal or *in situ* treatment of the contamination may cause more long-term ecological harm (often due to widespread physical destruction of habitat) than leaving it in place. Conversely, leaving persistent and/or bioaccumulative contaminants in place where they may serve as a continuing source of substantial exposure, may also not be appropriate (USEPA 1999). This RAO is further discussed in **Section 3.**4 in the designation of SMAs (versus risk management areas) and in **Section 6** when the remedial alternatives are compared.

The remedy evaluation will consider baseline risk conditions, the magnitude of risk reduction achieved for each remedy alternative, and the impacts of remediation on the existing resource.

3.3 Remedial Goal Options

The RGOs identified for this FS are used as part of the designation of SMAs. The RGOs described herein support protective management decisions that are consistent with the USEPA's *Ecological Risk Assessments and Risk Management Principles for Superfund Sites* directives (OSWER 1999). Two types of RGOs are considered in this FS and these reflect the manner in which human health and ecological receptors may be exposed to chemicals in the Site.

- Surface-weighted average concentration (SWAC) RGO for mercury and Aroclor 1268. SWAC RGOs are concentrations that are protective for humans that consume fish, shellfish, and wild game from the Site. In addition, SWAC RGOs are protective of the mammals, birds, and fish that nest, forage, and breed in the Site. The approach used to calculate SWACs is discussed further in **Section 3.4**.
- Benthic community RGO for PAHs, lead, mercury, and Aroclor 1268. Benthic community RGOs are protective of sediment-dwelling organisms and are considered over smaller scales because they reflect exposures that occur over smaller spatial scales.

The RGOs are based on the findings of the BERA and HHBRA, along with the following series of communications between the Agencies and Honeywell, ARCO, and Georgia Power, which are briefly described below.

- Letter regarding "*Human Health Risk Assessment for the Estuary, OU1 (Estuary): LCP Chemicals Superfund Site, Brunswick, Glynn County, GA*" (USEPA, November 30, 2011). This letter and associated memorandum:
    - Provides a range of RGOs deemed protective of human health and the environment.
    - Allows the use of other RGO values as long as the FS provides "justification for using such ranges in its development and screening of remedial action alternatives."
    - Defines the area of the benthic community over which RGOs should be applied as 50 meter by 50 meter areas.
- Letter and memorandum regarding "*Response to EPA's November 2011 Letter regarding Remedial Goal Option (RGO) Ranges for the Remedial Action Alternatives for OU1 (Estuary) – LCP Chemicals Site, Brunswick, GA*" (Honeywell, November 2, 2012).
    - On behalf of the potentially responsible parties (PRPs), Honeywell proposed a range of protective risk-based RGOs to be employed by risk managers in the FS.

  - Justification for the RGO ranges is provided.
- Agency Reply Letter "*Remedial Goal Option (RGO) Ranges for the Remedial Action Alternatives for OU1 (Estuary): LCP Chemicals Superfund Site (Site), Brunswick, Glynn County, Georgia*" (USEPA, November 20, 2012).
  - This letter acknowledges receipt of the November 2 letter and memorandum.
  - USEPA and the GAEPD committed to considering the broader RGO range established in the November 2, 2012 Honeywell letter during their review of the remedial alternatives developed for OU1 in the FS.
- Letter from USEPA, "*Remedial Goal Option (RGO) Ranges for the Remedial Action Alternatives of OU1 (Estuary): LCP Chemicals Superfund Site, Brunswick, Glynn County, GA*" (USEPA, February 20, 2013b)
  - USEPA and GAEPD agreed to accept a range of benthic community RGOs for use in developing and screening remedial alternatives in the FS.
- Letter from USEPA, "*Remedial Goal Option (RGO) Ranges for Remedial Action Alternatives for OU1 (Estuary): LCP Chemicals Superfund Site, Brunswick, Glynn County, GA*" (USEPA, March 8, 2013c)
  - This letter confirms that the SWAC RGOs are acceptable by USEPA and GAEPD for use in developing and screening remedial alternatives in the FS.
  - This letter reiterates the benthic community RGOs identified in the February 20, 2013 correspondence and clarifies the range of SWAC RGOs that are acceptable by the USEPA and GAEPD for use in developing and screening remedial alternatives in the FS.

The following RGOs are used in this FS:

Constituent	SWAC RGOs (mg/kg)	Benthic Community RGOs (mg/kg)
Mercury	1-2	4-11
Aroclor 1268	2-4	6 – 16
Lead	NA	90-177
Total PAHs	NA	4

NA = Not applicable

3.4 Development of Sediment Management Areas

SMAs were identified for OU1 based on the SWAC and benthic community surface sediment RGOs outlined in **Section 3.3**. Each SMA represents a different OU1 remediation footprint based on the risk criteria discussed in this section. The current surface sediment concentrations of Aroclor 1268, mercury, total PAHs, and lead for each sample location relative to the benthic community RGOs are provided on **Figures 3-1, 3-2, 3-3,** and **3-4.** The current conditions relative to the SWACs for mercury and Aroclor 1268 are summarized on **Table 3-5**.

SMAs were defined based on the following considerations:

- *Morphology* – Marsh morphology, including the location of channel banks and the presence of small tributaries to LCP Ditch and Eastern Creek, were considered when delineating surface sediment concentrations near the boundaries of the creeks. For example, a surface concentration from a sample collected within a small tributary was confined to the boundaries of the tributary and was not extrapolated to represent a larger area in the marsh. Changes in marsh topography and vegetation also were considered in delineating surface sediment concentrations between sample points. Visual observations, LiDAR information, and geographic information system (GIS) imagery were tools used to understand marsh morphological changes and characteristics.
- *Thiessen Polygons* – In the absence of changes in morphology, Thiessen polygon boundaries were used to delineate surface sediment chemical concentrations between sample locations. The size and shape of the Thiessen polygons were based on the position of neighboring sediment sample locations within in each domain or creek; each polygon contained one sample location and the boundaries of the polygon were equidistant from the neighboring sample locations.
- *Spatial Averaging* - Spatial averaging was applied in areas where more than one sample was collected within a 50 meter by 50 meter area. This approach is consistent with USEPA's RGO letter (USEPA 2011) and is conservatively protective when the movement of many of the most sensitive benthic organisms is considered, as described in the Honeywell letter and memorandum (Honeywell 2012). The averaging results are illustrated for the Western Creek Complex and Purvis Creek in **Figures 3-1** through **3-4**. An area in the Domain 3 marsh was also averaged, as three samples were collected within 10 feet of each other. Similarly, two lead samples in Domain 1 near the shoreline were averaged. The approach to averaging in the creeks was as follows:
    - Measured the length of the creeks
    - Divided the creek into segments that were each approximately 50 meters long
    - Averaged the samples that fell within each segment
- *Risk Management Decisions* – In accordance with RAO 7 and the USEPA Superfund Sites Directive (1999), risk managers should ask the following question: "*Will the cleanup cause more ecological harm than the current site contamination?"* Removal or in situ treatment of the contamination may cause more long-term ecological harm (often due to wide spread physical destruction of habitat) than no remedial action. Some areas that exceeded the RGOs did not ultimately get included in the final SMA footprint when:
    - The area was defined by a single detection above the RGO and was otherwise relatively isolated with regard to other areas exceeding RGOs.
    - Damage to a large portion of the marsh was likely to occur even in areas without chemical concentrations exceeding RGOs in order to access areas where concentrations exceeded or only marginally exceeded RGOs.

- SWAC RGOs were also considered with regard to SMA development. SWACs were calculated for mercury and Aroclor 1268 as follows:
  - All OU1 surface sediment data were included in the SWAC calculations and locations with more than one result were averaged as discussed in **Section 2.4.1**.
  - Thiessen Polygons were used to represent the area for each sample location. The average COC concentration of the sample location within the Thiessen Polygon was used to represent the concentration for the entire polygon. The average COC concentration for each sample location and the size of each Thiessen Polygon were then used to calculate the SWAC over a specified creek or domain with the following formula:

$$SWAC = \frac{\sum_{i=1}^{n}(C_i * A_i)}{\sum_{i=1}^{n}(A_i)}$$

where:

C_i = Concentration of an individual sample, i (mg/kg)

A_i = Area associated with sample, i (acres)

n = Number of sample locations within the area of interest

- The SWACs for the individual creeks and domains were calculated under current conditions for mercury and Aroclor 1268 (**Table 3-5**).

SWACs were also estimated for post-remedy conditions. Post-remedy SWACs were calculated by replacing the current surface sediment concentration with a value representing post-remedy surface sediment conditions. For post-remedy surface sediment COC concentrations, regional background values were employed. The regional background value was based on data from the Blythe Island marsh located across the Turtle River. Background values were 0.3mg/kg for mercury and 0.2 mg/kg for Aroclor 1268. Post-remedy SWACs are provided in **Table 3-5**.

The RGO analysis resulted in the identification of three proposed SMAs for OU1 as described in the following sections.

3.4.1 Sediment Management Area 1

SMA-1 (**Figure 3-5**) encompasses areas that exceed SWAC RGOs for mercury and Aroclor 1268 and the lower end of the benthic community RGOs (mercury, 4 mg/kg; Aroclor 1268, 6 mg/kg; total PAHs, 4 mg/kg; and lead, 90 mg/kg). Using spatial averaging, morphology, and Thiessen Polygons, the extent of the area that exceeds these benthic community RGOs is 81 acres. Following the application of risk management decisions, the area remaining for consideration of remedial action is 48 acres. SMA-1 and the risk management areas are shown in **Figure 3-5**. Post-remediation SWAC values for SMA-1 are included in **Table 3-5**.

Green shading in **Figure 3-5** designates risk management areas.

- The majority of these areas are to the west of Purvis Creek in the Domain 4 area. These locations are relatively isolated in the marsh. The majority of these detections only slightly exceed the benthic community RGOs (e.g., one location had a mercury concentration of 4.7 mg/kg versus the mercury RGO for SMA-1 of 4 mg/kg) and surrounding samples were below their respective RGO values, and based on the CSM one would not expect to see high concentrations of COCs in this area.

- A portion of Dillon Duck is defined as a risk management area because the GIS imagery, the topography, and the vegetation suggest that it may not have the same characteristics as the portion where higher concentrations are observed. Furthermore, this large portion of Dillon Duck is defined by a single location where lead was detected at 280 mg/kg (**Figure 3-3** shows the individual location sampled relative to the larger area of Dillon Duck).
- An additional risk management area in Domain 1 was previously remediated. This area is defined by a single detection of lead at a concentration of 210 mg/kg, located within the marsh near the shoreline. As such, it is only inundated an hour or two a day at high tide. Therefore, exposure to the sediment-dwelling organisms upon which the RGOs are based is very limited.

3.4.2 Sediment Management Area 2

SMA-2 (**Figure 3-6**) encompasses areas that exceed SWAC RGOs for mercury and Aroclor 1268, and the additional protective benthic community RGOs (mercury, 11 mg/kg; Aroclor 1268, 16 mg/kg; total PAHs, 4 mg/kg; and lead, 177 mg/kg). Using spatial averaging, morphology, and Thiessen polygons, the extent of the area that exceeds these benthic community RGOs is 25 acres. Following the application of risk management decisions, the area remaining for consideration of remedial action is 18 acres. SMA-2 and the risk management areas are shown on **Figure 3-6**. Post-remediation SWAC values for SMA-2 are included in **Table 3-5**.

Green shading on **Figure 3-6** designates risk management areas.

- One area is located to the west of Purvis Creek in Domain 4. This location is defined by a single detection of total PAHs at approximately 8 mg/kg versus the RGO of 4 mg/kg. Surrounding samples were below the RGO of 4 mg/kg.
- One area is identified in Purvis Creek and is defined by a single detection of two different chemicals. On the northern side of Purvis Creek, the detection is of Aroclor 1268 at a concentration of 18 mg/kg versus the benthic community RGO of 16 mg/kg. The second location, on the south side of Purvis Creek, is a single detection of total PAHs at 7.2 mg/kg versus the RGO of 4 mg/kg.
- A single isolated area is located at the northern end of Domain 3 Creek. This location has detections of mercury at 13 mg/kg and Aroclor 1268 at 17 mg/kg that slightly exceed the benthic community RGOs of 11 mg/kg and 17 mg/kg, respectively.
- A portion of Dillon Duck is identified on **Figure 3-6** for the same reasons as described for SMA 1 (refer to **Section 3.4.1**).
- The same portion of Domain 1 (single lead exceedance in the marsh along the shoreline) is identified on **Figure 3-6** for the same reasons as described for SMA 1 (refer to **Section 3.4.1**).

3.4.3 Sediment Management Area 3

SMA-3 encompasses the same areas as SMA-2, including the risk management area, plus additional COC-impacted areas in Purvis Creek and Domain 1. These additional areas were identified for the following reasons:

- Addressing areas in Purvis Creek and Domain 1 helps achieve lower SWAC-based RGOs for mercury and Aroclor 1268.
- Because most of Purvis Creek is permanently submerged, even at low tide, ecological exposure times are longest in Purvis Creek. Thus, a reduction in Purvis Creek SWAC levels could contribute to a commensurate improvement in fish COC concentrations.
- Purvis Creek is relatively accessible from water. Thus, is likely to be accessed when work is to be performed in LCP Ditch and possibly in Eastern Creek. If accessed by water, dredging in Purvis Creek will not adversely impact vegetated marsh areas significantly.
- The area proposed for Domain 1 is located immediately adjacent to areas were other work (i.e., work in LCP Ditch and Eastern Creek) is already planned, making an expansion into Domain 1 easily implementable.

The total area of SMA-3 is 24 acres and is presented in **Figure 3-7**. Post-remediation SWAC values for SMA-3 are included in **Table 3-5**. The SMA-2 area is shown using brown shading and the expansions into Purvis Creek and Domain 1a are shown using orange shading.

4 Identification and Screening of Remedial Technologies

This section identifies and initially screens remedial technologies to be assembled into remedial alternatives for the Site (**Section 5**). The technology and process screening approach described in this section is consistent with USEPA *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (1988), and the technologies screened are consistent with USEPA sediment remediation guidance (USEPA 1998b; 2005).

The evaluation of technologies potentially applicable to remedial alternatives for the Site was conducted in two steps consistent with CERCLA guidance (USEPA 1988). The first evaluation step, presented in this section, identifies an array of possible remedial technologies and evaluates these technologies based on technical effectiveness, implementability, and cost. Technologies and process options that (a) have clearly not been demonstrated as effective in addressing similar conditions at other sediment sites; (b) cannot be implemented due to site-specific conditions; or (c) do not meet the RAOs specified in **Section 3** are eliminated from further consideration for the purposes of this FS. The exception is the No Action alternative, which is retained per the NCP in Title 40 Code of Federal Regulations Part 300 (NCP 1994) to serve as a basis for comparison to other effective and implementable technologies. The second evaluation step, presented in **Sections 5** and **6**, assembles the retained remedial technologies into a range of potentially viable remedial alternatives that are further evaluated based on the NCP criteria (USEPA 1988).

4.1 General Response Actions

Remedial technologies evaluated for possible application to OU1 at the Site were organized under general response actions (GRAs). GRAs are broad categories of conceptual sediment remediation. Consistent with USEPA (2005), the following GRAs were identified:

a) No action, which serves as a basis for comparison to other effective and implementable technologies (NCP 1994).

b) Institutional controls include non-engineered instruments, such as administrative and legal controls, to minimize the potential for exposure and to ensure the long-term integrity of the remedy.

c) Monitored natural recovery (MNR) documents the effectiveness of natural physical, chemical, or biological processes in reducing contaminant concentrations to achieve RAOs.

d) Thin cover application uses sand, soil, or previously dredged sediment to enhance the process of natural recovery by placing the material on the sediment bed surface.

e) Sediment capping isolates contaminants from the water column and biological receptors by placing clean material on the sediment bed surface, and armoring the cap as needed to withstand erosive forces.

f) Sediment removal includes removal of sediment via dredging or excavation followed by placement of a clean backfill layer, and subsequent material management, such as dewatering and disposal of the excavated sediment.

Consistent with CERCLA guidance (USEPA 1988), this initial screening of remedial alternatives evaluates the GRAs against the following NCP Criteria:

- *Effectiveness* is evaluated based on the relative ability of the technology or process option to meet the RAOs in a reasonable timeframe, ensure long-term human health and environmental protection, protect against short-term human and environmental effects during construction, and proven reliability at sites with chemical constituents and conditions similar to those at the Site. Effectiveness also considers the potential for implementation of a technology or process option to generate higher, different, or unanticipated adverse human health effects or ecological impacts. Projected activities are evaluated for negative impact to community residents, changes such as disruption of baseline sediment geochemical or biological conditions that alter chemical bioavailability, increased erosion, or increased likelihood of off-site migration of contaminated sediment.
- *Implementability* encompasses both the technical and administrative feasibility of implementing a technology or process option. Technical feasibility refers to the ability to construct, operate, maintain, and monitor the action during and after construction and meet technology-specific regulations during construction. Technical feasibility also applies to the availability of necessary equipment, personnel, and services for implementation or construction, and industry experience in implementing the remedy. Administrative feasibility refers to the ability to obtain approvals (on-site response actions defined under CERCLA are exempt from the procedural requirements of federal, state and local environmental laws, though the action must nevertheless comply with the substantive requirements of such laws).
- *Costs* are used to compare different technologies or alternatives. While the total cost of a given technology is not normally estimated during the initial screening described in this section, relative costs of technologies (i.e., whether they are low, moderate, or high) are evaluated and compared during the initial screening phase. For this section, costs (including overall construction, operation, maintenance, and monitoring costs) are based on vendor information, cost-estimating guides, available historical information (for this site, as well as from other similar sites), and engineering experience and judgment associated with each option. In many cases, more efficient and cost-effective remedies can accomplish the same result or can outperform less efficient, more costly remedies. Detailed costs for each alternative are developed during the comparative evaluation (**Section 6**) and presented in **Appendix G**.

The evaluation and initial screening of potentially applicable remedial technologies for each GRA (i.e., Step 1) is described below and summarized on **Figure 4-1**.

4.2 Screening of Remedial Technologies

This section preliminarily evaluates possible remedial technologies based on technical effectiveness, implementability, and cost. Other than the No Action alternative, which is retained as a basis for comparison to other effective and implementable technologies (NCP 1994), only technologies and process options that (a) have been demonstrated as effective in addressing similar conditions at other sediment sites; (b) can be implemented at the Site; or (c) meet the RAOs specified in **Section 3** are evaluated in this section.

4.2.1 No Action

The No Action GRA is required by the NCP as the baseline case to which all other response actions and alternatives are compared.

Applicability to the Site

Under the No Action response, no remedial activities are conducted and there is no short- or long-term monitoring. No Action reflects the Site sediment conditions as they currently exist. No Action may be appropriate if a site currently meets the all of the RAOs or if a previous response (e.g., upland remedial activities and source control) eliminated the need for further action.

Evaluation Against Major Screening Criteria

Initial evaluation of the No Action response against the following major NCP screening criteria can be summarized as follows:

- *Effectiveness.* This response would not change baseline sediment conditions reported in the RI Report (EPS 2011a), except for changes that occur naturally (e.g., natural deposition of sediments). Construction hazards and health risks to remediation workers and residential communities during remediation would be nonexistent because no action is taken as part of this alternative. However, as a result of the No Action alternative, chemical concentrations exceeding the remedial targets developed for the increased protection of ecological and human health would be left in place in sediments in both the marsh and creek areas of OU1.
- *Implementability*. Because no action is taken, this response is readily implementable.
- *Cost.* Because no action is taken, no costs apply to this option.

No Action is retained for further evaluation to serve as a baseline alternative for comparison with other remedial alternatives as required by the NCP.

4.2.2 Institutional Controls

Institutional controls are non-engineered instruments (e.g., administrative or legal controls or restrictions, and informational devices) included as part of a remedial action to minimize, limit, or prevent potentially unacceptable human health or ecological exposures to contaminated media and/or protect the long-term integrity of the remedial action (USEPA 2010d). USEPA guidance on institutional controls is provided in OSWER Directive 9355.0-74FS-P, *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups* (USEPA 2000a) and OSWER Directive 9355.0-106, *Strategy to Ensure Institutional Control Implementation at Superfund Sites* (USEPA 2004). Institutional Controls are typically designed to work by one or both of the following approaches:

- Limiting land or resource use through land use or deed restrictions, maintenance agreements, physical restrictions (e.g., fencing or security guards) or permit conditions for future activities, and enforcement.

- Providing information that helps modify or guide human behavior and enhance protectiveness at a site, such as notices, signage, and fish consumption advisories that may be required until RAOs are met.

Applicability to the Site

Fish consumption advisories have been issued by the GADNR for Purvis Creek and the Turtle River system due to mercury and PCB contamination of fish and shellfish in these water bodies (GADNR 2012). In addition, a commercial fishing ban was issued in Purvis Creek due to mercury and PCB levels in fish tissue that exceed Food and Drug Administration (FDA) action levels. These restrictions will likely be maintained by GAEPD until such time that the criteria for delisting are attained. This FS assumes that the current fish advisories will be used in conjunction with other remedial actions at the Site.

Permits are currently required for dredging, capping, or other in-water construction activities in OU1 at the Site. USACE administers Section 404 of the Clean Water Act, which requires that a permit be obtained for the discharge of fill or dredged material in waters of the US. Under Section 401 of the Clean Water Act, required certification that proposed Section 404 discharges comply with applicable WQS. The USACE also administers Section 10 of the Rivers and Harbors Act, which requires that a permit be obtained for dredging and other activities in navigable waters. These permit requirements may be effective institutional controls for construction in and adjacent to OU1 at the Site.

Evaluation against Major Screening Criteria

Initial evaluation of institutional controls as a response against the following major NCP screening criteria can be summarized as follows:

- *Effectiveness.* Institutional controls may supplement other engineering controls or response actions during development and evaluation of the remedial alternatives.
- *Implementability.* This response action is readily implementable.
- *Cost.* Only administrative actions are taken for this response action; therefore, capital and operations and maintenance (O&M) costs are low.

Based on the initial evaluation against the major NCP screening criteria, institutional controls are not retained as a sole remedy, but may be evaluated as a component in the development of remedial alternatives. This FS assumes that institutional controls will be used in conjunction with other remedial actions in OU1 at the Site.

4.2.3 Natural Recovery

Natural recovery is the process by which contaminant concentrations in sediment are reduced through a combination of existing environmental processes (physical, chemical, or biological) to contain, destroy, alter, or otherwise reduce the bioavailability and toxicity of contaminants (Magar et al. 2009, NRC 1997). MNR involves monitoring this process and is one of the three primary sediment remediation technologies recognized by USEPA (USEPA 2005).

A variety of natural processes can contribute to MNR, including natural sedimentation over impacted sediments in depositional environments (e.g., off-channel areas such as river banks, marshes and turning basins), chemical transformation of contaminants (e.g., chemical reduction or biodegradation by native bacteria), and sequestration and stabilization (e.g., the precipitation of metals and hydrophobic chemical partitioning). Natural sedimentation and mixing can create a surface sediment layer with lower chemical concentrations through the physical burial of contaminated sediments over time (USEPA 2005, Brenner et al. 2004, Magar and Wenning 2006). Such natural capping can form a protective barrier that inhibits diffusion of chemicals into the water column, minimizes the potential of contaminated sediment resuspension, and helps isolate contamination from contact with ecological and human receptors.

Predictive modeling of natural recovery processes using site-specific tools (such as sediment transport models) can be performed to predict sediment recovery rates by assessing the rate at which new sediments from upstream areas mix with existing sediments within a particular deposit, as long as uncertainties associated with such predictions are adequately addressed. Performance monitoring of sediments at specified intervals is an integral component of the MNR remedy and is used to verify model predictions and to document the presence and effectiveness of the natural processes in reducing risks. Long-term monitoring of environmental restoration recognizes that uncertainty is inherent to any cleanup activity and must be managed through data collection and monitoring (US Department of Energy [USDOE] 1997).

Provided there is source reduction or control, MNR can be implemented as a sole remedy. However, it typically is part of a larger remedial strategy incorporating other sediment alternatives for areas where natural recovery alone cannot achieve site-specific goals within a reasonable period. Institutional or engineering controls are commonly employed in conjunction with MNR, such as navigational restrictions, physical access restrictions, and future dredging restrictions. These controls minimize the potential for disruption of the natural recovery processes.

The USEPA *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005) and the US Department of Defense (DoD) *Technical Guide: Monitored Natural Recovery at Contaminated Sediment Sites* (Magar et al. 2009) discuss advantages and limitations of MNR. MNR is readily implementable and reduces disturbances to the ecosystem that may jeopardize habitat and sensitive aquatic species. In addition, at sites where MNR satisfies risk-based remedial goals, MNR can effectively manage human and ecological risks. However, with MNR, contaminants are left in place and the timeframe to achieve remedial goals is typically slower than that for other remedies, such as capping or removal.

Applicability to the Site

MNR is applicable to areas where contamination is buried below cleaner stable sediment that does not exceed threshold criteria or areas where natural sediment transport may provide a source of clean sediment deposition within impacted areas.

MNR relies on source reduction, which occurred at the Site. However, high concentration deposits in the marsh, along with the potential intra-marsh redistribution of sediment, can act as a secondary source and can undermine natural recovery processes.

The dominant source of uncontaminated suspended sediment to the estuary is the Turtle River; no upland tributaries flow directly into the estuary. Although the Site, and especially the vegetated marsh areas, are characterized as “net depositional” (i.e., the general propensity is for sediment particles to deposit in the marsh), deposition rates are low. The basis for this assessment is the characterization of vertical sediment profiles (EPS and ENVIRON 2012). Most of the sediment contamination resides close to the sediment surface (i.e., within the upper 2 ft.), which indicates a relatively low historical deposition rate in the marsh. Furthermore, the general observation that surface sediment COC concentrations continue to exceed RAOs in portions of the marsh indicates that MNR alone has not adequately reduced surface sediment COC concentrations to achieve RAOs in those areas.

Evaluation Against Major Screening Criteria

Initial evaluation of MNR as a response against the following major NCP screening criteria can be summarized as follows:

- *Effectiveness.* MNR is effective at sites with strong evidence for natural recovery processes. However, in areas of the Site with high residual COC levels, estimated sediment deposition rates alone are unlikely to reduce risks within an acceptable time frame. If combined with other remedial technologies that are effective at reducing exposures to COCs, the effectiveness of MNR can be targeted for less-contaminated areas and can be demonstrated by long-term monitoring of sediment, chemical, geochemical, and biological conditions.
- *Implementability.* MNR is readily implementable for this site because upland contaminant sources have been controlled, and because it requires no action beyond detailed site characterization, monitoring, and possible execution and maintenance of institutional or engineering controls.
- *Cost.* MNR has a relatively low cost compared to other, more active remedial technologies. However, monitoring costs associated with MNR can be significant, particularly if monitoring is required over a large area and long duration. Even when considering monitoring and institutional control costs, costs for MNR are generally low compared to other sediment remedies.

Based on the initial evaluation against the major NCP screening criteria, MNR is not retained as a sole remedy but may be evaluated as a component of other remedies in the development of alternatives, particularly for long-term management of areas with relatively low COC concentrations.

4.2.4 Thin-cover placement

Thin-cover placement refers to acceleration of natural recovery and risk reduction by adding a thin layer of clean sediment over contaminated sediment. Acceleration of recovery can occur through several processes, including increased dilution through bioturbation of clean sediment mixed with underlying contaminants (USEPA 2005) and by rapidly providing a cleaner sediment surface and benthic environment. Thin covers generally are less than 15 centimeters (cm) (6 inches) thick and typically are constructed using clean sediment or sand. Given their shallow profile, thin-cover placement minimizes adverse impacts to the marsh hydrology and ecology associated with remedy implementation.

In many cases, clean materials can be dredged from nearby waterways instead of upland sources (e.g., quarries or mines). For example, potential sources of material local to the Site include material from navigational dredging of both the Brunswick Harbor and the Savannah Harbor Expansion Project (SHEP), which are ongoing projects managed by the USACE Savannah District (USACE 2012a, 2012b). Currently, dredged materials from both projects are managed at upland dredged material containment facilities (DMCF) and Ocean Dredged Material Disposal Sites (ODMDS). If the sediment from these sites are determined to be suitable for beneficial reuse at the Site, dredged material from either project offers multiple benefits:

- Reduced energy uses because new raw material does not need to be quarried, crushed, processed, cleaned, and transported to the Site.
- Increased DMCF or ODMDS capacity.
- Potentially lower project costs.
- Dredged sediment is likely to be better suited for marsh restoration than quarried sand. Dredged sediment is more likely to be organic-rich and will likely contain nutrients that support plant and wildlife growth; quarried sands tend to be virtually absent of natural organic matter.

Thin-cover placement is a readily implementable technology, particularly in low energy areas not subject to scour or erosion, and experience with marsh restoration projects in coastal environments is extensive. Thin-cover placement generally is most appropriate for locations where routine disturbance (e.g., maintenance dredging) is not required to support local functions such as navigation and where institutional controls can be implemented to restrict activities that could potentially impact long-term stability. Some methods for placement of material are shown on **Figure 4-2** and include broadcasting from land, aerial deposition, and hydraulic or pneumatic placement. Though initial impacts to marsh ecology may occur from material placement, vegetated marshes typically recover vigorously in one to two growing seasons (**Appendix E**).

Thin-cover placement leaves contaminants in place and could result in potential restrictions on future Site use. Such restrictions should pose little concern because State laws already protect saltwater marshes by restricting construction.

Because placement of material in vegetated marshes can potentially impact the Site hydrology and ecology if bed-elevations change (e.g., subtidal areas may be converted to intertidal areas and intertidal areas may be converted to upland areas), hydrodynamic modeling was used to evaluate the impact of thin-cover caps on water flow in the marsh. Concerns about hydrology are addressed in **Appendix B**, through the evaluation of hydrodynamic conditions using a surface water transport model. Results of the modeling analysis showed that thin cover placement does not significantly impact marsh hydrology, so that wetting and drying cycles for marsh areas remain effectively unchanged.

A monitoring program is commonly required when a thin cover is placed to remediate contaminated sediment sites. Monitoring may include bathymetric surveying and visual observation (e.g., camera or video profiling) to evaluate thin cover integrity and the potential for displacement, shifting, or erosion. Biological monitoring may be conducted to evaluate biological recovery of the thin cover surface, and surface sediment sampling may be conducted to monitor surface sediment deposition and recontamination potential.

Applicability to the Site

Thin-cover placement is applicable to low-energy areas not subject to scour or erosion, or areas where natural sediment transport may provide a source of clean sediment deposition within impacted areas. In OU1, only the existing creeks are subject to tidal erosion. The vegetated marsh areas are net depositional and are subject to a slow sediment deposition process, which make them well suited for thin-cover placement. In addition, cover materials could be placed in most, if not all areas, from land or water. Thin-cover placement minimizes adverse impacts to the marsh associated with remedy construction/implementation, which helps accelerate ecosystem recovery and minimizes some of the more permanent hydrological and biological impacts that can occur under more aggressive remedies. This is especially true if thin-cover placement relies on construction methods that do not require substantial intrusion of heavy equipment into the marsh, and if thin-cover placement relies on materials that support plant growth and ecosystem recovery.

Like MNR, thin-cover placement relies on source control, and can potentially be undermined if ongoing sources of sediment contamination are not completely eliminated. Potential sources from the Site that may contribute to the release of contaminants to OU1 have been identified and controlled, which has contributed to the ongoing natural recovery of the sediment and ecology. However, natural recovery has been limited by high-concentration secondary source areas, particularly in channels, which cause persistent elevated COC levels in marsh areas. To the extent that these secondary sources are controlled, thin-cover placement can be implemented within marsh areas.

Evaluation Against Major Screening Criteria

Initial evaluation of thin-cover placement as a response against the following major NCP screening criteria can be summarized as follows:

- *Effectiveness.* Placement of a thin cover accelerates the natural recovery process and can reduce risks within a shorter, acceptable time frame. However, thin-cover placement is most effective in depositional areas within vegetated marshes not subject to scouring or erosive forces. If combined with other remedial technologies that are effective at controlling secondary contaminant sources, the effectiveness of thin-cover placement can be reinforced by long-term monitoring of sediment, chemical, geochemical, and biological conditions.
- *Implementability.* Thin covers are implementable in marsh areas as these areas are accessible from land and, to a lesser extent, water.
- *Cost.* Thin-cover placement is higher in cost than MNR due to the need to purchase, transport, and place a thin layer of material on the sediment surface; however, this remedy

is relatively low in cost compared to other remedial technologies such as capping or sediment removal. Like MNR, monitoring costs can be significant, but are lessened due to the acceleration of the natural recovery process; further, costs for thin-cover placement are generally low compared to other sediment remedies, even when considering monitoring and institutional control costs.

Based on the initial evaluation against the major NCP screening criteria, thin-cover placement is not retained as a sole remedy, but may be included as a component in the development of remedial alternatives. This FS assumes thin-cover placement is an effective and implementable technology in vegetated marsh areas to be used in conjunction with other remedial actions that address tributaries, creeks, and ditches.

4.2.5 Sediment Cap

Sediment capping involves the controlled placement of suitable materials over contaminated sediment. Capping is a relatively mature, proven technology. USEPA (2005) identifies the following three primary cap functions: physical isolation, stabilization/erosion protection, and chemical isolation. Physical and chemical isolation separate contaminants from the surrounding environment, protect human or ecological receptors from chemical exposures, and minimize the potential for resuspension and transport. Sediment capping is a readily implementable technology and experience in coastal environments is extensive. However, sediment capping is generally most appropriate for locations where routine disturbance (e.g., maintenance dredging) is not required to support local functions such as navigation, and the institutional controls can be implemented to restrict activities that could potentially impact long-term stability. Some methods for placement of material are shown on **Figure 4-3** and include hydraulic and mechanical placement.

The sediment capping typically comprises at least two layers, an isolation layer and an erosion protection layer, with a total thickness of at least 6 inches. Erosion protection is employed, where required, to stabilize the isolation materials, and generally consists of the placement of gravel or riprap over the clean sand. In situations where the grain size differences between the armor and native sediments are significant, an additional filter layer may also be necessary to provide hydraulic protection. Armoring is used to stabilize caps under site-specific hydrodynamic conditions so that sediment caps may be used in higher energy environments where currents, waves, or mechanical disturbance (e.g., propeller wash) could potentially scour the cap material. A schematic cross-section of an armored cap is shown on **Figure 4-4**.

Materials commonly used in conventional capping include clean sediment, sand, or gravel (USEPA 1998b). As for thin-cover placement (**Section 4.2.4**), in many cases capping materials can be dredged from nearby waterways instead of relying on upland sources (e.g., quarried sands). If chemically and physically suitable for re-use at the Site, capping materials could consist of beneficial reused dredged materials from ongoing USACE dredging projects discussed in **Section 4.2.4**.

Optimum material thickness is determined on the basis of site-specific characterization information, natural recovery characteristics, and RAOs. The characteristics of the clean sediment used in sediment caps, such as grain size and organic carbon content, are considerations in the choice of materials to be used and are evaluated during the design.

The thickness and configuration of each cap layer is determined based on site-specific conditions, including COCs, and material properties and hydrodynamic conditions. If warranted, geosynthetics (e.g., geomembranes or geotextiles) may be incorporated into the capping system to serve as a filter layer between dissimilar materials, reinforce the cap, or decrease contaminant flow through the cap. For complex contaminants, reactive caps involving reagents (e.g., activated carbon, organoclays, or other natural or synthetic sorbents) typically added to the capping materials to decrease contaminant flow through the cap, enhance certain physical or geochemical properties or otherwise treat target contaminants may be considered. For the purposes of this FS, geosynthetics and reactive cap materials are not considered necessary and thus are not included in the evaluation of sediment caps. However, for areas for which a sediment cap is the selected remedy, geosynthetics or reactive materials may be reconsidered during design, so long as they enhance and do not undermine cap performance, as evaluated herein.

A monitoring program is commonly required when a cap is used to remediate contaminated sediment sites. Monitoring may include bathymetric surveying and visual observation (e.g., camera or video profiling) to evaluate cap integrity and the potential for cap displacement, shifting, or erosion. Biological monitoring may be conducted to evaluate biological recovery of the cap surface, and surface sediment sampling may be conducted to monitor surface sediment deposition and recontamination potential.

Sediment capping can be implemented as a sole remedy, or in conjunction with other remedial techniques. Institutional or engineering controls, such as navigational restrictions, physical access restrictions, and future dredging restrictions, are commonly employed in conjunction with caps. Such controls minimize the potential for cap disturbance and subsequent exposure to sediment contamination by human or ecological receptors.

The USEPA *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005) discusses advantages and limitations of sediment capping. Sediment capping immediately provides a clean sediment surface and quickly reduces exposure to chemicals in surface sediments. The clean sediment surface reduces exposure to contaminants without material handling, treatment, and disposal, and often provides a clean substrate for the re-colonization of benthic organisms. A reactive cap has the added benefit of limiting the migration of contaminants into sediment porewater and surface water, thereby reducing contaminant bioavailability.

Sediment capping leaves contaminants in place and could result in potential restrictions on future use of the Site. Because sediment caps are thicker than thin covers, impacts to site hydrology and ecology[6] can be more significant and can have a longer lasting impact than MNR

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[6] Sediment capping can impact the Site hydrology and ecology if bed-elevations change (e.g., subtidal areas may be converted to intertidal areas and intertidal areas may be converted to upland areas). Initial impacts to marsh ecology would result from placement of material, though the marsh could recover with time.

or thin-cover placement. The sediment cap may also alter water depths, reducing available habitat, navigation depths, and floodway conveyance capacity.[7] Some of these hydrology challenges can be overcome by optimizing cap design and applying caps in areas where impacts are minimized; these conditions are best evaluated using a site-specific hydrodynamic model.

Sediment capping results in unavoidable disruption of the benthic environment and usually includes at least a temporary destruction of the aquatic community and habitat within the remediation area. Sediment caps incorporating reagents or geosynthetics add implementation challenges (e.g., placement of geosynthetics or reagents, blending of reagents with cap materials). Sediment caps could also require routine repair or periodic replenishment if damaged and require long-term monitoring of its structural integrity and effectiveness.

Concerns about hydrology are addressed in **Appendix B** through the evaluation of hydrodynamic conditions using a surface water transport model. Concerns about marsh ecology may be addressed by minimizing capping, to the extent practicable, in vegetated marsh areas.

Applicability to the Site

Sediment capping satisfies the RAO goals that seek risk reduction while minimizing construction hazards and implementation risks to construction workers and the environment. Sediment capping physically and chemically isolates site contaminants from the environment while enhancing natural recovery processes via stabilization and containment of in situ sediment.

OU1 exhibits conditions suitable for sediment capping, including the relatively high- and low-energy environments along the sediment banks within the creeks of OU1. In addition, cap materials could be placed in most, if not all areas, from land or water using a combination of approaches (e.g., hydraulic, mechanical, broadcasting).

Evaluation Against Major Screening Criteria

Initial evaluation sediment capping as a response against the following major NCP screening criteria can be summarized as follows:

- *Effectiveness.* Capping isolates contaminants and decreases surface sediment contaminant concentrations, thereby reducing risks to human health and the environment. Capping may be effective in areas that cannot be dredged due to limited accessibility or protection of sensitive habitat where the benefits of conserving existing habitat outweigh the benefits of dredging. Capping reduces risks within an acceptable time frame. Cap effectiveness is reinforced by long-term monitoring of cap integrity and biological recovery following remedy implementation.
- *Implementability*. In general, sediment capping is readily implementable, as areas are accessible from land and, to a lesser extent, water. Capping is field proven, and can be

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[7] Placement of fill within the floodplain could increase the potential for flooding due to a reduction in the estuaries' flow conveyance capacity.

implemented in the relatively low-energy marsh environments and the high- and low-energy environments along the sediment banks within the creeks of OU1. Implementation may require the execution and maintenance of institutional or engineering controls.

- *Cost.* Capping costs are generally moderate. Capping usually has a lower cost than dredging and is more expensive than No Action, MNR, and thin-cover placement. Costs for reactive caps can be significantly higher than those of an engineered cap due to the additional costs of the reactive media, installation, long-term monitoring, and in some cases, replacement. Monitoring costs associated with capping can be appreciable, particularly if monitoring is required over a large area and a long duration and if extensive chemical and biological monitoring are required. Initial monitoring determines whether cap installation meets design specifications. Long-term monitoring assesses long-term remedy effectiveness.

Based on the initial evaluation against the major NCP screening criteria, sediment capping is retained for further evaluation as a sole remedy and also as a component in the development of remedial alternatives.

4.2.6 Sediment Removal and Disposal/Treatment

Dredging and excavation are the two most common means of removing contaminated sediment from a water body (USEPA 2005), either while the sediment is submerged (mechanical or hydraulic dredging) or after water has been diverted or drained (excavation). Both methods typically necessitate transporting the sediment to an on-site location for treatment and on- or off-site disposal.

The primary function of sediment dredging is to physically remove contaminated sediment from the aquatic environment. By removing contaminants from an impacted environment, dredging or excavation have the potential to reduce mobility and exposure of contaminants to humans and ecological receptors. However, dredging often is confounded by an inability to achieve very low target chemical concentrations due to concurrent surface sediment mixing, and the unavoidable resuspension, release and subsequent deposition of resuspended sediments (residuals). To address dredged residuals, sediment removal often relies on backfilling or natural deposition to meet target remediation goals.[8] A conceptual illustration of the hydraulic dredging processes is provided on **Figure 4-5**. Hydraulic and mechanical sediment removals are shown on **Figure 4-6**.

The USACE (2008a) *Technical Guidelines for Environmental Dredging of Contaminated Sediments* discusses advantages and limitations of sediment removal. If sediment removal achieves cleanup levels for the Site, removal can reduce uncertainty regarding long-term cleanup effectiveness. It also provides flexibility for future use of the water body without institutional controls that limit dredging or marine construction activities.

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[8] Dredging or excavation may enhance deposition rates (i.e., dredged areas often act as traps for sediment deposition) and accelerating natural recovery processes.

Removal can lead to short-term releases via resuspension, dissolution, and release to the water column. Moreover, even the most state-of-the-art dredging and excavation equipment methods have technical limitations that often result in contaminant residuals and off-site release. Sediment residuals limit the amount of risk reduction achieved by the remedy, and consequently reduce the effectiveness of dredging (NRC 2007). Research has shown that sediment residuals remaining on the post-dredge surface typically range from 2% to 9% of the remaining contaminated sediment mass prior to the final production dredge pass (USACE 2008b). Residuals are difficult to manage for complex environmental dredging projects, particularly when targeted sediments overlie a layer of hard material (e.g., rock or till) or where rocks/cobbles, logs, or other debris are present on the river bottom (Desrosiers and Patmont 2009). There is a level of uncertainty associated with estimating the extent of residual contamination following removal, often making the sediment removal processes and achievement of risk-based remediation goals difficult and costly. Management of potential post-removal residuals, by placement backfill material or natural recovery is commonly considered to help ensure that RAOs are achieved.

Resuspension of contaminants (dissolved or sorbed to suspended sediment particles) into the water column and potential downstream transport can result in downstream impacts, even if the removal area is enclosed by turbidity control devices. Experience at similar sites indicates that an estimated 2% to 4% of the dredged contaminant mass is typically resuspended in the water column and transported (often as dissolved phase contaminants) out of the removal area (USACE 2008a). Whereas sediment turbidity impacts in the removal area can be minimized in certain applications through best management practices (BMPs) such as silt curtains or temporary sheet piling, such BMPs have been demonstrated to be generally ineffective in reducing the downstream release of dissolved contaminants.

More so than capping and thin cover placement, dredging plus backfill can significantly impact marsh hydrology, primarily by removing and filling small creeks and tributaries that contribute to water conveyance during flood and ebb tides. Some of these hydrology challenges can be overcome by optimizing the use of dredging so that dredging is applied in areas where impacts are minimized; these conditions are best evaluated using a site-specific hydrodynamic model.

Sediment removal unavoidably disrupts the benthic environment, and usually includes at least a temporary destruction of the aquatic community and habitat within the remediation area. In addition, removal requires additional handling of dredged or excavated sediment including dewatering, transport, and disposal, each of which involves additional costs and the potential for further releases. Sediment removal may also be more complex and costly than other approaches due to accommodation of equipment maneuverability, portability/site access, presence of utilities and other infrastructure, surface and submerged structures (e.g., piers, bulkheads, or pilings), overhead restrictions, and narrow creek widths.

Sediment removal could impact the integrity and stability of shorelines and existing structures within or adjacent to the removal area (e.g., existing landfill area and bulkheads). These potential impacts must be considered and addressed during design.

The following subsections discuss aspects of dredging that require consideration when evaluating dredging as a component of a sediment remedy.

Sediment Dredging and Excavation

Dredging is used to describe the removal of sediment without water diversion or draining (i.e., “in the wet” under submerged-sediment conditions). Dredging is generally accomplished using one of two technologies: hydraulic (generally involves pumping sediment and water in a slurry) or mechanical (typically involves employing an excavator or crane with a clamshell bucket on a derrick barge). Photographs of hydraulic and mechanical dredging operations are shown on **Figure 4-6**. In contrast with sediment dredging, excavation is used to describe the removal of sediment “in the dry,” and relies on the use of excavators, backhoes, and other conventional earth moving equipment to remove contaminated sediment after water has been diverted or drained from the Site (or from portions of the Site). Water diversion from the excavation area can be facilitated through the installation of temporary cofferdams, sheet piling, or other water management structures and the subsequent lowering of the surface water elevation within the excavation area. It should be noted that installation of sheet pile or temporary cofferdams to support dry excavation could cause erosion adjacent to the work area due to constricted flow or other hydrodynamic forces. In addition, sheet pile installation may be inhibited by the presence of debris and/or other natural obstructions, and sheet pile installation and removal require heavy equipment that can be disruptive of marsh ecology.

Sediment dredging and excavation have been implemented at many sites. However, in general, dredges cannot operate in very shallow water, and typically require water depths of at least 2 feet. On the other hand, mechanical excavation typically is limited to near-shore areas accessible by conventional earthwork equipment or by the practicability of diverting flow from the remediation area to facilitate excavation. Sediment Transportation, Dewatering, Treatment and Disposal

Apart from actual dredging or excavation, sediment removal involves transportation of dredged material from the area being remediated to an upland staging area (i.e., barge, truck or pipeline), usually in close proximity to the dredge area. Dewatering, treatment and disposal of dredged materials account for a major proportion of the total cost of sediment removal projects, and the ability to process the sediment may be the rate-limiting step when planning the overall schedule (USACE 2008a). In a designated staging area, sediments can be segregated, solidified, dewatered, treated or handled for disposal. Shoreline and marine construction upgrades may be required, permits procured, and concerns with potential disruption of navigable waterways addressed to support dredging operations.

Dredged sediments can be dewatered using passive (e.g., gravity dewatering, confined disposal facilities, or geotextile tubes) or active methods (e.g., belt presses, hydro-cyclones), and can require settling basins due to the relatively large volume of water added for slurry transport. Additives (polymers) may enhance dewaterability, but may increase the net sediment volume for disposal and are expensive. The degree of dewatering effort necessary prior to transport depends on the physical properties (e.g., grain size and permeability) of the removed sediment and the amount of free water entrained during the removal process.

The management of water removed from wet sediments is inherent to the dewatering approach. The magnitude and extent of water management requirements depends on the dredging or excavation method and the dewatering method employed. Water generated by sediment dewatering activities typically requires treatment to meet discharge requirements and water discharges will have to be permitted.[9]

Sediment treatment following removal can be used to remove, destroy, or reduce the mobility of contaminants, making the treated material suitable for beneficial reuse as structural or non-structural fill. However, ex situ sediment treatment technologies have limited proven reliability at full-scale and tend to have very high costs. In addition, given the contaminants of concern at OU1, multiple treatment processes would be required, as well as pilot tests, to demonstrate effectiveness. Treatment also results in additional waste streams, such as undesirable emissions from thermal treatment processes (e.g., dioxin formation and greenhouse gases).

Sediment removed can be disposed on-site or off-site with or without pretreatment. Disposal in controlled facilities reduces contaminant mobility and human and environmental exposure to contaminants. On-site disposal entails the construction of an engineered disposal area requiring periodic inspection and maintenance to ensure its integrity and function are not compromised. On-site disposal reduces risks and emissions associated with trucking for off-site disposal, and—depending on the nature of sediments to be managed—can be more cost-effective than off-site disposal. However, creation of an on-site disposal area requires real property subject to future land use restrictions and long-term operation and maintenance. Off-site disposal alternatives are based on the types and levels of contaminant and the proximity and availability of approved disposal facilities that can accept sediment. If available, the off-site disposal facility may impose additional specific acceptance requirements pertaining to moisture content, chemical concentration, or other physical/chemical criteria.

For the purposes of this FS, only off-site disposal is retained for further evaluation as a component of the sediment removal and disposal alternative. During design, on-site disposal may be considered if supported by the Agencies. In addition, considering the challenges associated with ex situ treatment, ex situ treatment is not retained for further evaluation as a component in the development of alternatives.

Applicability to the Site

Sediment removal satisfies the RAO goals that seek risk reduction while minimizing construction hazards and implementation risks to construction workers and the environment. Sediment removal eliminates site contaminants from the environment, thereby reducing contaminant mobility and human and ecological receptor exposure to contaminants. Both dredging and excavation are mature technologies, used primarily for sediment mass removal. Though removal may have little positive impact on short-term risk reduction and would result in removal of the existing benthic community, the removal of target sediment mass is expected to effectively reduce long-term risks.

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[9] As per USEPA OSWER Directive 9355.7-03, “CERCLA response actions are exempted by law from the requirement to obtain Federal, State or local permits related to any activities conducted completely on-site.” However, consultation with the permitting authority is part of the process of evaluating against the NCP criteria, and to assure that the substantive requirements of relevant permits are met.

Potential post-removal residuals could be addressed by placement of backfill over removal areas to enhance the natural recovery process. Construction BMPs, such as controlling removal rates, or using Global Positioning System (GPS) to monitor removal progress, and backfilling soon after removal is complete can be implemented to minimize turbidity and the downstream release of dissolved contaminants.

OU1 constraints (e.g., tidal effects, drained and inundated areas, soft sediments) will impede sediment removal, and a combination of removal methods (e.g., water or land-based dredging, excavation from shorelines or using amphibious equipment) may be required. The Site can accommodate the dredged material handling areas and operations (e.g., dewatering or solidification/stabilization), although improvements to create haul roads for transfer of sediments and a dock/berthing area may be necessary.

Evaluation Against Major Screening Criteria

Initial evaluation sediment removal as a response against the following major NCP screening criteria can be summarized as follows:

- *Effectiveness.* Removal of sediment by dredging or excavation has been demonstrated at numerous sites. As a mass-removal or source-removal technology, dredging and excavation are both effective process options. However, sediment removal typically relies on natural recovery processes or post-removal backfill to achieve long-term, site-specific RGOs. Natural recovery after removal can be an effective means of achieving RAO goals, via natural sedimentation and reduction of surface sediment chemical concentrations. However, considering that natural deposition rates at OU1 are slow, the removal alternatives proposed for the Site do not rely on natural recovery. Instead, backfilling is proposed to accelerate natural recovery and achieve RGOs.
- *Implementability*. Both sediment dredging and sediment excavation can be implemented within OU1 at the Site. With the exception of ex situ sediment treatment, the industry and the region have substantial experience with each of the unit processes associated with such removal approaches and all are considered implementable, though different unit processes present unique challenges at the Site. A combination of sediment dredging or excavation techniques may be required to accomplish removal of sediments within OU1.
- Monitoring of dredge depth compliance and water quality during dredging could be required to determine attainment of cleanup goals. Monitoring dredging performance and monitoring sediments after dredging is readily implementable.
- Backfilling after dredging is implementable and is expected to achieve low-concentration residuals. However, backfilling to grade is challenging and likely would achieve elevations of approximately ±6 inches of the original elevation. Dredging and backfilling of vegetated marsh areas also will smooth out the contours of the marsh, eliminating small tributaries and creeks that contribute to the micro-hydrology of the marsh.
- *Cost.* Sediment removal is generally more costly than MNR, thin-cover placement, or capping. Dredging costs can be reduced by focusing dredging to remove contaminants from target areas, such as areas with elevated chemical concentrations, while relying on other remedies to achieve overall risk reduction. Such an approach greatly reduces the

removal volume requiring dewatering and off-site disposal. Costs also are controlled by establishing an elevation-based dredging program that acknowledges the presence of residuals and manages those residuals using backfill rather than targeting low concentrations when dredging.

Based on the initial evaluation against the major NCP screening criteria, sediment removal with subsequent backfilling[10] is retained for further evaluation as a sole remedy and also as a component in the development of remedial alternatives. This FS does not critically evaluate dredging or excavation methods or processes for sediment removal and assumes that excavation or dredging by mechanical or hydraulic means are implementable.

4.3 Overview Results of Technology Screening

The technologies and process options that are retained from the screening process are listed on **Figure 4-7**. These technologies and process options are carried forward for the development of remedial alternatives in **Section 5**. The screened sediment remedy technologies to be evaluated as part of remedial alternatives for addressing sediment contamination in OU1 at the Site include the following:

1. No action
2. Institutional controls
3. MNR
4. Thin-cover placement
5. Sediment cap
6. Sediment removal and backfill, and disposal/treatment

The No Action alternative was identified and retained as required by the NCP and will serve as a baseline condition against which other remedies are compared. Although institutional controls alone are not expected to serve as stand-alone remedies, they may be combined with other technologies to enhance human health protectiveness. While data indicate that natural recovery processes are ongoing in the estuary, these processes are slow. The thin-cover placement remedy would enhance the natural recovery process, particularly in marsh areas not subject to erosion and after secondary contaminant sources are controlled by other remedial actions. Sediment capping may be employed as a sole remedy or a component of a remedial alternative, because it rapidly reduces surface sediment COC concentrations, thereby reducing or eliminating chemical exposures. Sediment dredging and/or excavation could be employed as a sole remedy or a component of a remedial alternative, because it removes the contaminant mass from the estuary. Its long-term effectiveness is enhanced when combined with natural sedimentation processes or placement of backfill over post-removal residuals, which reduces surface sediment concentrations with time. The sediment removal alternatives encompass sediment dewatering and solidification, process water management, sediment transport, and sediment disposal.

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[10] Backfilling of dredged areas will address potential post-removal residuals, enhance the natural recovery process, and help meet target remediation goals.

5 Development of Remedial Alternatives

Section 4 identified a range of remedial technologies that are potentially applicable within OU1. In this section, technologies retained from the **Section 4** screening are incorporated into six potentially viable remedial alternatives for addressing OU1 sediments. The alternatives include combinations of remedial technologies and process options (i.e., thin-cover placement, capping, and sediment removal) and control measures (i.e., monitoring programs and institutional controls) identified as plausible based on the CERCLA criteria of effectiveness, implementability, and cost. The six remedial alternatives, which incorporate source control and institutional controls, are listed below and summarized in **Table 5-1**.

- Remedy Alternative 1: No action
- Remedy Alternative 2: Sediment Removal in SMA-1
- Remedy Alternative 3: Sediment Removal, Capping, and Thin-cover placement in SMA-1
- Remedy Alternative 4: Sediment Removal in SMA-2
- Remedy Alternative 5: Sediment Removal, Capping, and Thin-cover placement in SMA-2
- Remedy Alternative 6: Sediment Removal, Capping and Thin-cover placement in SMA-3

This section describes the general engineering scope and implementation considerations of each remedial alternative. The evaluation process presented in this section is consistent with USEPA guidance (1988, 2005) and CERCLA requirements to evaluate a range of remedial strategies for a given site. In **Section 6**, these alternatives are evaluated against the full range of NCP evaluation criteria.

The sediment remedies will be required to meet substantive State of Georgia and federal permit requirements for waterfront activities associated with disturbance to state and federal navigable waters. It is possible that state and/or federal substantive permitting requirements could alter the remedies described in this section. The nature of changes to one or more of the sediment remedy alternatives cannot be ascertained until the permitting process has been completed and regulatory requirements are known. However, at this time, it is not anticipated that the substantive permitting requirements would fundamentally alter the overall conclusions and recommendations presented in this FS.

This section is organized as follows: **Section 5.1** identifies and describes the range of remedial technologies applicable to the SMAs identified in **Section 2**; **Section 5.2** describes common elements associated with each of the sediment remedial alternatives; and **Section 5.3** through **Section 5.8** describe sediment remedy alternatives 1 through 6.

5.1 Remedial Technologies Applicable to Remedial Subareas

While SMAs are defined according to risk criteria (**Section 3.4**), remedial subareas are defined based on geographic, morphologic, hydrologic, and other physical characteristics, and are broken down under a Marsh category and a Creeks and Ditches category. Evaluation of remedial technologies considers both site-specific risk criteria and physical conditions to measure effectiveness and implementability. In this section, the implementability of screened remedial technologies (i.e., thin-cover placement, sediment capping, and sediment removal)[11] is evaluated for each subarea. This area-specific screening provides a basis for the sediment remedial alternatives described in **Sections 5.3** through **5.8**.

5.1.1 Vegetated Marsh Areas

OU1 comprises a number of vegetated marshes bounded by creeks or other waterways. Remedial technology implementation is severely impacted by accessibility to some of these vegetated marshes, particularly during ebb tide. In some marsh areas, potential short and long-term ecological impacts may significantly outweigh environmental benefits of remedy implementation. The following is an evaluation of remedial technology implementation and ecological impacts for SMAs or portions of SMAs located within the vegetated marshes of OU1.

Domain 1a, Domain 2 and Domain 3

Areas considered for remediation within the Domain 1a, Domain 2 and Domain 3 saltwater marshes are located around Eastern Creek, LCP Ditch, Western Creek, and Domain 3 Creek. These areas are net depositional and not subject to excessive erosion during tide cycles. Tidal cycles result in diurnal flooding and drainage of the marsh areas, limiting accessibility for both land-based and aquatic-based equipment. Areas along LCP Ditch, Eastern Creek, Western Creek, and Domain 3 Creek are accessible only from upland areas, because the creeks are narrow and completely drain at low tide, making aquatic access from Purvis Creek impracticable.

Land-based access to the Domain 1a, Domain 2 and Domain 3 remedial areas requires the construction of temporary access roads to establish surface elevations at least 1 foot above the mean high water elevation. These roads would be used to access remedial areas and facilitate material (e.g., excavated material, backfill material, cover or capping material) transfer. The roads would be removed upon completion of construction activities, or integrated into the remedial action, such as by using the road material as backfill after sediment removal.

Thin covers could be installed using spreader barges or by broadcasting or spraying material using land-based equipment staged in upland areas, on temporary access roads, or on water-based barges, where possible. Sediment excavation could be performed using low ground pressure earth moving equipment staged on upland areas or temporary access roads. Where water-based operations are possible, sediment could be excavated during ebb tide and mechanically dredged during flood tide. For either operation, multiple staging areas are required to facilitate and optimize material handling, access, and management. Movement of materials into and out of the marsh areas must be coordinated around the tide cycle, whether using land-based or aquatic-based equipment.

The evaluation of sediment removal, capping, or thin-cover placement in marsh areas involved consideration of the benefits of risk reduction achieved by each remedy, physical and ecological

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[11] The remedial alternatives also incorporate source control and institutional controls as a component of the final remedy. The alternatives also rely on existing natural recovery processes to meet long-term post-remedial objectives.

impacts to the marsh ecosystem, and physical impacts to marsh hydrology. Most of the marsh areas exhibit relatively low-risk conditions, with contaminant concentrations infrequently above the upper end of the RGO range (these areas are captured in SMA2).

Thin-cover placement achieves the project-specific RAOs with the least physical impact on the marsh ecosystem, and thus with minimal unintended negative impacts, due to the following points:

- A thin-cover of clean sediment immediately reduces surface sediment chemical concentrations and achieves levels below the low-end RGOs.
- Implementation can be performed without introduction of heavy equipment on the marsh.
- Thin covers do not significantly change the marsh bed elevations, minimizing the potential for ecological impacts. Further, though initial impacts to marsh ecology may occur from material placement, vegetated marshes typically recover vigorously in one to two growing seasons (**Appendix E**).
- Given their shallow profile, thin covers do not significantly impact hydrology, so that wetting and drying cycles for marsh areas remain effectively unchanged.
- The thin-cover material can be selected and specified to optimize ecological conditions for plant growth and benthic animal colonization.

Capping of marsh areas achieves the project-specific RAOs by reducing surface sediment chemical concentrations to levels below the target RGOs. Capping involves placement of clean sediment material—an engineered chemical isolation layer—to establish a low-concentration sediment surface. Cap armoring, which keeps the cap stable against high-energy currents, is not necessary in the vegetated marsh areas due to low current velocities. Though the overall thickness of an engineered cap causes negative impacts to surface water hydrology and habitat, these impacts are minimized by controlling placement methods and reducing the cap profile to the extent practicable while still achieving site-specific RAOs. However, unlike thin-cover placement, which minimizes hydrologic impacts to the marsh, capping causes further substantial negative impacts to the marsh ecosystem and hydrology:

- Heavy equipment is required to install an engineered cap so that the chemical isolation material is carefully placed according to the specifications of the remedy. Roads also must be built to access capping areas, further impacting the marsh ecosystem in ways that this FS cannot anticipate.
- Capping has a substantial impact on the existing ecosystem due to its potential to fill small tributaries, impacting hydrology and ecology in ways that may not be readily anticipated or predictable.
- Marsh plants and benthic animals are covered by capping. Restoration efforts, such as replanting, may accelerate recovery after remediation. However, restoration is expected to be slower with an engineered cap than with the thin-cover placement approach.
- For vegetated marsh areas, armoring can hinder the pace or extent of habitat restoration over capped areas.

Though capping is expected to meet the NCP threshold criteria of 1) overall protection of human health and the environment, and 2) compliance with ARARs, and is expected to be implementable, this remedial technology is likely to cause substantial negative impacts to the marsh ecosystem in vegetated marsh areas (significantly changing elevations, filling tributaries, and covering or altering marsh plants and benthos) without achieving commensurate risk reduction. For this reason, capping is not carried forward for further consideration in the vegetated marsh areas.

Removal involves the excavation of sediment, followed by backfilling with a clean sediment layer. Because removal alone may not achieve low surface sediment chemical concentrations due to the presence of residuals, backfilling is used to create a relatively clean sediment surface. When combined with backfilling, sediment removal is expected to meet the NCP threshold criteria of 1) overall protection of human health and the environment, and 2) compliance with ARARs, and is expected to be implementable. This remedial technology achieves the project-specific RAOs but may cause substantial short-term impacts on the marsh ecosystem, including unintended negative short-term impacts, due to the following points:

- Implementation must be performed with heavy equipment to excavate and backfill marsh areas. Roads also must be built to access sediment removal areas, further impacting the marsh ecosystem in ways that this FS cannot anticipate.
- Removal results in the complete excavation of the existing sediment surface and established benthic community, while backfilling fills the removal areas. Consequently, small tributaries are removed and backfilled, temporarily impacting hydrology in ways that are not readily anticipated or predictable.
- Backfilling returns sediment removal areas to grade, and thus helps minimize changes to the marsh bed elevations, which in turn minimize potential impacts to hydrology. However, backfilling exactly to an existing grade can be challenging. Removal and placement of materials in an aquatic environment is generally performed within a level of precision of ± 6 inches, depending on site-specific conditions. An elevation change of ± 6 inches may not be harmful to the marsh and is within the tolerance of the thin-cover placement technology and capping.
- Marsh plants and benthic animals are removed with sediment removal. Restoration efforts, such as replanting, accelerate recovery after remediation and minimize short-term impacts on the ecosystem. However, the success of replanting efforts varies depending on site-specific conditions.

Removal requires the construction of temporary access roads and multiple staging areas. Thin-cover placement also may require access roads and staging, unless those staging areas can be shared with those required for dredging or capping of marsh channels and tributaries. To the extent that water-based operations are implemented, productivity and accessibility of equipment, material, and personnel from work areas would be significantly limited by tidal effects.

In summary, thin-cover placement and sediment removal are retained for evaluation as remedial technologies for the saltwater marsh areas within Domain 1a, 2 and 3.

Dillon Duck

Dillon Duck is bound by upland areas to the north, east, and south, and the Domain 3 Creek to the west. This area drains into the Domain 3 Creek, thus it generally exhibits relatively constant and very shallow water depths and slow water velocities. As a result, this area is net depositional and not subject to excessive erosion. The configuration and location of Dillon Duck makes this area accessible only by land.

Given the relatively soft nature of wetlands materials, land-based access to the Dillon Duck remedial area requires the construction of temporary access roads with surface elevations at least 1 foot above the existing ground surface. These roads would be spaced about 100 feet apart and used to access remedial areas and facilitate construction material (e.g., excavated material, backfill material, cover or capping material) transfer. These roads would need to be dismantled upon completion of the construction activities or integrated as part of the remedial action.

For reasons discussed earlier, sediment capping is not recommended in Dillon Duck. Placement of 12 inches or more of material, as required by sediment capping, results in sediment bed elevation changes that could impact the Site hydrology and ecology. The resulting topography changes could convert portions of the wetlands areas into upland areas, limiting wetlands restoration potential.

Thin covers could be installed by broadcasting or spraying material using land-based equipment staged in upland areas or temporary access roads. Sediment excavation could be performed using low ground pressure earth moving equipment staged on upland areas or temporary access roads. For either operation, a single staging area is required to facilitate and optimize material handling, access, and management.

In summary, thin-cover placement and sediment removal are evaluated for remediation of the Dillon Duck marsh wetlands. Both technologies require the construction of temporary access roads and a staging area. Because the Dillon Duck wetlands are generally accessible by land and tidal effects are minimal, it is anticipated that ingress and egress of equipment, material, and personnel from work areas would not be limited by tidal effects.

5.1.2 Marsh Creeks and Ditches

Four main creeks (i.e., Eastern Creek, Western Creek Complex, Domain 3 Creek, and Purvis Creek) and a constructed ditch (LCP Ditch) subdivide OU1 east of Purvis Creek. Remedial technology implementation is severely impacted by accessibility issues within some of these creeks and ditches, and in some areas potential short and long-term ecological impacts significantly outweigh environmental benefits of remedy implementation. Sediment removal is a viable technology for all creeks and ditches, and sediment capping is feasible for creeks and ditches provided that its implementation does not restrict water conveyance capacity. Although all creeks and ditches are net depositional, they are subject to periods of high flow during flood and ebb tides. Tidal flows in the marsh have been modeled (**Appendix B**) to predict the range of velocities that can occur in the creeks and ditches and to assess the stability of thin-cover placement materials and the need for cap armoring. The results of the model analysis indicate that cap armoring is generally needed in the creeks, rendering thin-cover placement ineffective for creeks and ditches.

Both sediment removal with subsequent backfilling and capping achieve the project-specific RAOs by creating a clean sediment surface that meets the RGO target concentrations:

- Removal involves the excavation of sediment followed by backfilling with a clean sediment layer due to the presence of residuals to create a relatively clean sediment surface. When combined with backfilling, sediment removal is expected to meet the NCP threshold criteria of 1) overall protection of human health and the environment, and 2) compliance with ARARs, and is expected to be implementable.
- Capping, which involves the placement of a clean isolation layer on the sediment surface followed by an armoring layer, also creates a clean sediment surface. Thus, sediment capping is expected to meet the NCP threshold criteria of 1) overall protection of human health and the environment, and 2) compliance with ARARs, and is expected to be implementable.
- Implementation of both sediment removal/backfilling and sediment capping must be performed with heavy equipment. Roads also must be built to access remedial areas, further impacting the creek ecosystem in ways that this FS cannot anticipate.
- Sediment removal/backfilling and capping can have substantial impacts on the existing ecosystem. However, by confining activities to the channel areas, impacts to the vegetated marshes are minimized.
- Capping with armoring and sediment removal with backfill will temporarily impact marsh habitat during construction, although such impacts are expected to be temporary and the system is expected to recover with time. Short-term impacts could be minimized by controlling placement methods, material selection, and reducing the cap profile to the extent practicable while still achieving site-specific RAOs.
- The hydrologic impacts of capping with armoring and sediment removal with backfill have been examined using the hydrodynamic model. The model demonstrated that neither technology will permanently and adversely influence surface water hydrodynamics, as measured by flow velocities and wetting / drying cycles (**Appendix B**). However, the capping with armoring and removal with backfilling approaches have the potential to fill small creeks and tributaries in ways that cannot easily be predicted, thus potentially impacting hydrology in ways that may not be anticipated or predictable.
- Backfilling of sediment removal areas to grade helps minimize changes to the marsh bed elevations, thus minimizing potential impacts to hydrology. Removal and placement of materials in an aquatic environment is generally performed within a level of precision of ± 6inches, depending on site-specific conditions.
- Some impacts to marsh plants and benthic animals cannot be avoided, as access roads are required for both sediment removal/backfilling and sediment capping. Restoration efforts, such as replanting, are used to accelerate recovery after remediation and minimize short-term impacts on the ecosystem.

- Marsh plants and benthic animals are destroyed during dredging and they are covered by capping. However, recovery is expected to occur within approximately two years.

The following sections evaluate remedial technology implementation and ecological impacts for specific creeks and ditches of OU1.

Purvis Creek

Purvis Creek is the primary tidal channel that connects the Site to the Turtle River. Purvis Creek subdivides the marsh areas approximately in half and connects to several secondary creeks (e.g., Eastern Creek, the Western Creek Complex, LCP Ditch, Domain 3 Creek). Purvis Creek is subject to relatively high flows and elevated velocities approaching 2 ft/sec during peak tidal flows. Under these flow conditions, conventional thin covers are not stable without adequate armoring. For this reason, only capping and removal are evaluated for Purvis Creek.

Both sediment removal and armored sediment capping are technically viable technologies for Purvis Creek. While both remedial options produce temporary impacts to the benthic communities, these communities are expected to recover over time. Both sediment removal/backfilling and sediment capping incorporate the placement of a clean streambed surface.

Areas within Purvis Creek could be accessed by water. Work in South Purvis Creek would not be interrupted by tides, whereas work in North Purvis Creek would be interrupted by tides. In north Purvis Creek, tides would impact ingress and egress of equipment, material and personnel transport, and construction schedules. Because remedial areas in North Purvis Creek are isolated from other remedial areas, access via land requires construction of a network of temporary access roads and procurement of access agreements from adjoining property owners, possibly making land access even more difficult than aquatic access. Construction of these roads would result in significant impact to vegetated marshes located in areas where remediation is not required. Therefore, although limited by tides, access via water is expected to be the preferred implementation method for both North and South Purvis Creek.

Both sediment removal and capping can be performed using equipment staged on shallow draft barges. Sediment can be excavated during ebb tide and mechanically or hydraulically dredged during high tide. Similarly, sediment caps can be mechanically or hydraulically constructed. For either operation, a single staging area is required to facilitate and optimize material handling, access, and management. This staging area could be located near the Causeway, which runs parallel to the northern shore of LCP Ditch, to support water-based operations and material management (either sediment removed or capping materials).

In summary, only sediment capping and sediment removal are retained for evaluation as remedial technologies for Purvis Creek, both to be implemented as water-based operations, supported by a staging area located near the Causeway. Productivity and accessibility of equipment, material and personnel from work areas would be limited by tidal effects, particularly in the isolated remedial areas of North Purvis Creek.

LCP Ditch and Eastern Creek

The Eastern Creek is connected to LCP Ditch, a constructed channel that connects the Site to Purvis Creek along the southern edge of the Causeway. The Eastern Creek and LCP Ditch exhibit some of the highest contaminant concentrations, thereby potentially acting as secondary sources to other creeks and marsh areas. Although capping could effectively prevent exposure and future migration, because of the high contaminant concentrations and the need to prevent future transport to other areas of marsh, sediment removal is deemed the most appropriate remedy for Eastern Creek and LCP Ditch. Although sediment removal results in temporary impacts to benthic communities, these communities are expected to recover over time after backfilling.

Remedial work within Eastern Creek and LCP Ditch can be conducted by land or water; tides will limit productivity and accessibility of equipment, material, and personnel in either case. Land-based access to Eastern Creek and LCP Ditch requires construction of temporary access roads across the soft sediments of Domain 1a and may require improvements of the Causeway to facilitate access to remedial areas and material (e.g., excavated material, backfill material) transfer. Temporary access roads across the soft sediments of the marshes would be spaced about 100 feet apart, with surface elevations at least 1 foot above the mean high water elevation. The same roads could be used for marsh area remedy implementation and removed upon completion of construction or integrated in the remedial action (e.g., used as backfill).

In summary, only sediment removal is retained for evaluation as a remedial technology for Eastern Creek and LCP Ditch, to be implemented as land-based or water-based operation, supported by a staging area located near the mouth of LCP Ditch or the mouth of Eastern Creek. Due to tides, productivity and accessibility of equipment, material, and personnel from work areas may be limited by tidal effects.

Western Creek Complex

The Western Creek Complex is the southernmost secondary channel connected to Purvis Creek and is composed of three main branches. Because remedial areas within the Western Creek Complex are discontinuous and isolated from other remedial areas within the creek, capping discrete areas would likely result in the creation of troughs and valleys within the narrow and shallow Western Creek Complex; these troughs would likely restrict flow conveyance capacity, especially at low tides, and thus could negatively impact the vegetated marshes surrounding the creek. Therefore, sediment capping is not retained for evaluation for the Western Creek Complex, and sediment removal is considered the only viable remedial alternative in this area.

Remedial areas within the Western Creek Complex could be accessed by land or water, although tides would affect ingress or egress of equipment, material, and personnel from work areas. Access via land requires construction of a network of temporary access roads and procurement of access agreements from adjoining property owners. Construction of these roads would result in significant impact to surrounding marshes, including those where remediation is not required, to access remedial areas and material (e.g., excavated material, backfill material) transfer. The temporary access roads across the soft sediments of the marshes would have surface elevations at least 1 foot above the mean high water elevation.

The roads would be removed upon completion of the construction activities or integrated as part of the remedial action.

In summary, sediment removal is the only remedial technology evaluated for the isolated and discontinuous remedial areas of the narrow and shallow channels comprising the Western Creek Complex, to be implemented with a land-based operation, supported by a staging area located near the mouth of LCP Ditch. Productivity and accessibility of equipment, material, and personnel from work areas may be limited by tidal effects.

Domain 3 Creek

The Domain 3 Creek is the northernmost secondary channel connected to Purvis Creek. The northern portion of this creek is directly connected to the upper reaches of Purvis Creek. The southern reach of the Domain 3 Creek is indirectly connected to the central portion of Purvis Creek. Domain 3 Creek also is connected to the Dillon Duck marsh.

Both sediment removal and armored sediment capping are applicable to the Domain 3 Creek. Although both remedial options would impact the benthic community, those communities are expected to recover over time.

The impact of potential remedies on surface water hydrology was investigated using the hydrodynamic model (**Appendix B**). Placement of 12 inches of material is required for sediment capping and armoring, and additional thickness may result from construction tolerances. Model results show that the placement of a cap along the Domain 3 Creek is not expected to significantly impact the marsh hydrology.

Remedy areas within Domain 3 Creek could be accessed by land or water, though land-based access is more likely due to the creeks’ proximity to land. Tides will significantly affect ingress or egress of equipment, material, and personnel from work areas. Land-based access to the Domain 3 Creek requires construction of a small quantity of temporary access roads across the soft sediments of Domain 3 marshes and upland areas. These roads would be used to access remediation areas and material (e.g., excavated material, backfill material) transfer. The temporary access roads across the soft sediments of the marshes would need to have surface elevations at least 1 foot above the mean high water elevation. The roads would need to be dismantled upon completion of the construction activities or integrated as part of the remedial action.

To overcome tidal effects and upland area accessibility constraints, sediments can be excavated or capped using low ground pressure earthmoving equipment staged on upland areas or the temporary access roads. However, to facilitate and optimize material handling, access, and management, multiple staging areas are required.

In summary, sediment excavation and sediment capping are evaluated for remedial areas within the Domain 3 Creek, to be implemented as a land-based operation supported by multiple staging areas.

5.2 Elements Common to All Remedial Alternatives

Several common elements are relevant to OU1 remedial alternatives such as source controls, existing regulatory requirements, existing institutional controls, and site-wide monitoring. Related assumptions that are also common to all remedial alternatives include the following:

- Known upland sources of contamination to OU1 (i.e., sources associated with historical industrial discharges and overland runoff and identified in Table 7-1 of the RI report; EPS and ENVIRON 2012) have been controlled.
- A hydrodynamic assessment was performed (**Appendix B**) to determine whether modifications to the marsh and channel areas resulting from remedy implementation have the potential to adversely affect the hydrologic characteristics of the marsh. Under all conditions evaluated, the analysis indicated that likely hydrologic impacts to the marsh resulting from remedy implementation are minimal.
- Physical constraints across Purvis Creek (e.g., remnants of a bulkhead and bridge, potential cross-channel utilities, and debris) can hinder remedy implementation and must be evaluated during remedy design.
- Institutional controls, namely fish advisories already in place for Purvis Creek and the Turtle River system and an existing commercial fishing ban for Purvis Creek, will be maintained. With time, if and when fish chemical concentrations fall below the criteria to maintain the fish advisories and/or commercial fishing ban, the State of Georgia may elect to remove the advisories and/or commercial fishing ban. Current USACE permit requirements for dredging, capping, or other construction activities under Section 401 and 404 of the Clean Water Act will also serve as institutional controls for future construction in and adjacent to OU1 at the Site.
- Where incorporated as part of a remedial alternative, thin covers consist of a nominal 6 inches of sand to be broadcast pneumatically or sprayed hydraulically.
- Where incorporated as part of a remedial alternative, sediment caps are assumed to consist of a chemical isolation layer (approximately 6 inches of sand based on preliminary chemical flux evaluations presented in **Appendix H**) overlain with 6 inches of coarse sand-to-gravel armor material for physical isolation. Based on the preliminary hydrodynamic modeling presented in **Appendix B**, the sediment cap will be armored as needed to resist peak flow velocities in the marsh creeks and ditches. For the purpose of this FS, it is also assumed that the sediment cap requires no amendments, reagents or geosynthetics, based on the results of preliminary cap modeling (see **Appendix H**).
- Where incorporated as part of a remedial alternative, sediment removal entails the excavation or dredging of 18 inches of sediment and backfilling with 12 inches of clean material.
- The exact methods to be used to reduce potential sediment suspension and contaminant release will be assessed during remedy design. Construction BMPs, such as operational controls (controlling the bite size or limiting the removal rates) and specialty equipment (e.g., environmental clamshell buckets with open/closed sensors and GPS tracking to track progress) will be used during sediment removal operations to reduce potential contaminant release. BMPs will be specified in the detailed design phase.

- Where required, dewatering and water treatment will be performed as practicable at an on-site dewatering area. Removed materials (e.g., dewatered sediment) will be disposed at licensed off-site disposal facilities in conformance with applicable federal and state environmental laws and regulations.
- To the extent that materials dredged from nearby waterways (e.g., Brunswick Harbor and Savannah Harbor) meet state criteria, these materials could be reused beneficially at the Site as backfill, capping, or cover materials.
- Material and equipment staging areas and dock/berthing facilities for loading/offloading of materials (backfill, capping materials, cover materials, or dredged/excavated materials) will be constructed. In addition, shoreline and marine construction upgrades may be implemented, permits procured, and concerns about potential disruption of navigable waterways addressed.
- Construction activities within OU1 are anticipated to take place over a 1 to 2-year period (depending on the alternative), following remedial alternative selection, remedial design, and to meet substantive permit requirements. To the extent that water-based operations are implemented, accessibility of equipment, material, and personnel from work areas is limited significantly by tidal effects and consequently will extend the implementation schedule.
- Where required and as detailed for the selected remedial alternative, maintenance and monitoring will be performed. Future remedial design evaluations may be required for any remedial alternative selected. Details of the construction monitoring will be developed during remedial design.

5.3 Sediment Remedy Alternative 1: No Action

Pursuant to the requirements of the NCP to identify baseline environmental conditions in the absence of remediation, the No Action remedial alternative is included in the analysis for comparison to other alternatives. This remedial alternative reflects baseline river sediment conditions as described in the OU1 RI (EPS and ENVIRON 2012), and entails no further action for remediation of the OU1 sediments. With the No Action remedial alternative, natural recovery processes are expected to continue and institutional controls, namely fish advisories already in place for Purvis Creek and the Turtle River system, an existing commercial fishing ban for Purvis Creek, and permitting requirements or restrictions, are maintained.

5.4 Sediment Remedy Alternative 2: Sediment Removal in SMA-1

Remedy Alternative 2 addresses exceedances of any RGOs in the 48-acre SMA-1 remediation area by combining sediment removal with natural recovery, institutional controls, and long-term monitoring. This alternative targets the remediation of surface and subsurface sediments in the OU1 with the following benthic community RGOs:

- Lead concentrations greater than 90 mg/kg
- Mercury concentrations greater than 4 mg/kg
- Total PAHs concentrations greater than 4 mg/kg
- Aroclor 1268 concentrations greater than 6 mg/kg

This alternative also targets the SWAC RGOs protective of human health, mammals, and birds.

This remedy alternative calls for sediment removal and backfilling within Eastern Creek, Western Creek, LCP Ditch, Purvis Creek, the Domain 3 Creek, Dillon Duck, and the vegetated marshes of Domains 1a, 2 and 3 (**Figure 5-1** and **Table 5-2**).

5.4.1 Sediment Removal and Backfilling

The limits of dredging and backfilling for Remedy Alternative 2 are shown on **Figure 5-1**. The proposed sediment removal area is approximately 48 acres, distributed as summarized in **Table 5-1**.

In proposed sediment removal areas, removal targets a depth of 45 cm (18 inches), where the sediment chemistry is expected meet the RGOs. For the purpose of this FS, the estimated in-place sediment volumes targeted for removal in Remedy Alternative 2 amount to approximately 153,000 cubic yards (CY). Following removal, the remedial areas are backfilled with 12 inches (or approximately 96,000 CY) of clean material (e.g., sand) to manage risks associated with post-removal residuals, accelerate the natural recovery process, and establish a clean sediment surface.

Mechanical dredging and/or sediment excavation could remove sediments as part of Remedy Alternative 2. The construction of various sediment management/staging areas and temporary access roads is required to facilitate material management and sediment excavation. Debris must be removed during sediment removal, either during excavation/dredging or as part of a separate debris removal operation, which may hinder or slow sediment removal. The distribution of submerged debris is expected to be relatively high, particularly in sediment removal areas that have not been historically dredged or maintained. Debris will be disposed off-site at licensed facilities. Sediments will be dewatered on-site and disposed at licensed off-site facilities.

5.4.2 Short- and Long-Term Monitoring Requirements for Remedy Alternative 2

As part of the remedy design process, both short- and long-term maintenance and monitoring programs will be developed to ensure the long-term protectiveness of the remedy. Long-term monitoring of environmental restoration recognizes that uncertainty is inherent to any cleanup activity and must be managed through data collection and monitoring (USDOE, 1997). Short-term monitoring determines whether remedy implementation meets design specifications. These monitoring activities span the construction phase and are defined in the construction drawings, specifications, and the quality assurance/quality control (QAQC) plan, to be developed during the remedy design phase. QA/QC measures could include soundings and surveys to verify removal depths, depth verification measurements to document backfill material placed, and/or backfill material coverage assessments.

Long-term remedy monitoring ensures the remedy's long-term structural integrity and its effectiveness in enhancing ecosystem recovery and reducing risks to human health and the environment. Details of the long-term monitoring program will be developed during remedial design, and may include:

- Physical measurements to monitor backfilled areas or recovery processes (e.g., push cores, bathymetric surveys, or visual observation via camera or video profiling).
- Biological measurements to monitor benthic and fish community integrity on remediated areas.
- Visual observations and surveys of marsh recovery, including plant growth and plant density.
- Chemical measurements in fish to monitor trends in whole-body and/or fillet fish.
- Surface sediment chemical measurements to monitor area-weighted concentrations in remediated areas.
- Surface water quality measurements, as necessary to comply with ARARs.
- Physical measurements to monitor the integrity of backfilled areas (e.g., bathymetric surveys, push cores, or visual observation via camera or video profiling).

5.5 Sediment Remedy Alternative 3: Sediment Removal, Capping and Thin-Cover Placement in SMA-1

Remedy Alternative 3 addresses exceedances of any RGOs in the 48-acre SMA-1 remediation area by combining sediment removal, sediment capping, and thin-cover placement with natural recovery, institutional controls, and long-term monitoring **(Figure 5-2** and **Table 5-2)**. This alternative targets the remediation of surface and subsurface sediments in OU1 with the following benthic community RGOs:

- Lead concentrations greater than 90 mg/kg
- Mercury concentrations greater than 4 mg/kg
- Total PAHs concentrations greater than 4 mg/kg
- Aroclor 1268 concentrations greater than 6 mg/kg

This alternative also targets SWAC RGOs protective of human health, mammals, and birds.

This alternative includes sediment removal and backfilling in Eastern Creek, Western Creek and LCP Ditch; and capping in Purvis Creek and Domain 3 Creek. Thin covers would be placed within Dillon Duck and the vegetated marshes of Domains 1a, 2 and 3.

5.5.1 Sediment Removal and Backfilling

The limits of dredging and backfilling for Remedy Alternative 3 are shown on **Figure 5-2**. The proposed sediment removal area is approximately 8 acres, distributed as summarized in **Table 5-1**.

In proposed sediment removal areas, removal targets a depth of 45 cm (18 inches), where the sediment chemistry is expected to meet the RGOs. For the purpose of this FS, the estimated in-place sediment volumes targeted for removal in Remedy Alternative 3 amount to approximately 27,000 CY. Following removal, the remedial areas will be backfilled with 12 inches (or approximately 17,000 CY) of clean material (e.g., sand) to manage risks associated with post-removal residuals, accelerate the natural recovery process, and establish a clean sediment surface.

Mechanical dredging and/or sediment excavation could be used to remove sediments as part of Remedy Alternative 3. The construction of various sediment management/staging areas and temporary access roads is required to facilitate material management and sediment excavation. Debris must be removed during sediment removal, either during excavation/dredging or as part of a separate debris removal operation, which may hinder or slow sediment removal. The distribution of submerged debris is expected to be relatively high, particularly in sediment removal areas that have not been historically dredged or maintained. Debris will be disposed off-site at licensed facilities. Sediments will be dewatered on-site and disposed at licensed off-site facilities.

5.5.2 Sediment Capping

The limits of sediment capping for Remedy Alternative 3 are shown on **Figure 5-2**. The proposed sediment capping area is approximately 16 acres, distributed as summarized in **Table 5-1**.

Sediment caps are targeted for these areas to isolate underlying sediment contaminants; control chemical migration, physical erosion, and biological contact with underlying sediment contaminants; and provide a clean sediment surface for habitat restoration. As detailed in **Appendix H**, preliminary cap design evaluations were performed in general accordance with USEPA guidance and using conservative assumptions (e.g., maximum sediment concentrations and peak shear stresses). These evaluations were used to conceptually design the thickness and material size for the cap armor layer to ensure that the cap retains its integrity under worst-case shear stress conditions. The analysis in **Appendix H** shows that a 6-inch base chemical isolation layer with up to 6 inches of coarse sand to gravel armoring adequately protects against chemical migration through the cap as well as erosive forces resulting from storm events.

Cap placement could be performed as a water-based operation (north and south Purvis Creek) and a land-based operation (Domain 3 Creek). Given shallow water depths, narrow creeks and tidal effects, the cap may need to be placed by small mechanical equipment (e.g., backhoe or similar excavator with a fixed arm or a telescoping conveyor belt) operating from the shoreline and/or a shallow-draft barge. The construction of various material staging areas and temporary access roads is required to facilitate material management and sediment cap placement. While the anticipated distribution of submerged debris is expected to be relatively high because the proposed sediment removal areas have not been periodically maintained, debris will remain in place unless it interferes with capping operations. Any removed debris will be disposed off-site at licensed facilities.

5.5.3 Thin-cover placement

The limits of thin-cover placement for Remedy Alternative 3 are shown on **Figure 5-2**. The proposed thin-cover placement area is approximately 23 acres, distributed as summarized in **Table 5-1**.

Thin covers are targeted for the low-energy environments within OU1 to accelerate ongoing natural recovery processes (e.g., contaminant burial), reduce risks to human health and the environment, and provide a clean sediment surface for habitat restoration. Given their profile, thin-cover placement is best suited for wetlands or marsh environments as they minimize the negative ecological impacts of sediment capping (e.g., loss of aquatic habitat, potential changes in marsh inundation patterns) or implementation concerns with sediment removal (e.g., destruction of marsh habitat, areas of limited accessibility). Based on a literature review of thin-cover placement in marsh and wetlands restoration case studies (Ray 2007), it is anticipated that remediated areas will recover within two growing seasons. A detailed summary of research related to thin-cover placement, including marsh recovery time and issues related to bioturbation is provided in **Appendix E**.

Thin cover materials could be placed as a water-based operation and/or a land-based operation, in which materials are broadcast mechanically or pneumatically or sprayed hydraulically. If placement is a water-based operation (e.g., portions of vegetated marshes abutting the Eastern Creek or LCP Ditch), the equipment is staged along the shoreline and/or from shallow-draft barges. Land-based placement of thin covers (e.g., Dillon Duck or inland portions of all other vegetated marshes) requires the construction of a limited number of temporary access roads to place thin-cover materials. Both land- and water-based operations require the construction of a limited number of staging areas to facilitate material transport and manage operations. Submerged debris, if any, will remain in place.

5.5.4 Short- and Long-Term Monitoring Requirements for Remedy Alternative 3

As part of the remedy design process, both short- and long-term maintenance and monitoring programs will be developed to ensure the long-term protectiveness of the remedy. Long-term monitoring of environmental restoration recognizes that uncertainty is inherent to any cleanup activity and must be managed through data collection and monitoring (USDOE 1997). Short-term monitoring determines whether remedy implementation meets design specifications. These monitoring activities span the construction phase and are defined in the construction drawings, specifications, and the QA/QC plan, to be developed during the remedy design phase. QA/QC measures could include soundings and surveys to verify removal depths, depth verification measurements to document material placed, and/or material coverage assessments.

Long-term remedy monitoring ensures the remedy’s long-term structural integrity and its effectiveness in enhancing ecosystem recovery and reducing risks to human health and the environment. Details of the long-monitoring program will be developed during remedial design, and may include:

- Physical measurements to monitor cap integrity (e.g., push cores, bathymetric surveys, or visual observation via camera or video profiling).
- Biological measurements to monitor benthic and fish community integrity on dredged/excavated, capped, or thin-cover placement areas.
- Visual observations of marsh recovery and surveys, including plant growth and plant density.
- Chemical measurements in fish to monitor trends in whole-body and/or fillet fish.

- Surface sediment chemical measurements to monitor area-weighted concentrations in remediated areas.
- Surface water quality measurements, as necessary to comply with ARARs.

Although caps are designed to withstand high-energy event flows, they may require repair or periodic replenishment if damaged by erosion or unexpected environmental conditions (e.g., extreme storm events), particularly if such events occur before marsh grasses are restored in remediated areas. The extent of these potential repairs will be evaluated during programmed site inspections (e.g., annual, biennial or triennial) or site inspections following major storm events.

5.6 Sediment Remedy Alternative 4: Sediment Removal in SMA-2

Remedy Alternative 4 addresses exceedances of any RGOs in the 18-acre SMA-2 remediation area by combining sediment removal with natural recovery, institutional controls, and long-term monitoring. This alternative targets the remediation of surface and subsurface sediments in OU1 with the following benthic community RGOs:

- Lead concentrations greater than 177 mg/kg
- Mercury concentrations greater than 11 mg/kg
- Total PAHs concentrations greater than 4 mg/kg
- Aroclor 1268 concentrations greater than 16 mg/kg

This alternative also targets SWAC RGOs protective of human health, mammals, and birds.

This remedial alternative includes sediment removal and backfilling would be performed in the areas within Eastern Creek, LCP Ditch, the Domain 3 Creek, Dillon Duck and the vegetated marsh areas of Domains 1a, and 2 (**Figure 5-3** and **Table 5-2**).

5.6.1 Sediment Removal and Backfilling

The limits of dredging and backfilling for Remedy Alternative 4 are shown on **Figure 5-3**. The proposed sediment removal area is approximately 18 acres, distributed as summarized in **Table 5-1**.

In proposed sediment removal areas, removal targets a depth of 45 cm (18 inches), where the sediment chemistry is expected to be compliant with the RGOs. For the purpose of this FS, the estimated in-place sediment volumes targeted for removal in Remedy Alternative 4 amount to approximately 57,000 CY. Following removal, the remedial areas will be backfilled with 12 inches (or approximately 36,000 CY) of clean material (e.g., sand) to manage risks associated with post-removal residuals, accelerate the natural recovery process, and establish a clean sediment surface.

Mechanical dredging and/or sediment excavation could be used to remove sediments as part of Remedy Alternative 4. The construction of various sediment management/staging areas and temporary access roads is required to facilitate material management and sediment excavation. Debris must be removed during sediment removal, either during excavation/dredging or as part of a separate debris removal operation, which may hinder or slow sediment removal. The distribution of submerged debris is expected to be relatively high, particularly in sediment removal areas that have not been dredged or maintained. Debris will be disposed off-site at licensed facilities. Sediments will be dewatered on-site and disposed at licensed off-site facilities.

5.6.2 Short- and Long-Term Monitoring Requirements for Remedy Alternative 4

As part of the remedy design process, both short- and long-term maintenance and monitoring programs will be developed to ensure the long-term protectiveness of the remedy. Long-term monitoring of environmental restoration recognizes that uncertainty is inherent to any cleanup activity and must be managed through data collection and monitoring (USDOE, 1997). Short-term monitoring determines whether remedy implementation meets design specifications. These monitoring activities span the construction phase and are defined in the construction drawings, construction specifications, and the QA/QC plan, to be developed during the remedy design phase. QA/QC measures could include soundings and surveys to verify removal depths, depth verification measurements to document backfill material placed, and/or backfill material coverage assessments.

Long-term remedy monitoring ensures the remedy’s long-term structural integrity and its effectiveness in enhancing ecosystem recovery and reducing risks to human health and the environment. Details of the long-monitoring program will be developed during remedial design, and may include:

- Physical measurements to monitor backfilled areas or recovery processes (e.g., push cores, bathymetric surveys, or visual observation via camera or video profiling).
- Biological measurements to monitor benthic and fish community integrity on remediated areas.
- Visual observations and surveys of marsh recovery, including plant growth and plant density.
- Chemical measurements in fish to monitor trends in whole-body and/or fillet fish.
- Surface sediment chemical measurements to monitor area-weighted concentrations in remediated areas.
- Surface water quality measurements, as necessary to comply with ARARs.

5.7 Sediment Remedy Alternative 5: Sediment Removal, Capping and Thin-Cover Placement in SMA-2

Remedy Alternative 5 addresses exceedances of any RGOs in the 18-acre SMA-2 remediation area by combining sediment removal, sediment capping, and thin-cover placement with natural recovery, institutional controls and long-term monitoring. This alternative targets the remediation of surface and subsurface sediments in OU1 with the following protective benthic community RGOs:

- Lead concentrations greater than 177 mg/kg
- Mercury concentrations greater than 11 mg/kg
- Total PAHs concentrations greater than 4 mg/kg
- Aroclor 1268 concentrations greater than 16 mg/kg

This alternative also targets SWAC RGOs protective of human health, mammals, and birds.

This alternative primarily incorporates sediment removal, sediment capping and thin-cover placement as remedial components (**Figure 5-4** and **Table 5-2**). Sediment removal and backfilling are performed within Eastern Creek and LCP Ditch. Sediment in Domain 3 Creek is capped. Thin covers are placed within the vegetated marshes of Domains 1a and 2 and the wetlands of Dillon Duck.

5.7.1 Sediment Removal and Backfilling

The limits of dredging and backfilling for Remedy Alternative 5 are shown on **Figure 5-4**. The proposed sediment removal area is approximately 7 acres, distributed as summarized in **Table 5-1**.

In proposed sediment removal areas, removal targets a depth of 45 cm (18 inches), where the sediment chemistry is expected to meet the RGOs. For the purpose of this FS, the estimated in-place sediment volumes targeted for removal in Remedy Alternative 5 amount to approximately 22,000 CY. Following removal, the remedial areas are backfilled with 12 inches (or approximately 14,000 CY) of clean material (e.g., sand) to manage risks associated with post-removal residuals, accelerate the natural recovery process, and establish a clean sediment surface.

Mechanical dredging and/or sediment excavation could be used to remove sediments as part of Remedy Alternative 5. The construction of various sediment management/staging areas and temporary access roads is required to facilitate material management and sediment excavation. Debris must be removed during sediment removal, either during excavation/dredging or as part of a separate debris removal operation, which may hinder or slow sediment removal. The distribution of submerged debris is expected to be relatively high, particularly in sediment removal areas that have not been historically dredged or maintained. Debris will be disposed off-site at licensed facilities. Sediments will be dewatered on-site and disposed at licensed off-site facilities.

5.7.2 Sediment Capping

The limits of sediment capping for Remedy Alternative 5 are shown on **Figure 5-4**. As summarized in **Table 5-1**, the proposed sediment capping area is approximately 3 acres of the Domain 3 Creek.

Sediment caps are targeted for these areas to isolate underlying sediment contaminants, control chemical migration, physical erosion, and biological contact with underlying sediment contaminants, and provide a clean sediment surface for habitat restoration. As detailed in **Appendix G**, preliminary cap design evaluations were performed in general accordance with

USEPA guidance and using conservative assumptions (e.g., maximum sediment concentrations and peak shear stresses). These evaluations were used to conceptually design the thickness and material size for the cap armor layer to ensure that the cap retains its integrity under worst-case shear stress conditions. The analysis in **Appendix G** shows that a 6-inch base chemical isolation layer with up to 6 inches of coarse sand-to-gravel armoring adequately protects against chemical migration through the cap, as well as erosive forces under extreme storm events.

Cap placement could be performed as a land-based operation due to the creeks' proximity to land. Given shallow water depths, narrow creeks, and tidal effects, cap placement may require small mechanical equipment (e.g., backhoe or similar excavator with a fixed arm, or a telescoping conveyor belt). Land-based access to the Domain 3 Creek requires construction of a small quantity of temporary access roads across the soft sediments of Domain 3 marshes and upland areas. Construction of various material staging areas is also required to facilitate material management and sediment cap placement. While the anticipated distribution of submerged debris is relatively high since the proposed sediment removal areas have not been periodically maintained, debris will remain in place unless it interferes with capping operations. Any removed debris will be disposed off-site at licensed facilities.

5.7.3 Thin-Cover Placement

The limits of thin-cover placement for Remedy Alternative 5 are shown on **Figure 5-4**. The proposed thin-cover placement area is approximately 8 acres, distributed as summarized in **Table 5-1**.

Thin covers are targeted for the low-energy environments within OU1 to accelerate ongoing natural recovery processes (i.e., contaminant burial), reduce risks to human health and the environment, and provide a clean sediment surface for habitat restoration. Given their profile, thin covers are best suited for wetlands or marsh environments as they minimize the negative ecological impacts of sediment capping (e.g., loss of aquatic habitat, potential changes in marsh inundation patterns) or implementation concerns with sediment removal (e.g., destruction of marsh habitat, areas of limited accessibility). Based on a literature review of thin-cover placement in marsh and wetlands restoration case studies (Ray 2007), it is anticipated that remediated areas will recover within two growing seasons.

Thin-cover materials could be placed as a water-based operation and/or a land-based operation, in which materials are broadcast mechanically or pneumatically, or sprayed hydraulically. If placement is a water-based operation (e.g., portions of vegetated marshes abutting the Eastern Creek or LCP Ditch), the equipment is staged along the shoreline and/or from shallow-draft barges. For land-based placement of thin covers (e.g., inland portions of vegetated marshes), construction of a limited number of temporary access roads is required. For both water- and land-based operations, construction of a limited number of staging areas to facilitate material transport and management operations is required. Submerged debris, if any will remain in place.

5.7.4 Short- and Long-Term Monitoring Requirements for Remedy Alternative 5

As part of the remedy design process, both short- and long-term maintenance and monitoring programs will be developed to ensure the long-term protectiveness of the remedy. Long-term monitoring of environmental restoration recognizes that uncertainty is inherent to any cleanup activity and must be managed through data collection and monitoring (USDOE 1997). Short-term monitoring determines whether remedy implementation meets design specifications. These monitoring activities spanthe construction phase and are defined in the construction drawings, specifications, and the QA/QC plan, to be developed during the remedy design phase. QA/QC measures could include soundings and surveys to verify removal depths, depth verification measurements to document material placed, and/or material coverage assessments.

Long-term remedy monitoring ensures the remedy's long-term structural integrity and its effectiveness in enhancing ecosystem recovery and reducing risks to human health and the environment. Details of the long-monitoring program will be developed during remedial design, and may include:

- Physical measurements to monitor cap integrity (e.g., push cores, bathymetric surveys, or visual observation via camera or video profiling).
- Biological measurements to monitor benthic and fish community integrity on dredged/excavated, capped, or thin-cover placement areas.
- Visual observations and surveys of marsh recovery, including plant growth and plant density.
- Chemical measurements in fish to monitor trends in whole-body and/or fillet fish.
- Surface sediment chemical measurements to monitor area-weighted concentrations in remediated areas.
- Surface water quality measurements, as necessary to comply with ARARs.

Although caps are designed to withstand high-energy event flows, they may require repair or periodic replenishment if damaged by erosion or unexpected environmental conditions (e.g., extreme storms), particularly if such events occur before marsh grasses are restored. The extent of these potential repairs will be evaluated during programmed site inspections (e.g., annual, biennial or triennial) or site inspections following major storm events.

5.8 Sediment Remedy Alternative 6: Sediment Removal, Capping and Thin-Cover Placement in SMA-3

Remedy Alternative 6 addresses exceedances of any RGOs in the 18-acre-SMA-2 remediation area plus an additional 6 acres in Purvis Creek and Domain 1a. This remedy combines sediment removal, sediment capping, and thin-cover placement with natural recovery, institutional controls, and long-term monitoring. This alternative targets the remediation of surface and subsurface sediments in OU1 with the following protective benthic community RGOs:

- Lead concentrations greater than 177 mg/kg
- Mercury concentrations greater than 11 mg/kg
- Total PAHs concentrations greater than 4 mg/kg
- Aroclor 1268 concentrations greater than 16 mg/kg

This alternative also targets SWAC RGOs protective of human health, mammals, and birds.

This alternative primarily incorporates sediment removal, sediment capping and thin-cover placement as remedial components (**Figure 5-5** and **Table 5-2**). Sediment removal and backfilling are performed in the areas within Eastern Creek and LCP Ditch; sediment in Purvis Creek and Domain 3 Creek is capped; and thin covers are placed within the vegetated marshes of Domains 1a and 2 and the wetlands of Dillon Duck.

5.8.1 Sediment Removal and Backfilling

The limits of dredging and backfilling for Remedy Alternative 6 are shown on **Figure 5-5**. The proposed sediment removal area is approximately 7 acres, distributed as summarized in **Table 5-1**.

In proposed sediment removal areas, removal targets a depth of 45 cm (18 inches), where the sediment chemistry is expected to meet the RGOs. For the purpose of this FS, the estimated in-place sediment volumes targeted for removal in Remedy Alternative 6 amount to approximately 22,000 CY. Following removal, the remedial areas will be backfilled with 12 inches (or approximately 14,000 CY) of clean material (e.g., sand) to manage risks associated with post-removal residuals, accelerate the natural recovery process, and establish a clean sediment surface.

Mechanical dredging and/or sediment excavation could be used to remove sediments as part of Remedy Alternative 6. The construction of various sediment management/staging areas and temporary access roads is required to facilitate material management and sediment excavation. Debris must be removed during sediment removal, either during excavation/dredging or as part of a separate debris removal operation, which may hinder or slow sediment removal. The distribution of submerged debris is expected to be relatively high, particularly in sediment removal areas that have not been dredged or maintained. Debris will be disposed off-site at licensed facilities. Sediments will be dewatered on-site and disposed at licensed off-site facilities.

5.8.2 Sediment Capping

The limits of sediment capping for Remedy Alternative 6 are shown on **Figure 5-5**. The proposed sediment capping area is approximately 6 acres, distributed as summarized in **Table 5-1**.

Sediment caps isolate underlying sediment contaminants; control chemical migration, physical erosion, and biological contact with underlying sediment contaminants; and provide a clean sediment surface for habitat restoration. As detailed in **Appendix G**, preliminary cap design evaluations were performed in general accordance with USEPA guidance and using conservative assumptions (e.g., maximum sediment concentrations and peak shear stresses). These evaluations were used to conceptually design the thickness and material size for the cap armor layer to ensure that the cap retains its integrity under worst-case shear stress conditions. The analysis in **Appendix G** shows that a 6-inch base chemical isolation layer with up to 6 inches of coarse sand-to-gravel armoring adequately protects against chemical migration through the cap as well as erosive forces under extreme storm events.

Cap placement could be performed as a water-based operation (north and south Purvis Creek) and a land-based operation (Domain 3 Creek due to proximity to land). Given shallow water depths, narrow creeks, and tidal effects, cap placement may require small mechanical equipment (e.g., backhoe or similar excavator with a fixed arm, or a telescoping conveyor belt) operating from the shoreline and/or a shallow-draft barge. Land-based access to the Domain 3 Creek requires construction of a small quantity of temporary access roads across the soft sediments of Domain 3 marshes and upland areas. Construction of various material staging areas and temporary access roads is required to facilitate material management and sediment cap placement. While the anticipated distribution of submerged debris is expected to be relatively high since the proposed sediment removal areas have not been periodically maintained, debris will remain in place unless it interferes with capping operations. Any removed debris will be disposed off-site at licensed facilities.

5.8.3 Thin-cover placement

The limits of thin-cover placement for Remedy Alternative 6 are shown on **Figure 5-5**. The proposed thin-cover placement area is approximately 11 acres, distributed as summarized in **Table 5-1**.

Thin covers are targeted for the low-energy environments within OU1 to accelerate ongoing natural recovery processes (i.e., contaminant burial), reduce risks to human health and the environment, and provide a clean sediment surface for habitat restoration. Given their profile, thin covers are best suited for wetlands or marsh environments as they minimize the negative ecological impacts of sediment capping (e.g., loss of aquatic habitat or potential changes in marsh inundation patterns) or implementation concerns with sediment removal (e.g., destruction of marsh habitat and areas of limited accessibility). Based on a literature review of thin-cover placement in marsh and wetlands restoration case studies (Ray 2007), it is anticipated that remediated areas will recover within two growing seasons.

Thin-cover materials could be placed as a water-based operation and/or a land-based operation in which materials are broadcast mechanically or pneumatically or sprayed hydraulically. If placement is a water-based operation (e.g., portions of marshes abutting the Eastern Creek or LCP Ditch), equipment would be staged along the shoreline and/or from shallow-draft barges. For land-based placement of thin cover (e.g., inland portions of marshes), construction of a limited number of temporary access roads is required. Both land- and water-based operations require construction of a limited number of staging areas to facilitate material transport and management operations. Submerged debris, if any, will remain in place.

5.8.4 Short- and Long-Term Monitoring Requirements for Remedy Alternative 6

As part of the remedy design process, both short- and long-term maintenance and monitoring programs will be developed to ensure the long-term protectiveness of the remedy. Long-term monitoring of environmental restoration recognizes that uncertainty is inherent to any cleanup activity and must be managed through data collection and monitoring (USDOE 1997). Short-term monitoring determines whether remedy implementation meets design specifications. These monitoring activities span the construction phase and are defined in the construction drawings, specifications, and the QA/QC plan, to be developed during the remedy design phase. QA/QC measures could include soundings and surveys to verify removal depths, depth verification measurements to document material placed, and/or material coverage assessments.

Long-term remedy monitoring ensures the remedy's long-term structural integrity and its effectiveness in enhancing ecosystem recovery and reducing risks to human health and the environment. Details of the long-monitoring program will be developed during remedial design, and may include:

- Physical measurements to monitor cap integrity (e.g., push cores, bathymetric surveys, or visual observation via camera or video profiling).
- Biological measurements to monitor benthic and fish community integrity on dredged/excavated, capped, or thin-cover placement areas.
- Visual observations and surveys of marsh recovery, including plant growth and plant density.
- Chemical measurements in fish to monitor trends in whole-body and/or fillet fish.
- Surface sediment chemical measurements to monitor area-weighted concentrations in remediated areas.
- Surface water quality measurements, as necessary to comply with ARARs.

Although caps are designed to withstand high-energy event flows, they may require repair or periodic replenishment if damaged by erosion or unexpected environmental conditions (e.g., extreme storms), particularly if such events occur before marsh grasses are restored. The extent of these potential repairs will be evaluated during programmed site inspections (e.g., annual, biennial or triennial) or site inspections following major storm events.

6 Detailed Evaluation and Comparative Analysis of Alternatives

This chapter evaluates and compares the six remedy alternatives identified in **Section 5** according to NCP 40 CFR 300.430(e)(9)) criteria. The NCP criteria and Assessment Method are introduced in **Section 6.1**, followed by an introduction to environmental sustainability principles for remediation projects. **Section 6.2** contains a detailed comparative analysis of the six alternatives in accordance with the NCP, as well as a discussion of how remedial action in OU1 can support environmental sustainability objectives consistent with USEPA (2008) guidance.

6.1 Overview of NCP Evaluation Criteria and Assessment Method

This section provides an overview of the nine evaluation criteria established under NCP (40 CFR 300.430(e)(9)) and USEPA (2008) environmental sustainability goals for remediation of contaminated sites. The nine NCP evaluation criteria provide a basis for comparing proposed alternatives to select the most appropriate remedy for a site (USEPA 1988):

Threshold Criteria

1) Overall protection of human health and the environment
2) Compliance with ARARs

Balancing Criteria

3) Long-term effectiveness and permanence
4) Reduction of toxicity, mobility, or volume
5) Short-term effectiveness
6) Implementability
7) Cost

Modifying Criteria

8) State acceptance
9) Community acceptance

As indicated by the list above, the nine criteria include two threshold criteria, five balancing criteria, and two modifying criteria. Alternatives must meet threshold criteria to be considered viable. Balancing criteria support detailed comparative evaluation of five measures of remedy suitability. Modifying criteria generally must be met before alternative selection can be finalized. The discussion of each criterion below summarizes the assessment methods for its evaluation.

6.1.1 Overall Protection of Human Health and the Environment

This threshold criterion measures how the alternative achieves and maintains protection of human health and the environment. Overall protection of human health and the environment is assessed by determining the extent to which the alternative is able to achieve RAOs and maintain adequate short- and long-term protection of human health and the environment. The evaluation of this criterion relies on assessments of the balancing criteria discussed below, particularly effectiveness and implementability (USEPA 1988). This criterion also is assessed by reviewing potential short-term and cross-media impacts associated with the alternative.

6.1.2 Compliance with ARARs

Compliance with ARARs is the second threshold criterion. Its evaluation involves summarizing applicable requirements and describing how the alternative meets these requirements. Chemical-specific, location-specific, and action-specific ARARs are considered. When an ARAR cannot be met, justification for one of the six waivers permitted by CERCLA (Section 1.2.1.1) is considered and evaluated (USEPA 1988).

6.1.3 Long-Term Effectiveness and Permanence

Long-term effectiveness, a balancing criterion, measures long-term risk reduction and remedy permanence. This criterion is assessed by determining the adequacy and reliability of the proposed alternative to manage human health and ecological risks associated with COCs that remain on site following remedy implementation (USEPA 2005). Evaluation of long-term effectiveness and permanence includes assessing residual risks after RAOs have been met.

Controls may be required to manage residual risks. For each proposed alternative, the magnitude of residual risk is defined and the adequacy and reliability of controls evaluated. A permanent and effective alternative limits exposure to human and environmental receptors to within protective levels in the long term (USEPA 1988).

Long-term effectiveness also is evaluated based on the alternative’s ability to minimize the potential for future remedial obligations. The assessment considers future operation and maintenance requirements, difficulties, and uncertainties associated with long-term monitoring, the potential need to replace technical components of the alternative, and whether a 5-year review is anticipated.

Assessing reliability includes evaluating the effectiveness of the remedial technologies comprising the alternative at sites with similar chemical constituents and conditions. The permanence of the alternative is determined by evaluating the aspects of the remedy that result in the physical and chemical stability of COCs that remain in place. Finally, probability that the alternative can adequately handle unforeseen or unplanned conditions is evaluated (USEPA 1988).

6.1.4 Reduction of Toxicity, Mobility, or Volume

When selecting a remedial alternative for a site, there is an inherent preference for techniques that permanently and significantly reduce the toxicity, mobility, or volume of hazardous substances through treatment (EPAUSEPA 1988), the second balancing criterion of the NCP Assessment Method.

For this FS, each alternative is evaluated based on the extent to which it reduces the total mass, mobility, and volume of toxic contaminants present at the sediment surface, the extent to which the alternative and its effects are irreversible, and the type and quantity of residuals that remain following implementation. As part of this assessment, a distinction between the portion of contaminated material removed and the portion controlled by the alternative is made, and the risks posed by post-remedy residuals are quantified.

6.1.5 Short-Term Effectiveness

Assessing short-term effectiveness, the third balancing criterion, includes evaluating positive and negative environmental impacts of remedy implementation, potential impacts to the community and site workers during remedy implementation, and the time until the RAOs are achieved (Magar et al. 2008; Wenning et al. 2005, 2007).

This criterion primarily assesses whether the proposed alternative minimizes short-term risks to human health and the community, and whether those risks can be eliminated or controlled by remedy design and BMPs. Assessing short-term effectiveness includes identifying short-term risks that cannot be readily controlled, such as quality-of-life impacts, including noise, odors, and traffic; effects on on-site workers, including safety risks associated with remedy implementation; and temporary physical disturbance of the environment, including destruction of vegetation beds and benthic organisms, alteration of the marsh hydrology, elimination of possible shallow habitat within the creeks and marsh, and reduced water quality.

This assessment also includes evaluating whether measures that can be used to ameliorate short-term impacts, such as habitat restoration to restore lost or temporarily impaired ecological resources, BMPs, or safety measures.

6.1.6 Implementability

Implementability, the fourth balancing criterion of the NCP Assessment Method, encompasses both the technical and administrative feasibility of implementing a remedial alternative. Assessment of this criterion incorporates an evaluation of the technical challenges associated with construction and operation of the remediation system, the reliability of the selected technologies, the ability to implement all facets of the alternative, and challenges associated with process options that support each remedy, such as treatment, storage and disposal services, transportation, and equipment availability. This evaluation also considers whether specialized equipment or personnel is required for implementation, and whether such equipment and personnel are readily available. This includes the likelihood that technical or implementation problems or constraints will lead to schedule delays.

Evaluation of implementability also considers the ability to monitor the effectiveness of the alternative and the difficultly in undertaking additional future remedial actions. Migration or exposure pathways that cannot be monitored adequately are identified.

Assessing administrative feasibility focuses on the ability to obtain necessary permits and the impact of state and local regulations (USEPA 1988), the steps required to coordinate implementation with appropriate regulatory agencies, and long-term or future agency coordination.

6.1.7 Cost

Assessing cost, the fifth balancing criterion, includes an evaluation of direct and indirect and O&M costs (EPAUSEPA 1988, 2000b). Direct costs include equipment costs, land and site-development costs, construction material costs, building and services costs, relocation expenses, and disposal costs. Indirect costs include engineering expenses, license and permit costs, and contingency allowances. Annual O&M costs include labor, maintenance materials, monitoring, and rehabilitation. Costs also are estimated for remedy maintenance and repair if there is a reasonable expectation that a component of the alternative will require future work.

Costs are calculated as present-value-worth costs for comparison of alternatives. O&M costs are estimated for a 30-year period, discounted to a net present value (NPV) in 2013 dollars. The overall cost for each alternative is the sum of capital and discounted annual costs. The discounted costs are calculated based on the NPV methods described in the USEPA guidance document, *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (USEPA 2000b). The discount rate selected for the net present worth calculations is 7% (USEPA 2000b).

FS-level cost estimates provide an accuracy of +50% to -30% (USEPA 1988). The present-value-worth costs are used for comparison of alternatives. Where there is sufficient uncertainty associated with the alternative, a sensitivity analysis may be conducted.

6.1.8 State Acceptance

Evaluating State Acceptance, the first modifying criterion of the NCP Assessment Method, involves securing USEPA and state agency acceptance. Though briefly addressed in **Section 6.2**, this criterion is more fully addressed in the Record of Decision (ROD), and possibly in the final FS draft, following agency review of the draft FS.

6.1.9 Community Acceptance

Community Acceptance, the second modifying criterion, addresses the general public's issues and concerns. Evaluation considers whether the alternative is consistent with community preferences and concerns. Evaluation also determines the extent to which the alternative minimizes impacts on:

- Community safety during implementation
- Quality of life, such as the generation of odors, light, diesel emissions, and noise during construction
- Ease of access to and use of areas in the vicinity of the remediation

Finally, the assessment considers whether the alternative adequately addresses technical and administrative issues raised by the community. Though briefly addressed in **Section 6.2**, this criterion is more fully addressed in the ROD following public review of the FS.

6.1.10 Environmental Sustainability

USEPA has begun “examining opportunities to integrate sustainable practices into the decision-making processes and implementation strategies that carry forward to reuse strategies” (USEPA 2008, 2010e). Federal Executive Order 13423 (Federal Register 2007) defines sustainability as;

> “…the capacity to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations of Americans.”

Sustainable practices for site remediation emphasize six core elements (USEPA 2008): energy requirements of the treatment system, air emissions, water requirements and impacts on water resources, land and ecosystem impacts, material consumption and waste generation, and long-term stewardship actions. The primary goal of the sustainability evaluation is to identify alternatives that minimize the environmental and energy footprints of site remediation while still achieving short- and long-term risk management goals specified in the RAOs and RGOs. This assessment also evaluates whether:

- Potential exists to use passive-energy technologies
- Equipment will operate at peak efficiency
- Fossil-fueled equipment use can be minimized
- Renewable energy systems can replace or offset utility electricity requirements

In addition, this assessment evaluates the ability to minimize the release of dust and toxins through waste generation, air emissions, and greenhouse gas production relative to short-term effectiveness; the alternative’s ability to minimize freshwater consumption and maximize reuse; recycling practices during daily operations; and factors such as the potential for soil and habitat disturbances.

Examples of long-term environmental sustainability measures incorporated in remedial alternatives include the installation of renewable energy systems to power long-term cleanup and future activities and the incorporation of passive sampling devices for long-term monitoring.

6.2 Analysis of Alternatives against NCP Criteria

This section evaluates Alternatives 1 through 6 against the nine NCP criteria discussed in **Section 6.1**. This discussion is organized by criterion, starting with an overview that assesses the remedial technologies that comprise each alternative (i.e., sediment removal, capping, and thin-layer placement), followed by a detailed assessment of the alternatives. Alternatives are grouped together in the detailed discussions when common features (such as remedial footprint or remedial technology) render them highly similar in terms of the criterion being assessed.

6.2.1 Overall Protection of Human Health and Environment

Other than the No Action Alternative, all alternatives would achieve long-term reduction of risks to both human health and the environment:

- Sediment removal, which is incorporated in Alternatives 2 through 6, targets the removal of contaminants exceeding the RGOs for mercury, Aroclor 1268, lead, and total PAHs, thus immediately reducing the COC mass in OU1. Sediment removal coupled with backfilling improves long-term surface sediment conditions that reduce risks to human health, mammals, birds, fish, and benthic organisms. However, sediment removal negatively impacts short-term surface sediment concentrations during construction and disrupts the natural environment. Water-column releases also are a risk during removal, and are discussed in **Section 6.2.5**, Short-Term Effectiveness. Backfilling in sediment removal areas and, to a lesser extent, natural surface sediment deposition processes, accelerates recovery of the natural environment and contributes to reduced chemical concentrations to achieve RAOs and RGs.
- Sediment capping and thin-cover placement, which are incorporated in Alternatives 3, 5, and 6, reduce and control risks by isolating contaminated sediment from contact with ecological and human receptors. Capping and thin-cover placement improve long-term surface sediment conditions by creating a clean sediment surface, thereby immediately reducing risks to human health, mammals, birds, fish, and benthic organisms. Sediment capping, and to a lesser extent, thin-cover placement, temporarily disrupt the natural environment. However, recovery of the natural environment is anticipated within approximately two years. Generally, capping is used to target sediment contamination in creeks, whereas thin-cover placement is used to target vegetated marsh areas to minimize construction impacts on the existing natural habitat. Additional information related to the effectiveness of thin covers is provided in **Appendix E**.
- Institutional controls, which are incorporated into all alternatives, are designed to protect human health and the environment. Institutional controls include land use or deed restrictions, maintenance agreements, permit conditions limiting land use for future activities, and advisories.
    - The Coastal Marshlands Protection Act (OCGA§ 12-5-280 et seq) protects marshland areas against altering marshlands in the State of Georgia for construction without first obtaining a permit from the Coastal Marshlands Protection Committee.
    - Fish consumption advisories exist to prevent human exposures to PCBs in the Purvis Creek and the Turtle River system (GADNR 2012). These restrictions likely will remain in place until such time that the criteria for delisting are achieved. **Table 3-4** lists changes in fish consumption advisories over time, showing that approximately 20 advisories in various areas of the TRBE have been reduced since 1997. However, there are still advisories in most of the areas of the TRBE. Edible (fillet) fish and shellfish tissue data are compiled in **Appendix F**. **Appendix F** illustrates the concentrations of mercury and Aroclor 1268 over time in OU1 and provides a full report of the 2011 fish collection effort. These data were reported to the USEPA, the GAEPD, and the GADNR in tabular form by EPS (2011b), and were used by GADNR to establish

2012 fish consumption advisories for TRBE. **Appendix F** also shows time trends in fish and shellfish compared to the GADNR (2004) concentration thresholds for fish consumption advisories.

- Construction hazards and health risks to local residents and remediation workers during construction and post-remedy recovery will be managed through BMPs, site-specific health and safety plans, and public communication.

In evaluating overall protectiveness of human health and the environment, the following environmental components are considered:

- Human health risk reduction
- Mammal and bird populations
- Finfish populations
- Sediment-dwelling organism community
- Surface water quality

Alternative 1: No Action

The No Action Alternative results in no change in conditions in OU1 and relies on existing institutional controls and advisories to meet RAOs. These controls and advisories alone do not meet the RAOs. The HHBRA concluded that unacceptable risks to human health exist from the ingestion of fish and shellfish (**Section 2.4.2**). While fish tissue data show concentration reductions in most species over time, detected concentrations of mercury and Aroclor 1268 in many species continue to exceed fish consumption advisories for the TRBE, including at some locations in OU1. Thus, while existing fish consumption advisories minimize the potential adverse impacts on human health and a continuing trend in fish tissue reduction is expected, the timeframe to achieve RAOs and fish-consumption criteria is uncertain and could be lengthy. Therefore, the No Action Alternative does not achieve some of the RAOs identified **Section 3.2**.

The SWAC RGOs for mercury and Aroclor 1268 are concentrations that are protective for humans who consume fish, shellfish, and wild game from OU1 (**Section 3.2**). Although the No Action Alternative achieves the SWAC RGOs in some areas, SWAC RGOs are not achieved for either mercury or Aroclor 1268 when measured in the all creeks (i.e., Total Creeks), suggesting that No Action is not adequately protective for the fish-consumption pathway. Human health exposure to sediment from direct contact (incidental ingestion and dermal skin) was not found to be a significant risk in the HHBRA even when very conservative exposure assumptions were applied (i.e., 52 visits per year). Therefore, the No Action Alternative is protective of this pathway.

SWAC RGOs are protective of the mammals, birds, and fish that nest, forage, and breed in OU1 (**Sections 3.2**). The No Action Alternative results in no change in conditions in OU1 that currently pose a risk to piscivorous avian populations and viability of indigenous finfish populations (**Section 2.4.3**).

- **Figure 6-1A** (mercury) and **Figure 6-1B** (Aroclor 1268) show that the No Action Alternative is reasonably protective for most species, particularly when balancing the harm to receptor populations from residual chemical exposures and harm from the remedy itself. Among the seven species evaluated for mercury, only the Green Heron HQ was greater than 1. None of the HQs are greater than 1 among the seven species evaluated (including the Green Heron) for Aroclor 1268.
- HQs in **Figure 6-2A** are less than 1 for the Green Heron in a number of areas around OU1 (e.g., Western Creek Complex, Dillon Duck, Domain 4, Domain 2). However, the HQs exceed the value of 1 elsewhere. Thus, for the Green Heron, the No Action Alternative does not meet the RAOs or RGOs.

The benthic community RGOs described in **Section 3.3** are designed to protect sediment-dwelling organisms. The No Action Alternative results in no change in conditions in OU1, which poses some risk of toxicity to the benthic community (**Section 2.4.3)**. Many areas of OU1 exceed benthic community RGOs (**Figures 3-1, 3-2, 3-3,** and **3-4** for mercury, Aroclor 1268, lead, and total PAHs, respectively). Therefore, the No Action Alternative is not adequately protective of the sediment-dwelling community.

RAO 6 in **Section 3.2** considers surface water quality criteria based on total or dissolved mercury and PCBs. The No Action Alternative meets federal and state water quality criteria when the dissolved-phase mercury data are considered, as was discussed in **Section 2.4**. The USEPA NRWQC identifies that dissolved phase data (total mercury or methyl mercury) are the appropriate values for comparison to NRWQC, when available. However, Georgia WQS does not state that dissolved phase data are the appropriate values for comparison but rather identifies that total phase data should be used for the comparison. Because some recent detections of total mercury exceeded Georgia WQS (including one detected from a reference location), the No Action alternative does not meet the state water quality criteria when total mercury data are considered.

It is anticipated that this criterion would be met if dissolved-phase PCB data were considered. However, existing PCB WQS are based on total PCB concentrations. Measurements of total PCBs also have shown exceedances of the federal and state water quality criteria, in OU1 and in reference locations. As with mercury, the No Action alternative does not meet the federal and state water quality criteria when total PCB data are considered.

Alternatives 2 and 3 (SMA-1), 4 and 5 (SMA-2), and 6 (SMA-3)

Alternatives 2 through 6 are protective of human health and environment, as these alternatives are designed to comply with ARARs, RAOs, and RGOs set forth in **Section 3**. Each alternative results in SWACs that meet the RGOs. Therefore, each alternative results in reductions of mercury and Aroclor 1268 in fish and shellfish concentrations that eventually will lead to reductions in fish and shellfish consumption advisories within the TRBE.

Alternatives 2 through 6 are effective for Green Heron risk reduction (**Figure 6-2A)** (all areas) and **Figure 6-2B** (focused on areas with the highest HQs). Each of the areas in OU1 are predicted to have HQs at or below 1 for the Green Heron. Because the Green Heron was deemed most sensitive in the BERA, these results indicate that conditions in OU1 after implementation of Alternatives 2 through 6 would result in conditions that are protective for all mammal and bird populations likely to be present.

Alternatives 2 through 6 address toxicity to sediment-dwelling organisms. SMA-1 (**Figure 3-5**) is the basis for Alternatives 2 and 3 and is delineated according to the lower boundary of the RGO range; that is, the most stringent criteria for protection of the benthic community. SMA-2 (**Figure 3-6**) is the basis for Alternatives 4 and 5 and addresses the upper boundary of the benthic community RGOs. SMA-3 (**Figure 3-7**) is the basis for Alternative 6 and encompasses SMA-2 as well as some SMA-1 areas that could improve conditions in Purvis Creek and Domain 1 and reduce the overall SWAC. Each alternative is protective of the benthic community because each reduces surface-sediment COC concentrations that exceed the range of acceptable levels established as RGOs.

The larger remedy footprint associated with SMA-1 achieves lower residual COC concentrations than the smaller remedy footprints associated with SMA-2 and SMA-3. However, the larger footprint also results in much more substantial destructive impacts to the existing benthic habitat. The need to remediate to the lower end of the RGO range must be balanced against the physical impacts of the remedy, so that the remedy itself does not do more harm than good to the marsh ecosystem. Current conditions indicate that the existing benthic community is not negatively impacted in areas impacted by the low-end range of RGOs (Black & Veatch 2011). **Appendix E** summarizes indigenous grass shrimp and sediment dwelling community studies that were identified in the BERA. These studies show that the RGOs are not thresholds above which adverse effects are definitive and absolute. In situ impacts to Grass Shrimp were observed only in LCP ditch and Eastern Creek, where OU1 COC concentrations are highest; no significant differences in grass shrimp populations were seen in other areas, even in areas where in situ COC concentrations were above the RGO range (see Figure E2-4A in **Appendix E**). Similarly, benthic community impacts were observed in Eastern Creek and Domain 3 Creek, also where COC concentrations were well above the RGO range; no significant populations differences were seen in other areas, even in areas where in situ COC concentrations were above the RGO range (see Figure E2-5 in **Appendix E**). Alternatives 2 through 6 all capture the areas where differences were observed in grass shrimp and the benthic community, when comparing OU1 and reference locations; so all are protective against levels where measurable differences have been observed. Surface water quality is expected to improve with each alternative so that water quality criteria are achieved, meeting the requirements of RAO 6. The lower surface-sediment COC concentrations in OU1, compared to the No Action Alternative, will substantially decrease the potential for the suspension and transport of contaminated sediment particles. Alternatives 2 through 6 are expected to achieve federal and state water quality criteria for dissolved-phase and total mercury and PCBs. However, considering that Troop Creek (one of the water quality sampling reference locations) had an exceedance of the state water quality criterion for total mercury and Crescent River (another water-quality-sampling reference location) had an exceedance of both the federal and State water quality criterion for PCBs, total mercury and total PCB concentrations alone cannot define overall protectiveness of the alternatives.

Although Alternatives 2 and 3 (SMA-1) address the largest SMA footprint, they do not provide a substantially greater overall risk reduction for mammal and bird populations, the sediment-dwelling organism community, or water quality when compared to Alternatives 4 and 5 (SMA-2) or 6 (SMA-3).

6.2.2 Compliance with ARARs

Alternatives 2 through 6 are designed to comply with ARARs and all federal and state permits required for remedy implementation. ARARs for the LCP Brunswick Site are provided in **Tables 3-1** through **3-3**. Other than the No Action Alternative, which would result in no change in conditions in OU1, all alternatives would comply with ARARs:

- Location-specific, chemical-specific, and action-specific ARARs will be met by obtaining or substantially complying with appropriate federal, state, and local permits and approvals required to implement the remedial activities.
- Chemical-specific ARARs will be met through waste characterization of materials designated for off-site disposal and ensuring that licensed haulers and disposal facilities are used in the management of such materials.
- Sediment removal may disturb contaminated sediments during implementation. Such disturbances may result in short-term exceedances of chemical-specific ARARs. However, these short-term exceedances would be mitigated in large part by backfilling sediment removal areas, which accelerates recovery of the natural environment, and by using various BMPs to minimize the potential for contaminants suspension and off-site transport. BMPs help ensure compliance with action-specific ARARs, such as those directing the disposal of materials.
- Work will be scheduled to minimize impacts to fish species in the LCP estuary during remedy implementation by adhering to fish windows (i.e., designated significant timeframes associated with fish or shellfish spawning and larval development under the Magnuson Stevens Act, if listed species are identified for the LCP estuary), if any, and employing BMPs to minimize ecological impacts to the extent practicable.

The following is a comparative discussion on the ability of each of the alternatives to comply with all chemical-specific, location-specific, and action-specific ARARs.

Alternative 1 – No Action

Alternative 1 is expected to comply with location-specific ARARs because it requires no construction and thus requires no permitting or access. There are no action-specific ARARs associated with the No Action Alternative. Surface water quality conditions are not expected to change beyond current ongoing trends under this alternative. Under this alternative, there are exceedances of chemical-specific ARARs for surface water (**Section 6.2.1)**.

Alternatives 2 (SMA-1) and 4 (SMA-2) – Removal Only

Alternatives 2 and 4 are designed to comply with all ARARs and will substantially comply with all appropriate federal, state, and local permits and approvals required to implement each alternative. Implementation of Alternatives 2 or 4, which only incorporate sediment removal, could potentially result in temporary noncompliance of certain chemical-specific ARARs, such as impacts to water quality. Potential water quality impacts associated with sediment removal for Alternative 2 are greater than for Alternative 4 because of the larger area associated with Alternative 2; Alternative 2 includes sediment removal in 48 acres while Alternative 4 includes removal in 18 acres. The reduced remedial footprint associated with Alternative 4 also shortens the construction schedule from 18 months to 9 months, thereby reducing the time during which potential water quality impacts can occur.

Alternatives 3 (SMA-1), 5 (SMA-2), and 6 (SMA-3) – Combined Remedies

Alternatives 3, 5, and 6 are designed to comply with all ARARs and will substantially comply with all appropriate federal, state, and local permits. These alternatives incorporate sediment removal, sediment capping, and thin-cover placement, portions of which could potentially result in temporary noncompliance of certain chemical-specific ARARs, such as impacts to water quality. The sediment removal components of the remedy raise similar concerns to those discussed for Alternatives 2 and 4, except that Alternatives 3, 5, and 6 minimize the removal-area footprint by integrating removal of high-concentration areas in the marsh creeks with capping and thin-cover placement in lower-concentration and vegetated marsh areas.

Sediment capping and thin covers require placement of clean material over respective target areas. They can result in the generation of turbidity plumes if placed under submerged conditions. However, most of the suspended material is associated with the cap material itself and is not contaminated; contemporary capping techniques greatly minimize the potential for contaminated sediment resuspension during cap placement (Lyons et al. 2006). Because turbidity plumes associated with capping are made up mostly of clean sediment, these temporary plumes are expected to comply with chemical-specific ARARs.

The smaller footprints associated with Alternatives 5 and 6 result in shorter construction schedules for these remedies, thereby reducing the time during which water quality impacts may occur. Alternatives 3, 5, and 6 have estimated construction durations of approximately 17, 10, and 11 months, respectively.

6.2.3 Long-Term Effectiveness and Permanence

Other than the No Action Alternative, all alternatives provide long-term human health and ecological risk reduction by targeting site-specific RGOs. As part of Alternatives 2 through 6, sediments contributing to RGO exceedances are targeted for removal, capping, or thin-cover placement, thus reducing or eliminating potential risk of exposure to contaminated material. Sediment removal, sediment capping, and thin-cover placement have proved reliable and effective at sites similar to OU1. Sediment removal removes COCs from the Site permanently. Cap armoring and cover material are designed to ensure permanence. Institutional controls (e.g., land use or deed restrictions, maintenance agreements, permits limiting land use for future activities, and fish consumptions advisories) will be used, as necessary, to control residual risks following remedy implementation. In addition, long-term monitoring ensures long-term structural integrity and effectiveness.

Risk Reduction and Residual Risk

Alternative 1 provides no reduction in risk to humans or the environment beyond current ongoing natural processes. Fish and shellfish tissue concentrations have decreased over time and future fish and shellfish concentrations are reasonably expected to continue on a downward trajectory. Therefore, Alternative 1 could eventually satisfy the RAO goals over the long-term. However it is not clear how long this would take and without monitoring, risk reduction cannot be confirmed. Therefore, No Action does not provide adequate risk reduction or adequately address residual risk for human health and some ecological receptors.

In Alternatives 2 through 6, sediments contributing to RGO exceedances would be targeted for removal, capping, and/or thin-cover placement, thus eliminating potential risk of exposure to contaminated material. Sediment removal permanently eliminates long-term risks of exposure since contaminated material is removed. Backfilling addresses dredge residuals that otherwise pose risks. Capping and thin-cover placement—which leave contaminant material in place—isolate COCs and reduce bioavailability through burial with clean material. Alternatives 2 through 6 are each protective with regard to risk reduction and residual risks.

Although Alternatives 2 and 3 (SMA-1) have the largest SMA footprint and result in the lowest residual-risk levels, they do not provide a substantially greater overall risk reduction when compared to Alternatives 4 and 5 (SMA-2) or 6 (SMA-3) (**Section 6.2.1**). Therefore, considerations of other criteria that also impact risk to the environment need to be considered, such as the damage to the marsh from remedial actions, which is defined both by the size of the SMA footprint and incidental areas that are damaged in efforts to access remediation areas (**Table 6-1**). Construction activities that impact the marsh also impact long-term ecological recovery. Larger surface sediment recovery times are required for larger-scale remedies. Similarly, sediment removal and capping are far more intrusive in to vegetated marsh areas than thin-cover placement, and thus require longer recovery periods. Marsh recovery times associated with thin-cover placement are generally less than two years (**Section 4.2.4** and **Appendix E**), largely because the biomass is not destroyed and provides a basis for recovery.

Permanence

Except for Alternative 1 (No Action), all alternatives provide permanent risk reduction by targeting sediment concentrations that exceed RGOs.

Sediment removal permanently removes COCs from OU1 and backfilling permanently addresses post-removal residuals. Capping and thin covers are engineered to account for hydrodynamic conditions to ensure their permanence. Overall OU1 is characterized as stable and relatively resistant to scour and sediment resuspension. The results from hydrodynamic model simulations (**Appendix B**) demonstrated relatively low velocities (less than 2 ft/sec) throughout the OU1 during spring-neap tidal cycles, 100-year flood conditions, and hurricane storm surge conditions. Velocities that could result in cap material instability are addressed through armoring to resist erosion.

Materials for sediment capping and thin-cover placement will be sized to ensure protection against erosion and scour. However, the thin cover is not an armored chemical barrier. Some burrowing and other types of biological activity will occur in the thin-cover layer, but are not expected to adversely impact its effectiveness (**Appendix E)**. Monitoring and maintenance will be performed as necessary to ensure long-term remedy effectiveness.

6.2.4 Reduction of Toxicity, Mobility, or Volume

All alternatives, except the No Action Alternative, provide varying degrees of long-term reduction COC toxicity, mobility, and volume. The No Action Alternative does not reduce toxicity, mobility, or volume of chemicals in OU1 beyond ongoing natural processes.

All of the alternatives include sediment removal which reduces of the volume of COC-impacted sediment in OU1 following remedy implementation. However, short-term increases in COC mobility and toxicity can result from sediment removal via materials management.

Where alternatives include sediment capping and thin-cover placement, long-term COC toxicity and mobility are reduced by creating a clean sediment surface through burial with clean materials. The thin cover is not intended as an absolute chemical barrier, but as a layer to jump start ongoing natural recovery processes, and therefore, some bioturbation beyond the cover depth does not diminish the effectiveness of this remedy and thus does not preclude its beneficial use as a protective remedy. Residual risks posed by COCs left unremediated are addressed through institutional controls (e.g., permit requirements, which already exist, limiting use or future activities in the marsh; and fish consumption advisories) and long-term monitoring to ensure the remedy's long-term structural integrity and effectiveness.

Alternatives 2 (SMA-1) and 4 (SMA-2)

Alternatives 2 and 4 feature the removal of high-concentration sediments from areas within SMA-1 (Alternative 2) and SMA-2 (Alternative 4) to achieve RGOs. Removal reduces the volume of COCs, thereby reducing COC toxicity and mobility. The COC-impacted sediment volume reduced in Alternatives 2 and 4 is approximately 153,000 CY and 57,000 CY, respectively. The estimated mass of COCs removed from OU1 is provided in **Table 6-2**. The resulting SWACs for the COCs as a result of Alternatives 2 and 4 are presented in **Table 6-3**; both alternatives achieve the RGO SWACs established in **Section 3.3**.

Experience at other sites indicates that sediment removal does not completely remove all contaminated sediments, leaving behind a layer of residuals on the post-dredge surface. The residual sediment reduces the overall effectiveness of the sediment removal remedy (NRC 2007, Bridges et al. 2010). Alternatives 2 and 4 rely on backfilling to manage residuals by reducing exposures. Experience at other dredge sites also indicates that an estimated 2% to 4% of dredged contaminant mass typically resuspends into the water column and is transported out of the removal area (USACE 2008a, Bridges et al. 2010).

Thus, whereas both Alternatives 2 and 4 reduce the long-term toxicity and mobility associated with elevated concentrations of COCs in sediments by removing contaminated material from the environment, some contaminated material is left behind and some may resuspended and migrate to other areas during construction.

Alternatives 3 (SMA-1), 5 (SMA-2), and 6 (SMA-3)

Alternatives 3, 5, and 6 achieve RGOs through a combination of sediment removal, sediment capping, and thin-cover placement within SMA-1, SMA-2, and SMA-3 respectively. Removal of the highest concentrations from the SMAs reduces the volume of COCs in OU1, thereby reducing COC toxicity and mobility. The COC-impacted sediment volume reduced in Alternatives 3 is approximately 57,000 CY, and for Alternatives 5 and 6 it is approximately 22,000 CY. **Table 6-1** shows the estimated mass of COCs removed from OU1. The sediment removal components of the remedy raise similar concerns to those discussed previously for Alternatives 2 and 4, except that Alternatives 3, 5, and 6 minimize the removal-area footprint by integrating removal of high-concentration areas in the marsh creeks with capping and thin-cover placement in lower-concentration and vegetated marsh areas.

Capping and thin-cover placement reduce COC toxicity and mobility by isolating contaminants through burial with clean materials. All three alternatives achieve the RGO SWACs established in **Section 3.3**.

Unlike removal, contaminant mass does not substantially resuspend during cap placement (Lyons et al. 2006), thus reducing the potential for contaminant mobility during construction. Therefore, Alternatives 3, 5, and 6 reduce the long-term toxicity and mobility associated with elevated concentrations of COCs in sediments.

6.2.5 Short-Term Effectiveness

Implementation of any alternative, other than the No Action Alternative, presents short-term impacts associated with on-site construction and remediation operations. The extent of these impacts is proportional to the remedial footprint, the sediment removal volume, the selected remedy components, the time required to complete the remedy, and on-site material handling requirements.

Sediment removal provides the opportunity to achieve risk reduction by the removal of sediment contaminants from OU1. However, depending on the size and complexity of the project, sediment removal increases the potential for negative short-term impacts to the environment and to the surrounding community. The following short-term risks relate to sediment removal:

- Sediment excavation, handling, transportation, and disposal increase community impacts, including traffic, odors, and noise. Community impacts are in proportion to the volume of material removed, on-site sediment handling requirements, and time required to complete remedy implementation.
- Sediment removal poses adverse risks to the community and construction workers via potential exposures to contaminated sediment, prolonged construction impacts to the community, and increased transportation to and from the Site. The risks of sediment suspension and accidental spills of Site-related materials increase during excavation and transportation. Transportation of contaminated material increases human exposure risks due to extended sediment handling. Although these risks are reduced by BMPs and site-specific health and safety plans, the risks cannot be eliminated entirely. Sediment removal increases the risk of sediment resuspension and short-term impacts on water quality. Minimizing the sediment-removal component of the remedy reduces the potential for sediment scouring and off-site contaminant transport and minimizes ecological exposures to chemicals in surface water resulting from sediment resuspension and dissolved-phase partitioning of compounds. These risks also are minimized by employing BMPs and adhering to site-specific permitting requirements, but risks cannot be eliminated entirely.

- Sediment removal requires extensive heavy equipment use, including barge- or shoreline-mounted excavation equipment, and on-site sediment handling equipment (e.g., backhoes or cranes). Though the construction industry has extensive experience working with such heavy equipment, the increased risk of worker injury cannot be eliminated entirely.

Sediment capping and thin-cover placement bury contaminants through deposition of a layer of clean material on the sediment bed surface. The short-term risks associated with capping and thin-cover placement include the following:

- Clean material transportation to the Site increases community impacts, including traffic, noise, and diesel exhaust. Community impacts are in proportion to the volume of material delivered and time required to complete remedy implementation. Clean material transport also is necessary for the backfill component of the removal alternatives. Depending on tidal conditions and contractor preferences, some material may be transported by water.
- Sediment capping and thin-cover placement require extensive heavy equipment use, including barge- or shoreline-mounted excavation equipment, and on-site material handling equipment. Though the construction industry has extensive experience working with heavy equipment, the increased risk of injury to workers cannot be eliminated entirely.

Sediment removal, sediment capping, and thin-cover placement will result in short-term ecological impacts to the marsh. Marsh plants and benthic animals will be covered by capping or thin covers, and will be excavated with sediment removal.

- Thin covers have the least impact to the existing ecology. Based on a literature review of thin layer placement in marsh and wetlands restoration case studies (**Appendix E)**, areas remediated with thin covers are expected to recover within approximately two growing seasons. While restoration efforts, such as replanting, may accelerate recovery after sediment capping or removal, restoration is expected to be slower. However, recovery is not completely certain. Marsh dieback is prevalent in portions of the estuary, and throughout TRBE. In some cases, dieback may hinder marsh vegetation recovery; under these conditions, replanting and maintenance may not necessarily accelerate recovery to overcome dieback and thus may not beget positive results.
- Thin covers, applied accurately, limit the loss of aquatic habitat and changes in marsh elevations; hydrodynamic modeling (**Appendix B)** shows that thin-cover placement does not adversely impact hydrology in OU1.
- Capping, limited to marsh creeks in Alternatives 3, 5, and 6, minimally impacts the marsh ecosystem. Hydrology is relatively unaffected (**Appendix B**), and capping within the creeks does not impact marsh vegetation directly.
- Removal has the most substantial impact to the marsh ecosystem. Besides the risk of chemical residuals and chemical release during construction, removal is the most damaging to the existing habitat because it destroys the existing marsh ecosystem (i.e., marsh plants and the benthic community) to remove contaminants. When confined to the marsh creeks in Alternatives 3, 5, and 6, the impacts of removal to the ecosystem are minimized by targeting only those areas with the highest COC levels.

- Short-term risks associated with sediment removal should be commensurate with the long-term gains of removal. The most frequent post-removal measurement used to assess effectiveness is contaminant concentrations in surface sediment. Surface concentrations (as opposed to concentrations in deeply buried sediments) are the most relevant to risk (NRC 2007). Targeting buried chemical deposits may exacerbate risks associated with sequestered sediment that is not currently bioavailable or bioaccessible.

Alternatives 2 (SMA-1) and 4 (SMA-2)

Alternatives 2 and 4 only feature sediment removal, resulting in the most substantial potential negative short-term impacts to the environment and surrounding community. The extent of these impacts is proportional to the remedial footprint, the use of removal only, the time required to implement the remedy, and on-site material handling requirements.

Alternative 2 (SMA-1) requires the removal, transportation, and disposal of 153,000 CY of contaminated sediment material from 48 acres of OU1 and construction is estimated to span 18 months. Alternative 4 (SMA-2) includes the removal of 153,000 CY of contaminated sediment material from 18 acres of OU1 and construction is estimated to span 12 months. Thus, Alternative 2 poses greater short-term risks and potential impacts to human health and the environment than Alternative 4, and both Alternatives 2 and 4 pose greater short-term risks than Alternatives 3, 5, and 6.

Alternatives 3 (SMA-1), 5 (SMA-2), and 6 (SMA-3)

Alternatives 3, 5, and 6 incorporate sediment removal, sediment capping, and thin-cover placement resulting in potential negative short-term impacts to the environment and surrounding community. In comparison to Alternatives 2 and 4, Alternatives 3, 5, and 6 minimize short-term risks by reducing the scope of sediment removal through removing only those sediments that exceed the RGOs and cannot be remediated via capping or thin-cover placement.

Alternative 3 includes the removal of 27,000 CY of contaminated sediment from 48 acres of OU1, while Alternatives 5 and 6 require the removal, transportation, and disposal of 22,000 CY of contaminated material from 18 and 24 acres of OU1, respectively. These volumes represent approximately 18% (Alternative 3) and 14% (Alternatives 5 and 6) of the volume considered for removal in Alternative 2. Based strictly on the volume of contaminated materials to be removed, Alternative 3 poses greater community impacts and risks to human health and the environment than either Alternative 5 or Alternative 6.

The short-term human-health and ecological impacts of sediment capping and thin-cover placement are generally limited to transportation of clean material and heavy equipment usage, so risks strongly correlate to the duration of construction activities, and can be managed by BMPs and site-specific safety plans. The estimated construction duration for Alternatives 3, 5, and 6 is 17, 10, and 11 months, respectively. Thus, Alternative 3 poses a greater short-term risk than Alternative 6, which poses a marginally greater short-term risk than Alternative 5.

6.2.6 Implementability

There are no implementability constraints for the No Action Alternative because no remedial action is taken.

Portions of each SMA pose different challenges and technical difficulties associated with remedy implementation (**Section 5.1** and **Table 6-4**). Tides severely impact accessibility of the marsh by equipment, material, and personnel. Thus, tides severely impact productivity, regardless of whether a land- or water-based operation is employed. Implementation of any remedial technology (whether sediment removal, sediment capping, or thin-cover placement), will encounter the following constraints:

- Marsh areas and creeks (except for portions of Purvis Creek) completely fill and drain during one tidal cycle (Photos 6-5A through 6-5H on **Figure 6-5**). This condition limits water-based operations to north Purvis Creek, LCP Ditch, Eastern Creek, and Western Creek. Water-based operations are further restricted by the shallow, narrow, and tortuous nature of the Eastern Creek, Western Creek, and Domain 3 Creek (Photos 6-5I and 6-5J on **Figure 6-5**).
- Land-based operations require construction of temporary access roads across the soft sediments in the marshes and creeks (Photos 6-6-5J through 6-5L on **Figure 6-5**). These roads will access remedial areas and allow material (e.g., excavated material, backfill material) transfer. The temporary access roads must have surface elevations at least 1 foot above the mean high water elevation to avoid flooding. Staging areas are needed to facilitate and optimize material handling, access, and management. The roads and staging areas are to be removed upon completion of construction activities, or integrated into the remedial action as appropriate (e.g., road material may be used as backfill after sediment removal). Access via land to some isolated remedial areas, such as the Western Creek or even North Purvis Creek and Domain 3 Creek, require access agreements from adjoining property owners, possibly making land access even more difficult than aquatic access.
- As with other sediment remediation projects, the removal, transportation, off-loading, dewatering/solidification, and disposal of contaminated sediment and debris presents implementation challenges, such as traffic management, noise, and suitable disposal facility capacity.
- Scattered debris has been observed throughout OU1, including large stone lining of the banks of the LCP Ditch (Photos 6-5M through 6-5P on **Figure 6-5**). The distribution of submerged debris is unknown, but is expected to be present, particularly in sediment removal areas that have not been dredged or maintained historically. Debris within removal areas will be removed and disposed of off-site during remedy implementation. Debris removal also may be required for capping, in the event that debris prevents or obstructs cap placement and cover. Debris removal is not anticipated for thin-cover placement, except perhaps to groom near-shore marsh areas where surface debris is prevalent.
- Marsh recovery will be monitored. However, recovery is not completely certain as marsh dieback, which may hinder marsh vegetation recovery, is prevalent in portions of the estuary, and throughout TRBE (Photo 6-5Q on **6-5)**. Thus, replanting and maintenance

may not necessarily accelerate recovery to overcome dieback and thus may not beget positive results.

Techniques exist to meet the challenges associated with working among soft sediments in tidally influenced marsh areas. These include the use of low-ground-pressure earth moving equipment, telescoping conveyor belts for cap placement, water-based sediment removal and sediment capping using shallow draft barges, and hydraulic placement of thin-cover material. Most of these considerations will be resolved during design and the construction bidding process.

Alternatives 2 (SMA-1) and 4 (SMA-2)

Alternatives 2 and 4 face similar implementation challenges as they both feature only sediment removal (**Table 6-4**). In addition to the implementation constraints discussed above, Alternatives 2 and 4 face the following challenges:

- Generally, creek sediments will be removed in water- or land-based operations; sediments from the marshes will be removed in land-based operations.
- Implementation of a land-based operation requires access with owners of adjacent off-site properties.
- The pier remnants across Purvis Creek (see photo 6-5R on **Figure 6-5**) may require removal (particularly for Alternative 2).
- The soft marsh sediments require substantial fill material to construct temporary access roads and staging areas capable of supporting anticipated loads.

Since Alternative 2 has a footprint that is approximately 30 acres larger than that of Alternative 4, Alternative 2 will result in greater implementation challenges, such as:

- More temporary access roads and staging areas.
- More sediments requiring removal, dewatering/solidification, management, transport and off-site disposal, resulting in more substantial community impacts due to traffic, noise, and overburdened disposal facilities.
- More debris to be removed and disposed off-site.
- Greater magnitude temporary short-term ecological impacts to remediated marshes.
- Greater magnitude short-term ecological impacts to marshes not targeted for remediation (e.g., footprints of access roads and staging areas).

Remedy effectiveness is evaluated through the implementation of short-term and long-term monitoring plans (**Sections 5.4.2** and **5.6.2**, respectively). These monitoring programs and potential future corrective actions are implementable.

Alternatives 3 (SMA-1), 5 (SMA-2), and 6 (SMA-3)

Alternatives 3, 5, and 6 face similar implementation challenges as they combine sediment removal, sediment capping, and thin-cover placement. In addition to the implementation constraints discussed above (**Section 6.2.6**, **Table 6-4**), Alternatives 3, 5, and 6 face the following challenges:

- Generally, creek sediments will be removed in water- or land-based operations; sediments from the marshes will be removed in land-based operations.
- Implementation of a land-based operation requires access agreements with owners of adjacent off-site properties.
- Portions of the pier remnants (see photo 6-5R on **Figure 6-5**) across Purvis Creek may require removal (particularly for Alternatives 3 and 6).
- Soft marsh sediments require substantial fill material to construct temporary access roads and staging areas capable of supporting anticipated loads.
- Thin-cover placement may require equipment which may not be as prevalent as typical earthmoving equipment, but nonetheless generally available (e.g., equipment to broadcast mechanically or pneumatically, or spray hydraulically).

Because Alternative 3 has a footprint that is approximately 30 acres larger than Alternative 5, and approximately 22 acres larger than Alternative 6, Alternative 3 will result in greater implementation challenges. Similarly, Alternative 6 is approximately 8 acres larger than Alternative 5, so it will encounter comparatively greater implementation challenges such as:

- More temporary access roads and larger staging areas.
- Limited access and productivity (water-based operation) or need for access agreements (i.e., land-based operation) to implement the remediation of isolated and discontinuous areas in the Western Creek (Alternative 3 only).
- Construction of temporary roads and staging areas to remediate the Domain 3 marsh (Alternative 3 only).
- More sediments requiring removal, dewatering/solidification, management, transport, and off-site disposal, resulting in higher community impacts due to traffic, noise, and overburdened disposal facilities.
- More debris to be removed and disposed off-site.
- Greater-magnitude temporary short-term ecological impacts to remediated marshes.
- Greater-magnitude short-term ecological impacts to marshes not targeted for remediation (e.g., footprints of access roads and staging areas).
- Alternatives 3 and 6 require access to the upper reaches of North Purvis Creek, which are tidally influenced and will have limited access during low tides.

Remedy effectiveness is evaluated through the implementation of short-term and long-term monitoring plans (**Sections 5.5.2, 5.7.2** and **5.8.2**, respectively). These monitoring programs and potential future corrective actions are implementable.

6.2.7 Cost

Cost estimate details are provided in **Appendix G**, including material and construction unit costs and assumptions used to develop the cost estimates, such as monitoring assumptions. Although considered reasonable to provide sufficient detail to compare technology costs, monitoring assumptions (e.g., quantities, frequencies, and durations) are not intended to be prescriptive.

Remedy costs are summarized in **Table 6-5**. Besides the No Action Alternative, Alternative 5 has the lowest present-worth capital cost (i.e., sum of direct and indirect construction costs), approximately $25MM. Alternative 2 has the highest present worth cost, $57MM. The present worth cost of Alternatives 3, 4 and 6 are $33MM, $30MM, and $23MM, respectively. Alternative 2 is approximately 1.7 to 2.5 times more expensive than Alternatives 3, 4, 5, and 6.

6.2.8 State Acceptance

The modifying criterion of state acceptance is not been addressed in this draft FS. It may be addressed in the final FS or the ROD. USEPA and GAEPD have been involved with the various tasks and decisions that have been incorporated into the development of the alternatives presented in this FS, thus this FS anticipates USEPA and state acceptance. The alternatives identified in this FS aim to balance remediation to reduce risks to human health and the environment, while preserving the existing habitat and ecological communities, both of which are important criteria for USEPA and GADEP. USEPA and GAEPD will continue to participate in the review and evaluation of the alternatives presented in this FS, and in the selection of the most appropriate sediment remedy for the Site.

6.2.9 Community Acceptance

The modifying criterion of community acceptance is not addressed in this draft FS. It may be addressed in the final FS or the ROD. The LCP property is surrounded primarily by commercial and industrial property (EPS and ENVIRON 2012). The Glynn County Planning Commission Land Use Maps show the area designated as industrial for both present and future use. Nonetheless, remedial activities for any alternatives except the No Action Alternative may increase short-term impacts to neighboring communities through construction noise, odors, and diesel emissions related to site activities and off-site material transport. Other effects of remedy implementation on the community include safety issues associated with implementation, which could restrict use of areas in the vicinity of the remediation.

Remediation will ultimately improve the marsh ecosystem as a community resource, by lowering sediment contaminant concentrations, contaminant bioavailability, and chemical concentrations in fish; this in turn will lessen fish restrictions associated with OU1. However, by destroying existing marsh habitat, all of the remedies will temporarily diminish the aesthetic value of the marsh for the local community, larger remedies will have a more substantial impact on the existing marsh habitat than smaller remedies, and alternatives that require sediment removal of vegetated marsh areas will have a more substantial impact than the thin-cover placement alternatives.

Public education is necessary to build support of remedial action. Public education informs the public, adjacent businesses, and other stakeholders of the physical and visual impacts that construction activities will have on the estuary and the short- and long-term benefits that are expected.

This FS anticipates community acceptance because each alternative, except No Action, is designed to meet RAOs established by USEPA and RGOs established for OU1. The FS will undergo public review before being finalized.

6.2.10 Environmental Sustainability

The evaluation of alternatives for environmental sustainability is focused primarily on maximizing the net environmental benefit of remediation while optimizing the use of resources (e.g., energy and water) and minimizing the impact on the ecosystem (e.g., minimizing waste generation and impacts on land and habitat). For OU1, the following are environmentally sustainable practices:

- Reuse of clean dredged material from nearby waterways in lieu of borrow material from upland sources (e.g., quarries or mines). Potential sources of material local to OU1 include material from navigational dredging of both the Brunswick Harbor and SHEP, which are ongoing projects managed by the USACE Savannah District (USACE 2012a; 2012b). Currently, dredged materials from both projects are managed at upland DMCF and ODMDS. If the sediment from these sites are determined to be suitable for beneficial reuse at the LCP OU-1 Site, dredged material from either project would result in the following sustainability benefits:
  - Reduce the space consumed in the DMCF or ODMDS.
  - Reduce the energy required to generate newly quarried cap material, which must be mined, crushed, processed, cleaned, and transported to the Site.
  - Provide material better suited for marsh restoration than quarried sand. Dredged sediment is more organic-rich and contains natural nutrients that support plant and wildlife growth, whereas quarried sands tends to lack natural organic matter.
- Ensuring that equipment is operating at peak efficiency, thereby minimizing fossil fuel usage, air emission, and waste generation.
- Using biodiesels in lieu of diesel to reduce air emissions and greenhouse gas contribution.
- Using mufflers and sound attenuation equipment, where possible (e.g., pump enclosures) to reduce noise.
- Minimizing temporary road and staging area footprints to limit habitat disturbance.
- Incorporating remedial technologies that achieve RGOs while decreasing the short-term and long-term bioavailability of COCs (e.g., sediment capping or thin-cover placement).
- Evaluating, as part of the remedial design, the possibility of incorporating passive sampling devices for long-term monitoring.

All alternatives, except the No Action Alternative, would incorporate sustainable practices. The extent to which these environmentally sustainable practices are incorporated depends on the selected remedy components and the remedy footprint (e.g., incorporating technologies that decrease the short-term and long-term bioavailability of COCs), the project duration (e.g., sustainable equipment and operational practices), and the volumes of clean fill required for remedy implementation (e.g., beneficial reuse of clean dredged material from nearby waterways).

7 Conclusions

This FS identified six remedial alternatives, which have been screened (**Section 5**) and evaluated against NCP criteria (**Section 6**). Alternative 1 (No Action), included in the screening and evaluation as required by NCP to provide a baseline, is not carried forward for the comparative analysis in this section because—while it is readily implementable and low-cost, Alternative 1 does not:

- Achieve some of the RAOs or RGOs
- Adequately protect human health or the environment
- Comply with the ARARs
- Reduce COC toxicity, mobility, or volume
- Mitigate long-term risks

This section comparatively evaluates Alternatives 2 through 6 against the RGOs identified in **Section 3** (**Section 7.1**) and provides analysis in support of remedy selection (**Section 7.2**).

7.1 Summary of the Comparative Analysis

Alternatives 2 through 6 achieve RAOs and all achieve protection of human health and the environment. All provide long-term human health and ecological risk reduction by decreasing surface sediment COC concentrations, which leads to reduced chemical bioavailability and chemical uptake by human and ecological receptors and reduced risks to human health, mammals, birds, fish, and the benthic community. Long-term monitoring ensures long-term remedy integrity and effectiveness.

To varying degrees, the remedies achieve the RAOs established in **Section 3** by dredging and backfilling, capping, or covering sediments. Alternatives 2 through 6 achieve RAOs 1 through 7 as follows:

> RAO 1: Alternatives 2 through 6 mitigate potential COC releases of contaminated in stream sediment deposits and help prevent releases into Purvis Creek. All five alternatives remediate the highest COC concentrations in OU1 (i.e., all five include LCP Ditch, Eastern Creek, and Domain 3 Creek), and substantially reduce the potential for transport from in-stream deposits to Purvis Creek.
>
> RAO 2: Lower surface sediment concentrations reduce exposures to piscivorous bird and mammal populations from ingestion of COCs in prey exposed to contaminated sediment in the estuary. Alternatives 2 through 6 achieve the Site-specific remedial goals insofar as all achieve the RGO range for the target COCs. Furthermore, post-remediation HQs for all species, including the most sensitive species (Green Heron) are at or below 1 for all alternatives. Thus, the five remedies reduce sediment concentrations to acceptable levels, especially when considering spatial forage areas of wildlife and movement of forage prey.
>
> RAO 3: Alternatives 2 through 6 reduce human exposure to COCs through ingestion of fish and shellfish associated with Site contaminants. Each alternative results in SWACs that

meet the RGOs, leading to reductions of mercury and Aroclor 1268 in fish and shellfish concentrations that eventually will reduce fish and shellfish consumption advisories within the TRBE.

RAO 4: Alternatives 2 through 6 reduce ecological risks to benthic organisms exposed to contaminated sediment to levels that will result in self-sustaining benthic communities with diversity and structure comparable to that of reference areas. The remedies address the areas where adverse effects to benthic organisms have been observed—areas containing the highest COC concentrations in the marsh—and reduce surface sediment concentrations to levels at or below the Site-specific RGO range, which is well below COC concentrations at locations where adverse benthic effects were observed. Thus, all five alternatives are protective of benthic communities.

RAO 5: Alternatives 2 through 6 reduce finfish exposures to COCs to acceptable levels. In all five remedies the post-remedy residual finfish HQs are at or below 1.

RAO 6: Alternatives 2 through 6 are expected to meet the applicable USEPA and Georgia WQS for protection of aquatic life in the estuary, using total or dissolved-phase mercury and PCB measures. The five remedies address the highest concentrations in the estuary, including elevated concentrations in major creeks that have the highest potential to increase surface water COC concentrations and ambient water quality criteria exceedances.

RAO 7: Because the physical impact of the remedies on the existing marsh habitat is in proportion to the size and scope of the remedy, Alternatives 2 through 6 balance human and ecological risk reduction with sustaining and protecting existing habitat and wildlife to varying degrees. The SMA-1 alternatives (Alternatives 2 and 3) more substantially impact the existing vegetated marsh habitat than the SMA-2 alternatives (Alternatives 4 and 5) and the SMA 3 alternative (Alternative 6). Furthermore, the dredging-only remedies (Alternatives 2 and 4) have a more destructive impact on the vegetated marsh habitat than the remedies that integrate dredging, capping, and thin-cover placement (Alternatives 3, 5, and 6).

In summary, Alternatives 2 through 6 meet the RAOs and are designed to achieve the SWAC-based and benthic-community-based RGOs. The SMA-1 remedies and the dredge-only remedies have a greater impact on habitat than the SMA-2 and SMA-3 remedies and those that incorporate capping and thin-cover placement, respectively. Habitat disturbance is proportional to the remedial footprint and is more substantial for removal and capping compared to thin-cover placement.

7.2 Analysis in Support of Remedy Selection

CERCLA and the NCP require that every selected remedy be “cost-effective” (USEPA 1996). A remedy is cost effective if its “costs are proportional to its overall effectiveness” (40 CFR 300.430(f)(1)(ii)(D)). Overall effectiveness of a remedial alternative is determined by evaluating long-term effectiveness and permanence; reduction in toxicity, mobility, and volume through treatment; and short-term effectiveness. Overall effectiveness is then compared to cost to determine whether the remedy is cost-effective (USEPA 1996).

The evaluation of alternatives with respect to long-term effectiveness and cost (**Sections 6.2.3** and **6.2.7**) can be summarized as follows:

- While Remedial Alternatives 2 and 3 (SMA-1) include the remediation of the largest areas, they do not provide a significantly greater overall risk reduction than Remedy Alternatives 4 and 5 (SMA-2) or 6 (SMA-3).
- Costs are presented in Table 6-4 and in Appendix G. Remedy Alternative 5 has the lowest present-worth cost of approximately $26MM. Remedy Alternative 2 has the highest present-worth cost of $64MM. The present-worth costs of Remedy Alternatives 3, 4 and 6 are $38MM, $34MM and $28MM, respectively.

7.2.1 Cost-Effectiveness Analysis

Remedy cost effectiveness, defined herein as the cost associated with risk reduction following remedy implementation, is evaluated by comparing post-remediation residual risks for each alternative against remedy costs. **Figures 7-1A, 7-1B,** and **7-1C** show risk reduction compared to costs for the Green Heron, and finfish exposed to Aroclor 1268, and finfish exposed to mercury, respectively. Alternatives 2 through 6 achieve HQs at or below 1. Although Alternatives 2 and 3 have the greatest predicted COC risk reduction, they do not provide a substantially greater overall risk reduction in proportion to their greater costs when compared to Alternatives 4 and 5 or 6, for bird and fish populations. Therefore, Alternatives 2 and 3 have the lowest cost effectiveness (i.e., the highest cost relative to effectiveness) because they provide only an incremental increase in risk reduction at a significantly greater cost than Alternatives 4, 5, and 6.

Risk reduction is virtually the same among Alternatives 4, 5, and 6, although the Alternative 6 residual risks are slightly lower than those for Alternatives 4 and 5, because Alternative 6 includes areas in Purvis Creek and Domain 1. Alternatives 5 and 6 are more cost effective than Alternative 4 because they achieve the same degree of risk reduction at lower costs. The uncertainty in costs and risk reduction make it impossible to compare Alternatives 5 and 6, so both are considered comparably cost effective.

All five remedies are protective of the benthic community. Alternatives 2 through 6 reduce ecological risks to benthic organisms exposed to contaminated sediment to levels that will result in self-sustaining benthic communities with diversity and structure comparable to reference areas. All five alternatives reduce surface sediment concentrations to levels at or below the Site-specific RGO range, which is well below Aroclor 1268, PAH, lead, and mercury concentrations at locations where adverse benthic effects were observed in the marsh. Thus, the increased cost associated with the larger sediment footprint (SMA-1, Alternatives 2 and 3) and those associated with removal only (Alternative 2 and 4) are disproportionate to their benefit. Cost effective remedies are those that are protective of the benthic community at the lowest cost and the lowest negative impact to the ecosystem. Accordingly, for this Site, Alternatives 5 and 6 are the most cost-effective remedies.

In summary, **Figures 7-1A** through **7-1C,** and the remedy effectiveness discussions in **Section 6**, indicate that the marginal improvement in risk reduction for mammals, birds, fish, and sediment-dwelling organisms under Alternatives 2 and 3 is disproportionately expensive compared to Alternatives 4, 5, and 6. Furthermore, much higher costs are associated with removal only when compared to remedies that combine and optimize the use of removal, capping, and thin-cover placement. However, these higher costs are not commensurate with correspondingly reduced risks; thus, the combined remedies are more cost effective than the removal-only remedies.

7.2.2 Ecosystem Impacts Analysis

Long-term ecological recovery of the estuary is a time-dependent process, with longer recovery times required for larger-scale remedies (Alternatives 2 and 3 versus Alternatives 4, 5, and 6), and for dredging remedies (Alternatives 2 and 4) compared to remedies that rely on a combination of dredging plus backfill, capping, and thin-cover placement (Alternatives 3, 5, and 6). Predictions of ecological impacts such as damage to the vegetated marsh areas are driven by the size of the SMA footprint plus incidental areas not targeted for remediation but damaged as part of the construction process (e.g., road construction in the marshes to access areas targeted for remediation).

Figure 7-2 plots remedy cost versus area disturbed by each remedy. Alternatives 2 and 3 impact the largest areas (56 and 57 acres, respectively); Alternatives 4 and 5 impact the smallest areas (29 and 26 acres, respectively); and Alternative 6 falls between those alternatives (31-acres impacted). **Figures 7-3A, 7-3B,** and **7-3C** show risk reduction compared to the area remediated and impacted by each remedy for the Green Heron, and finfish exposed to Aroclor 1268, and finfish exposed to mercury, respectively. These figures are similar to **Figures 7-1A** through **7-1C**, except that the impacted area is shown on the x-axis instead of cost. Though similar, the observations between **Figures 7-3** and **7-1** differ slightly. The SMA-1 remedies (Alternatives 2 and 3) have the largest area of impact at 56-59 acres. Alternatives 3, 4, and 5 are comparable and impact 26 to 31 acres. Although the residual risks associated with SMA-1 (Alternatives 2 and 3) are lower than those associated with SMA-2 (Alternatives 4 and 5) and SMA 3 (Alternative 6), all remedies reduce HQ levels to 1 or below 1; thus, all alternatives are adequately protective of the environment.

Because all the alternatives, except for the No Action alternative, meet the ARARs, RAOs, and RGOs, Alternatives 4, 5 and 6 are most cost-effective in achieving goals while minimizing vegetated marsh disturbance and recovery. These alternatives will comply with project goals, while limiting vegetated marsh disturbance to approximately half of that resulting from implementation of Alternatives 2 or 3 (**Figure 7-2**).

7.2.3 Marsh Recovery Analysis

Predictions of ecological recovery time frames depend on the remediation approach as well as on the remediation footprint. Sediment removal is much more intrusive to vegetated marsh areas than thin-cover placement, leading to longer recovery times. As a result, the alternatives that incorporate only sediment removal (i.e., Remedy Alternatives 2 and 4) require longer periods for ecological recovery than remedies that combine removal with sediment capping and thin-cover placement for vegetated marsh areas (Alternatives 3, 5, and 6).

7.2.4 Summary

Based on all the remedy selection criteria, including the ecosystem impact analysis, marsh recovery analysis, and cost effectiveness analysis discussed above, Alternatives 5 and 6 are the most effective remedial alternatives for OU1. These alternatives satisfy the Site-specific RAOs, achieve the Site-specific RGOs, and meet the NCP criteria of protectiveness, implementability, and permanence while limiting risks associated with disturbing sensitive habitat.

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Tables

Table 2-1
Names and Areas of Site Estuary Domains
LCP Chemical, Brunswick, GA

Name	Approximate Area (acres)
Domain	
Dillon Duck	1.8
Domain 1	21
Domain 2	115
Domain 3	108
Domain 4 East	192
Domain 4 West	224
Creek	
Domain 3 Creek	12
Eastern Creek	4.2
LCP Ditch ("Main Canal")	2.5
Purvis Creek	70
Western Creek Complex	9
Total Domains	**662**
Total Creeks	**98**

Table 2-2
Range of Percent Inundation Times for Areas within the LCP Marsh Based on Elevation
LCP Chemical, Brunswick, GA

Domain/Creek Name	Average Thalweg Depth (ft)	Range in Bank Elevation (ft)	Range in Percent Time of Water in Marsh Land (%)
Purvis Creek	-12.3	2-3	4-13
Eastern Creek	-3.35	2-3	4-13
Domain 3 Creek	-2.43	2-3	4-13
LCP Ditch	-1.5	1.5-2.5	10-20

%	Percent.
ft	Feet.

Table 2-3
Total Aroclor 1268 Concentrations in Surface Water Compared to GAEPD and USEPA WQS
LCP Chemical, Brunswick, GA

Year	Mouth of Eastern Creek C-9	Mouth of Western Creek C-15	Upper Purvis Creek C-36	Mid-Stretch Purvis Creek C-29	Mouth of Purvis Creek C-16	Control TC	Control CR
2000	0.19	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	0.33
2002	---	---	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
2003	---	---	*0.25*	*0.25*	1	*0.25*	*0.25*
2004	---	---	*0.6*	*0.6*	*0.6*	*0.6*	*0.6*
2005	---	---	*0.01*	*0.01*	*0.01*	*0.5*	*1.4*
2006	0.18	0.026	0.021	0.044	0.029	0.0012	*0.0005*
2007	0.44	0.22	0.024	0.031	0.037	0.0024	---

---	Not analyzed.
GAEPD	Georgia Environmental Protection Division.
USEPA	United States Environmental Protection Agency.
WQS	Water quality standard.

All results in micrograms per liter (µg/L).
GAEPD and USEPA WQS for Aroclor 1268 in Coastal and Marine Estuarine Waters is 0.03 µg/L.

Numbers italicized and in gray were non-detected values that were assigned a value of 1/2 of detection limit.

Cells shaded in yellow were above the WQS. Please note that PCB detection limit was above the threshold level of 0.03 µg/L.

Control locations were Troup Creek (TC) and Crescent River (CR).
Surface water results taken from Table 4-2b (Black & Veatch 2011).

Table 2-4
COCs Identified in Sediment and Biological Tissue
LCP Chemical, Brunswick, GA

LCP Chemical, Brunswick, GA	**Sediment**	**Fish**	**Shellfish**	**Clapper Rail**
Aluminum	X			
Aroclor 1268 (a)	X	X	X	X
B(a)P TEQ (b)	X			
Copper			x	
Chromium (c)	X			
Lead	X			
Manganese	X			
Mercury (d)	X	X	X	X
Thallium	X			
Zinc			X	

COC	Constituent of concern.
HHBRA	Human health baseline risk assessment.
MeHg	Methyl mercury.
RSL	Regional screening level.
TEQ	Toxic equivalent.

(a) Aroclor 1268 was identified as a COC based on comparisons to the RSLs for Aroclor 1254.

(b) B(a)P TEQ = Benzo(a)pyrene toxic equivalents.

(c) As a conservative assumption, chromium in sediment and biota was assumed to be in the hexavalent state, despite the reducing conditions of the sediment.

(d) Although mercury and MeHg were considered separately for sediment exposure in the HHBRA, both chemical forms were assessed conservatively as MeHg.

Table 2-5
Summary of Calculated Risks and Hazards from the HHBRA
LCP Chemical, Brunswick, GA

	Cancer Risk		Noncancer HI	
Exposure Scenario / Receptor	**RME**	**CTE**	**RME**	**CTE**
Marsh Trespasser				
Lifetime	1E-05	2E-07		
Adult			0.06	0.005
Adolescent			0.08	0.006
Recreational Finfish Consumer				
Lifetime	1E-04	2E-05		
Adult			3	0.8
Adolescent			3	0.9
Child			4	1
High Quantity Finfish Consumer				
Lifetime	2E-04	4E-05		
Adult			5	2
Adolescent			5	3
Child			8	2
Shellfish Consumer				
Lifetime	6E-05	9E-06		
Adult			2	0.6
Adolescent			0.7	0.2
Child			4	2
Clapper Rail Consumer				
Lifetime	1E-04	8E-06		
Adult			2	0.4
Adolescent			1	0.1
Child			5	0.4

CTE	Central tendency exposure.
HHBRA	Human health baseline risk assessment.
HI	Hazard index.
RME	Reasonable maximum exposure.

Table 2-6
Experimental Design of the BERA
LCP Chemical, Brunswick, GA

Measurement [(a)]	Number of Sampling Stations [(b, c)]	Method [(d)]	Typical Detection Limit	Other Details
Surface Water Chemistry -- Creek Water				
General water quality characteristics	12	Hydrolab	-----	Temperature, salinity, specific conductance, turbidity, pH, and dissolved oxygen evaluated
Total mercury	12 + 29 (2005)	1631E	0.07 ng/L	Total and dissolved mercury evaluated by "clean-hands" technique
Methyl mercury (2005)	28	Bloom, 1989	0.02 ng/L	Evaluated by "clean-hands" technique; all 28 data employed in analysis
Aroclor 1268	12	8082	0.001 µg/L	-----
Lead	12	200.8	0.002 µg/L	Total and dissolved lead evaluated
Surface Water Toxicity -- Creek Water				
Mysids	6 (2000)	1007	-----	7-day test designed to evaluate chronic effects; 8 replicates per sampling station; evaluation of survival and growth of mysids exposed to water in laboratory
Sheepshead minnows	6 (2000)	1004	-----	7-day test designed to evaluate chronic effects; 4 replicates per sampling station; evaluation of survival and growth of fish exposed to water in laboratory
Surface Sediment Chemistry -- Creek Sediment [(e)]				
Grain-size distribution	27	ASTM D-422	1% passing sieve	-----
Total organic carbon	27	ASTM D4129-82M	0.02% (dry wt)	-----
Total mercury	27 +150 + 31 (2005)	1631E	0.001 mg/kg (dry wt)	-----
Methyl mercury (2005)	31	Bloom, 1989	0.008 µg/kg (dry wt)	
Aroclor 1268	27 +150	8082	0.003 mg/kg (dry wt)	-----
Lead	27 +150	6020	0.02 mg/kg (dry wt)	-----
Total PAHs	27 +150	8270C	0.001 mg/kg (dry wt)	18 different PAHs evaluated
Secondary metals	20	6010B/6020	<1 mg/kg (dry wt)	21 different metals evaluated
Simultaneously extracted metals SEM	20	6010B-SEM	1 mg/kg (dry wt)	6 different metals (Cd, Cu, Pb, Ni, Ag, and Zn) evaluated
Acid-volatile sulfide (AVS)	20	EPA (1991)	0.5 mg/kg (dry wt)	-----

Table 2-6
Experimental Design of the BERA
LCP Chemical, Brunswick, GA

Measurement [(a)]	Number of Sampling Stations [(b, c)]	Method [(d)]	Typical Detection Limit	Other Details
Surface Sediment Chemistry -- Marsh Sediment) [e]				
Grain-size distribution	26	ASTM D-422	1% passing sieve	-----
Total organic carbon	26	ASTM D4129-82M	0.02% (dry wt)	-----
Total mercury	26 + 29 (2005)	1631E	0.001 mg/kg (dry wt)	
Methyl mercury (2005)	29	Bloom, 1989	0.008 µg/kg (dry wt)	
Aroclor 1268	26	8082	0.003 mg/kg (dry wt)	-----
Lead	26	6020	0.02 mg/kg (dry wt)	-----
Total PAHs	26	8270C	0.001 mg/kg (dry wt)	18 different PAHs evaluated
Secondary metals	4	6010B/6020	1 mg/kg (dry wt)	21 different metals evaluated
Simultaneously extracted metals (SEM)	4	6010B-SEM	1 mg/kg (dry wt)	6 different metals (Cd, Cu, Pb, Ni, Ag, and Zn) evaluated
Acid-volatile sulfide (AVS)	4	EPA (1991)	0.5 mg/kg (dry wt)	-----
Surface Sediment Toxicity -- Creek and Marsh Sediment [(e)]				
Amphipods	24	EPA/600/R-01/020	-----	Main Amphipod Study: 28-day chronic test; 5 replicates per sampling station; evaluation of survival, growth, and reproduction of amphipods exposed to sediment in laboratory
Amphipods	150	EPA/600/R-01/020	-----	Apparent Effects Threshold (AET) Study: As above except only 1 replication per sampling station
Amphipods	3	Metals: usually 6020A; Aroclors: 8082; Total PAHs: 8270-SIM	Various	Toxicity Identification Evaluation (TIE): Analytical methods pertain to pore-water analyses
Grass shrimp	9	Special Lee test	-----	Direct evaluation of reproduction and DNA strand damage (Comet Test) of shrimp collected in field (no laboratory exposure to sediment)
Benthic Community -- Creek Surface Sediment				
Benthic macroinvertebrates	6 (2000)	Relative numerical abundance	-----	Evaluation of number of taxa, taxonomic groups, and individuals; density of individuals; diversity of equitability indices

Table 2-6
Experimental Design of the BERA
LCP Chemical, Brunswick, GA

Measurement [(a)]	Number of Sampling Stations [(b, c)]	Method [(d)]	Typical Detection Limit	Other Details
Biota Collected for Evaluation of Chemical Body Burdens (Residue) -- Creek and Marsh Stations				
Cordgrass (2005)	20	-----	-----	1 replicate (>100 g) per sampling station collected above 15 cm from ground
Eastern oysters	8	-----	-----	3 replicates of about 100 composited young-of-year (Year 0) oysters and 20 composited older (Years I and II) oysters per sampling station
Fiddler crabs	15	-----	-----	4 - 7 replicates of about 15 - 50 composited crabs (mostly males) per sampling station; replicate weight = about 16 - 55 g
Grass shrimp	9	-----	-----	3 replicates of about 50 composited shrimp per sampling station
Blue crabs	3	-----	-----	7 replicates of individual male crabs per sampling station; crab length (point-to-point on carapace) = about 130 - 170 mm (155 - 352 g)
Mummichogs	13	-----	-----	1 to 3 replicates of 5 - 30 composited fish (about 45 - 100 mm in length) per sampling station; replicate weight = 18.4 - 59.6 g
Silver perch	2	-----	-----	8 replicates of individual silver perch per sampling station; fish length (total length) = 155 - 185 mm (50 - 89 g)
Red drum	1	-----	-----	3 replicates of individual red drum at sampling station; fish length (total length) = 355 - 415 mm (527 - 832 g)
Black drum	2	-----	-----	8 replicates of individual black drum per sampling station; fish length (total length) = 170 - 220 mm (87- 158 g)
Spotted seatrout	2	-----	-----	8 replicates of individual spotted seatrout per sampling station; fish length (total length) = 290 - 390 mm (236 - 627 g)
Striped mullet	2	-----	-----	5 - 8 replicates of individual striped mullet per sampling station; fish length (total length) = 230 - 340 mm (177 - 497 g)
Chemical (Residue) Analyses Performed on Biota (Whole Bodies Analyzed)				
Total mercury	-----	1631E	0.0001 mg/kg (wet wt)	-----
Methyl mercury (2005)	-----	1630 (mod)	0.0004 mg/kg (wet wt)	-----
Aroclor 1268	-----	8082	0.0006 mg/kg (wet wt)	-----
Lead	-----	6020	0.001 mg/kg (wet wt)	-----
Lipids	-----	NOAA NOS ORCA 71	0.05% (wet wt)	Evaluated in just blue crabs and large finfishes (not reported).

Table 2-6
Experimental Design of the BERA
LCP Chemical, Brunswick, GA

BERA	Baseline ecological risk assessment.
cm	Centimeter(s).
g	Gram(s).
µg/kg	Microgram(s) per kilogram.
µg/L	Microgram(s) per liter.
mg/kg	Milligram(s) per kilogram.
mm	Millimeter(s).
ng/L	Nanogram(s) per liter.
PAH	Polycyclic aromatic hydrocarbon.
wt	Weight.

(a) All measurements (studies) were performed in 2006 except those identified as occurring in 2000 or 2005.

(b) Number of sampling stations includes reference locations -- Crescent River and/or Troup Creek.

(c) The 150 creek sediment samples are associated exclusively with the AET study conducted during this investigation. Evaluation of sediment for secondary metals, SEM, and AVS was performed on just those sediment samples also tested for toxicity in the main amphipod study.

(d) Analytical methods are USEPA methods unless otherwise indicated.

(e) Surface sediment is defined as between 0 and 15 cm in depth.

Table 3-1
Chemical-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
Clean Water Act, Section 301-302	33 USC §§ 1251, Section 301-302 40 CFR 129	Toxic Pollutant Effluent Standards	ARAR
Safe Drinking Water Act	42 USC §§ 300f - 300j-26 40 CFR 141	Establishes Maximum Contaminant Criteria for drinking water	ARAR
Instream Water Quality Standards	O.C.G.A. 12-5-20 391-3-6.03	Adopted Federal National Recommended Water Quality Criteria to protect water uses.	ARAR
Clean Water Act 40, Section 304	USEPA Federal Register, Volume 57, No. 246, December 22, 1992 and subsequent updates; current list:http://water.epa.gov/scitech/swguidance /standards/current/index.cfm	Establishes ambient water quality criteria (National Recommended Water Quality Criteria) which provide guidance for states and tribes to use in adopting water quality standards.	TBC
Safe Drinking Water Act	42 USC §§ 300f - 300j-26 40 CFR 141	Establishes maximum contaminant level goal (MCLGs) which are nonenforceable health codes to be set at a level at which no known or anticipated adverse effects on the health of persons occur and which allow an adequate margin of safety. These serve as guidelines for MCLs.	TBC
Total Maximum Daily Load (TMDL) - PCBs	July 2001, EPA TMDL Development for Fish Consumption Guidelines & Commercial Fishing Ban due to PCBs	Establishes TMDL 0.00045 ug/l (Gibson Creek, Terry Creek, Purvis Creek, Turtle River System)	TBC
TMDL - Mercury	July 2001 TMDL Development for Mercury	Establishes Satilla Watershed TMDL for Mercury at 3.76 Kg/yr to achieve 2.5 ng/l	TBC
NOAA Sediment Quality Guidelines [SQGs]	Screening Quick Reference Tables for Organics (SQRTs)	Tables with screening concentrations for inorganic and organic contaminants.	TBC

ARAR	Applicable or relevant and appropriate requirement.
TBC	To be considered.

Table 3-2
Location-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
Rivers and Harbors Act, Section 10	33 USC § 403 33 CFR Parts 320, 322, 323, 325, 329 and 330	U.S. Army Corps of Engineers approval is generally required to excavate or fill, or in any manner to alter or modify the course, location, condition, or capacity of the channel of any navigable water of the U.S.	ARAR
Clean Water Act, Section 404	33 USC § 1344 33 CFR Parts 320, 322, 323, 325, 328 and 330	These regulations apply to discharges of dredged or fill materials into U.S. waters, which include wetlands. Includes special policies, practices, and procedures to be followed by the U.S. Army Corps of Engineers in connection with the review of applications for permits to authorize the discharge of dredged or fill material into waters of the United States pursuant to Section 404 of the Clean Water Act.	ARAR
Clean Water Act, Section 404	33 USC § 1344 40 CFR Parts 230 and 231	No activity which adversely affects aquatic ecosystems, including wetlands, shall be permitted if a practicable alternative that has less adverse impact is available. If there is no other practical alternative, impacts must be minimized.	ARAR
Endangered Species Act	16 USC § 1531 et. seq.	Federal statute establishing programmatic protection for endangered and threatened species.	ARAR
FEMA Operation Regulations and National Flood Insurance Program Regulations	42 USC 4001 et seq; 42 USC 4101	Prohibits alterations to river or floodplains that may increase potential for flooding; provides federal flood insurance to local authorities and requires that the local authorities not allow fill in the river that would cause an increase in water levels associated with floods.	ARAR
Fish and Wildlife Coordination Act	16 USC § 662 40 CFR 6.302	Whenever the waters of any stream or other body of water are proposed or authorized to be impounded, diverted, the channel deepened, or the stream or other body of water otherwise controlled or modified for any purpose, by any department or agency of the U.S., such department or agency first shall consult with the U.S. Fish and Wildlife Service, Department of the Interior, and with the head of the agency exercising administration over the wildlife resources of the particular State in which the impoundment, diversion, or other control facility is to be constructed, with a view to the conservation of wildlife resources by preventing loss of and damage to such resources.	ARAR
Migratory Bird Treaty Act	16 USC §§703-712 50 CFR 10.12	Makes it unlawful to take, import, export, possess, buy, sell, purchase, or barter any migratory bird. “Take” is defined as pursuing, hunting, shooting, poisoning, wounding, killing, capturing, and trapping and collecting.	ARAR
Bald and Golden Eagle Protection Act	16 USC §668a-d	Makes it unlawful to take, import, export, possess, buy, sell, purchase, or barter any bald or golden eagle, nest, or egg. “Take” is defined as pursuing, hunting, shooting, poisoning, wounding, killing, capturing, trapping and collecting, molesting, or disturbing.	ARAR

Table 3-2
Location-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
Marine Mammal Protection Act	16 USC 1361 et seq	Makes unlawful the harassment, hunting, capturing, or killing of marine mammals and the importation of marine mammals and marine mammal products without a permit from either the Secretary of the Interior or the Secretary of Commerce, depending upon the species of marine mammal involved.	ARAR
National Historic Preservation Act	16 USC § 470 et seq. 36 CFR Part 800	Proposed remedial actions must take into account effect on properties in or eligible for inclusion in the National Registry of Historic Places. Federal agencies undertaking a project having an effect on a listed or eligible property must provide the Advisory Council on Historic Preservation a reasonable opportunity to comment pursuant to section 106 of the National Historic Preservation Act of 1966 (NHPA), as amended. While the Advisory Council comments must be taken into account and integrated into the decision-making process, program decisions rest with the agency implementing the undertaking. A Stage 1A cultural resource survey may be necessary for any active remediation to identify historic properties along the lakeshore to determine if any areas should be the subject of further consideration under NHPA.	ARAR
Coastal Zone Management Act	16 USC 1451 15 CFR § 923	Specifies requirements for state coastal management program approval by the Assistant Administrator for Ocean Services and Coastal Zone Management	ARAR
Shore Protection Act (Georgia)	O.C.G.A. 12-5-230	Limits activities in shore areas and requires a permit for certain activities and structures on the beach.	ARAR
Coastal Marshlands Protection Act (Georgia)	O.C.G.A. 12-5-280	Provides the Coastal Resources Division with the authority to protect tidal wetlands. The Coastal Marshlands Protection Act limits certain activities and structures in marsh areas and requires permits for other activities and structures.	ARAR
Protection of Tidewaters Act (Georgia)	O.C.G.A. 52-1-1	Establishes the State of Georgia as the owner of the beds of all tidewaters within the state, except where title by a private party can be traced to a valid British Crown or State land grant.	ARAR
USEPA Office of Solid Waste and Emergency Response	Policy on Floodplains and Waste and Wetland Assessments for CERCLA Actions, August 1985	This memorandum discusses situations that require preparation of a floodplain or wetlands assessment and the factors that should be considered in preparing an assessment for response actions taken pursuant to Section 104 or 106 of CERCLA. For remedial actions, a floodplain/wetlands assessment must be incorporated into the analysis conducted during the planning of the remedial action.	ARAR
Flood Damage Prevention (Glynn County)	Glynn County Code, Section 2-5-120	Establishes requirements to minimize public and private losses due to flood conditions	ARAR

Table 3-2
Location-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
Executive Order No. 11988, 42 Fed. Reg. 26951 (May 25, 1977)	Floodplain Management	Executive Order describes the circumstances where federal agencies should manage floodplains.	ARAR
Executive Order No. 11990, 42 Fed. Reg. 26961 (May 25, 1977)	Protection of Wetlands	Executive Order describes the circumstances where federal agencies should manage wetlands.	ARAR
Coastal Management Act (Georgia)	O.C.G.A. 12-5-320	Provides enabling authority for the State to prepare and administer a coastal management program	TBC

ARAR	Applicable or relevant and appropriate requirement.
TBC	To be considered.

Table 3-3
Action-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
Clean Water Act, Section 401	33 USC 1341 40 CFR Part 121	State Water Quality Certification Program	ARAR
Toxic Substances Control Act	Title 1,15 USC § 2601 40 CFR §§ 761.65 – 761.75	TSCA facility requirements: Establishes siting guidance and criteria *for* storage (761.65), chemical waste landfills (761.75), and incinerators (761.70).	ARAR
Resource Conservation and Recovery Act	40 CFR Part 257	Establishes criteria for classification of waste disposal facilities and practices	ARAR
Resource Conservation and Recovery Act 42 USC s/s 6901 et seq. (1976)	40 CFR Part 261	Identification and listing of hazardous waste	ARAR
Resource Conservation and Recovery Act 42 USC s/s 6901 et seq. (1976)	40 CFR Part 262	Standards applicable to generators of hazardous waste	ARAR
Resource Conservation and Recovery Act 42 USC s/s 6901 et seq. (1976)	40 CFR § 262.11	Hazardous waste determination	ARAR
Resource Conservation and Recovery Act, 42 USC s/s 6901 et seq. (1976)	40 CFR Part 262.34	Standards for Hazardous Waste Generators, 90-Day Accumulation Rule	ARAR
Resource Conservation and Recovery Act, 42 USC s/s 6901 et seq. (1976)	40 CFR Part 263	Standards for Transporters of Hazardous Waste	ARAR
Resource Conservation and Recovery Act, 42 USC s/s 6901 et seq. (1976)	40 CFR Part 264 and 265, Subparts	Standards for Owners/Operators of Hazardous Waste Treatment, Storage and Disposal Facilities.	ARAR
	B-264.10 - .19	B- General Facility Standards	
	F-264.90 - .101	F- Releases from Solid Waste Management Units	
	G-264.110 - .120	G- Closure and Post Closure	
	J-264.190 - .200	J- Tank Systems	
	S-264.550 - .555	S- Special Provisions for Cleanup	
	X-264.600 - .603	X- Miscellaneous Units	
Section 3004 of the Resource Conservation and Recovery Act (Solid Waste Disposal Act, as amended),	40 CFR § 264. 13(b)	Owner or operator of a facility that treats, stores or disposes of hazardous wastes must develop and follow a written waste analysis plan.	ARAR
Resource Conservation and Recovery Act, 42 USC s/s 6901 et seq. (1976)	40 CFR Part 264 and 265, Subparts	Standards for Owners/Operators of Hazardous Waste Treatment, Storage and Disposal Facilities.	ARAR
	K-264.220 - .232	K- Surface Impounds	
	L-264.250 - .259	L- Waste Piles	
	N – 264.300 - .317	N- Landfills, Subtitle C	
Section 3004 of the Resource Conservation and Recovery Act, as amended, 42 USC § 6924	40 CFR § 264.232	Owners and operators shall manage all hazardous waste placed in a surface impoundment in accordance with 40 CFR Subparts BB (Air Emission Standards for Equipment Leaks) and CC (Air Emission Standards for Tanks, Surface Impoundments and Containers).	ARAR
Resource Conservation and Recovery Act, 42 USC s/s 6901 et seq. (1976)	40 CFR Part 268	Land disposal restrictions C- Prohibitions on Land Disposal	ARAR

Table 3-3
Action-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
Hazardous Materials Transportation Act, as amended, 49 USC §§ 5101 – 5127	49 CFR Part 170	Transport of hazardous materials program procedures.	ARAR
Hazardous Materials Transportation Act, as amended, 49 USC §§ 5101 – 5127	49 CFR Part 171	Department of Transportation Rules for Transportation of Hazardous Materials, including procedures for the packaging, labeling, manifesting and transporting of hazardous materials.	ARAR
Occupational Safety and Health Act	29CFR 1904, 1910, and 1926	Specifies minimum requirements to maintain worker health and safety during hazardous waste operations, including training and construction safety requirements.	ARAR
Control of Erosion and Sedimentation (Georgia & Glynn County)	O.C.G.A. 12-7-1 391-3-7 Glynn County Code, Section 2-5-100	Establishes a statewide comprehensive soil erosion and sedimentation control program to be administered by local issuing authorities	ARAR
Air Pollution Control Act (Georgia)	O.C.G.A. 12-9-1 391-3-1	Provides regulations pertaining to control of air pollution and emissions. May have specific regarding odor thresholds or particulate matter	ARAR
Clean Water Act, Section 402	33 USC §§ 1251- 1387 40 CFR 122, 125 & 401	Authorizes issuance of a permit for discharge of pollutants or combination of pollutants, not withstanding other CWA requirements. Provisions related to the implementation of the NPDES program, including wastewater Discharge Permits; Effluent Guidelines, and Best Available Technology.	TBC
Clean Air Act Section 109	U.S.C. 7409 40 CFR Part 50	Clean Air Act, National Ambient Air Quality Standards	TBC
Water Quality Control Act (Georgia) NPDES Program	O.C.G.A. 12-5-30 391-3-6.06	Specifies requirements for issuing NPDES permits associated with a discharge of pollutants into waters of the State	TBC
Hazardous Waste Management Act & Hazardous Sites Response Act (Georgia)	O.C.G.A. 12-8-60 O.C.G.A. 12-8-90 O.C.G.A. 12-8-200 391-3-.04	Requires owner to report and remediate a release of a regulated substance to soil or groundwater	TBC
USEPA Rules of Thumb for Superfund Remedy Selection	EPA 540-R-97- 013, August 1997	Describes key principles and expectations, as well as "best practices" based on program experience for the remedy selection process under Superfund. Major policy areas covered are risk assessment and risk management, developing remedial alternatives, and groundwater response actions.	TBC

Table 3-3
Action-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
USEPA Land Use in the CERCLA Remedy Selection Process	OSWER Directive No. 9355.7-04, May 1995	Presents information for considering land use in making remedy selection decisions at NPL sites.	TBC
USEPA Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites	OSWER Directive 9285.6-08, February 2002	Presents risk management principles that site managers should consider when making risk management decisions at contaminated sediment sites.	TBC
USEPA Ecological Risk Assessment and Risk Management Principles	OSWER Directive 9285.7-28P, USEPA	Presents risk management principles that site managers should consider when making risk management decisions at contaminated sediment sites. Specific to consider the ecological impacts.	TBC
USEPA Contaminated Sediment Strategy	EPA-823-R-98- 001, April 1998	Establishes an Agency-wide strategy for contaminated sediments, with the following four goals: 1) prevent the volume of contaminated sediments from increasing; 2) reduce the volume of existing contaminated sediment; 3) ensure that sediment dredging and dredged material disposal are managed in an environmentally sound manner; and 4) develop scientifically sound sediment management tools for use in pollution prevention, source control, remediation, and dredged material management.	TBC
USEPA Contaminated Sediment Remediation Guidance for Hazardous Waste Sites	EPA-540-R-05-012, December 2005	Provides technical and policy guidance for addressing contaminated sediment sites nationwide primarily associated with CERCLA actions.	TBC
USEPA Five-Year Review Guidance	Structure and Components of Five-Year Reviews (OSWER Directive 9355.7-02, May 1991) Supplemental Five-Year Review Guidance (OSWER Directive 9355.7-02A, July 1994) Second Supplemental Five-Year Review Guidance (OSWER 9355.7-03A, December 1995)	Provides guidance on conducting Five-Year Reviews for sites at which hazardous substances, pollutants, or contaminants remain on-site above levels that allow for unrestricted use and unlimited exposure. The purpose of the Five-Year Review is to evaluate whether the selected response action continues to be protective of public health and the environment and is functioning as designed:	TBC
USEPA Remedial Design/Remedial Action Handbook	USEPA 540-R-95-059, OSWER Directive 9355.0-4B	General reference manual that provides remedial project managers with an overview of the remedial design and remedial action processes.	TBC
USEPA Area of Contamination Policy	OSWER Directive 9347.3-05FS	Guidance outlines the process used to determine whether RCRA land disposal restrictions established under the Hazardous and Solid Waste Amendments are "applicable" to a CERCLA response action.	TBC
USEPA Off-site Disposal Policy	OSWER Directive 9834.11a	The off-site policy describes procedures that should be observed when a response action under CERCLA involves off-site storage, treatment, or disposal of CERCLA waste.	TBC

Table 3-3
Action-Specific ARARs and TBC Items
LCP Chemical, Brunswick, GA

Requirement	Citation (Statutory & Regulatory)	Requirement Synopsis	Status for LCP Brunswick OU1
USEPA Policy on Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action and	OSWER Directive 9200.4-17, April 1999	Clarifies USEPA's policy regarding the use of monitored natural attenuation for the cleanup of contaminated soil and groundwater.	TBC
USEPA Region 4 Clean and Green Policy	USEPA Region 4 Memorandum, 2/17/2010	Memo defines USEPA Region 4's policy to enhance environmental benefits of federal cleanup programs by promoting technologies and practices that are sustainable.	TBC

ARAR	Applicable or relevant and appropriate requirement.
BMPPT	Best management practices with preferred technologies.
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act.
CWA	Clean Water Act.
NPDES	National Pollutant Discharge Elimination System.
NPL	National Priority List.
RCRA	Resource Conservation and Recovery Act.
TBC	To be considered.
TSCA	Toxic Substances Control Act.
USEPA	United States Environmental Protection Agency.

Table 3-4
Fish Consumption Advisories for Turtle River/Brunswick Estuary over Time
LCP Chemicals, Brunswick, GA

Values in table correspond to # meals allowable per month (a).

	Purvis & Gibson Creeks (Zones H and I)			Middle Turtle River (Zone D)			Upper Turtle and Buffalo Rivers (Zones A, B, and C)			Lower Turtle and S. Brunswick Rivers (Zones E, F, and G)		
Species	1997 Survey	2002 Survey	**2011 Survey**	1997 Survey	2002 Survey	**2011 Survey**	1997 Survey	2002 Survey	**2011 Survey**	1997 Survey	2002 Survey	**2011 Survey**
Atlantic Croaker	0	0	0	1	1	1	1	1	1	4	1	1
Black Drum	0	→ 1	1	1	1	→ 4	0	1	→ 4	1	→ 4	4
Blue Crab	0	1	→ 4	1	1	→ 4	4	4	4	4	4	NR
Red Drum	0	4	4	1	→ 4	4	4	4	4	NR	4	→ NR
Sheepshead	NC	1	1	NC	1	1	NC	1	→ 4	NC	4	→ NR
Southern Flounder	0	→ 4	4	4	4	4	4	4	→ NR	NR	NR	NR
Southern Kingfish	NC	1	1	NC	1	1	NC	1	1	NC	1	→ 4
Spot	NC	1	1	NC	0	0	NC	1	1	NC	1	1
Spotted Seatrout	0	→ 1	1	1	1	1	1	→ 4	1	1	→ 4	4
Striped Mullet	NC	0	→ 4	NC	0	→ 1	NC	0	→ 4	NC	1	→ NR
Penaeid Shrimp	0	1	→ NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Notes:

FCG	Fish consumption guidelines.	(a)	GADNR 2012.
NC	Species not collected (no FCG).		
NR	No restrictions to consumption.		

		→	Arrow denotes improvement from one survey period to another.
Summary: 2002	11 cases show improvement. 2 cases more restrictive.	🟩	Green highlight denotes where FCG improved from previous survey event.
		🟧	Orange highlight denotes where FCG worsened from previous survey event.
2011	15 cases show improvement. 1 case more restrictive.	🟨	Yellow highlight denotes where data shows improvement but previous FCG. Is carried forward due to insufficient number of fishes caught.

Table 3-5
Mercury and Aroclor 1268 SWACs
LCP Chemicals, Brunswick, GA

Domain	Domain Area (acres)	Current SWAC (mg/kg)	Post-Remediation SWAC (mg/kg)		
			SMA 1	SMA 2	SMA 3
Mercury					
Dillon Duck	1.8	1.4	0.3	0.3	0.3
Domain 1	21.0	5.1	0.6	1.6	1.1
Domain 2	114.6	2.5	0.9	1.3	1.3
Domain 3	107.7	1.7	1.5	1.7	1.7
Domain 4 East	191.9	2.0	2.0	2.0	2.0
Domain 4 West	224.5	0.7	0.7	0.7	0.7
Total Domains	**661.5**	**1.7**	**1.2**	**1.4**	**1.3**
Domain 3 Creek	12.4	5.9	1.0	3.7	3.7
Eastern Creek	4.2	14.6	0.3	0.3	0.3
LCP Ditch	2.5	7.7	0.3	0.4	0.4
Purvis Creek	70.5	1.2	0.9	1.2	1.1
Western Creek Complex	9.0	2.1	1.2	2.1	2.1
Total Creek	**98.5**	**2.6**	**0.9**	**1.5**	**1.4**
Mercury Total Estuary	**760.0**	**1.8**	**1.2**	**1.4**	**1.4**
Aroclor 1268					
Dillon Duck	1.8	2.1	0.2	0.2	0.2
Domain 1	21.0	3.1	0.6	1.2	0.9
Domain 2	114.6	1.9	1.4	1.5	1.5
Domain 3	107.7	1.7	1.5	1.7	1.7
Domain 4 East	191.9	2.1	2.1	2.1	2.1
Domain 4 West	224.5	0.8	0.8	0.8	0.8
Total Domains	**661.5**	**1.6**	**1.4**	**1.5**	**1.4**
Domain 3 Creek	12.4	5.7	1.1	3.4	3.4
Eastern Creek	4.2	43.5	0.2	0.2	0.2
LCP Ditch	2.5	25.4	0.2	0.3	0.3
Purvis Creek	70.5	3.6	1.7	3.6	2.7
Western Creek Complex	9.0	3.0	1.7	3.0	3.0
Total Creeks	**98.5**	**6.0**	**1.6**	**3.3**	**2.7**
Aroclor 1268 Total Estuary	**760.0**	**2.2**	**1.4**	**1.7**	**1.6**

mg/kg	Milligram(s) per kilogram.
No Action	Remedy alternative 1.
SMA-1	Remedy alternatives 2 and 3.
SMA-2	Remedy alternatives 4 and 5.
SMA-3	Remedy alternatives 6.
SWAC	Surface-weighted average concentrations.

Table 5-1
Summary of Remedial Footprints
LCP Chemicals, Brunswick, GA

Remedial Area	Remedy Alternative 2 - Sediment Removal in SMA-1	Remedy Alternative 3 - Sediment Removal, Capping, and Thin Cover in SMA-1	Remedy Alternative 4 - Sediment Removal in SMA-2	Remedy Alternative 5 - Sediment Removal, Capping, and Thin Cover in SMA-2	Remedy Alternative 5 - Sediment Removal, Capping, and Thin Cover in SMA-3
Purvis Creek	Dredge (10)	Cap (10)	--	--	Cap (3.0)
Western Creek	Dredge (1.5)	Dredge (1.5)	--	--	--
Eastern Creek	Dredge (4.3)	Dredge (4.3)	Dredge (4.3)	Dredge (4.3)	Dredge (4.3)
LCP Ditch	Dredge (2.4)	Dredge (2.4)	Dredge (2.2)	Dredge (2.2)	Dredge (2.2)
Domain 3 Creek	Dredge (6.0)	Cap (6.0)	Dredge (3.0)	Cap (3.0)	Cap (3.0)
Dillon Duck	Dredge (1.0)	Thin-cover (1.0)	Dredge (1.0)	Thin-cover (1.0)	Thin-cover (1.0)
Marsh 1a	Dredge (7.2)	Thin-cover (7.2)	Dredge (2.1)	Thin-cover (2.1)	Thin-cover (5.1)
Marsh 2	Dredge (10.6)	Thin-cover (10.6)	Dredge (5.0)	Thin-cover (5.0)	Thin-cover (5.0)
Marsh 3	Dredge (4.5)	Thin-cover (4.5)	--	--	--

(#)	Acres.
SMA-1	Remedy alternatives 2 and 3.
SMA-2	Remedy alternatives 4 and 5.
SMA-3	Remedy alternatives 6.

Table 5-2
Summary of Remedial Alternatives
LCP Chemicals, Brunswick, GA

Remedial Alternative	Remedy Description	Total Remedy Area (acres)	Sediment Removal Areas (acres)	Removal Volume (cubic yards)	Backfill Volume (cubic yards)	Capping Area (acres)	Thin Cover Area (acres)
1	No Action	0	0	0	0	0	0
2	Sediment Removal in SMA-1	48	48	153,000	96,000	0	0
3	Sediment Removal, Capping, and Thin Cover in SMA-1	48	9	27,000	17,000	16	23
4	Sediment Removal in SMA-2	18	18	57,000	36,000	0	0
5	Sediment Removal, Capping, and Thin Cover in SMA-2	18	7	22,000	14,000	3	8
6	Sediment Removal, Capping, and Thin Cover in Expanded SMA-2	24	7	22,000	14,000	6	11

No Action	Remedy alternative 1.
SMA-1	Remedy alternatives 2 and 3.
SMA-2	Remedy alternatives 4 and 5.
SMA-3	Remedy alternatives 6.

Table 6-1
Estimated Marsh Disturbance Associated with Remedy Alternatives
LCP Chemicals Brunswick, Georgia

Alternative	Remedy Footprint (Acres)	Marsh Disturbance w/in Remedy Footprint (Acres)	Marsh Disturbance Beyond Remedy Footprint (Acres)	Total Disturbance (Remedy Footprint + Beyond Remedy Footprint) (Acres)
NO ACTION				
Alternative 1	0	0	-	-
SMA-1 (48 Acres)				
Alternative 2	48	48	11	59
Alternative 3	48	48	8	56
SMA-2 (18 Acres)				
Alternative 4	18	18	11	29
Alternative 5	18	18	8	26
SMA-3 (24 Acres)				
Alternative 6	24	24	7	31

No Action	Remedy alternative 1.
SMA-1	Remedy alternatives 2 and 3.
SMA-2	Remedy alternatives 4 and 5.
SMA-3	Remedy alternatives 6.

Table 6-2
Summary of Remedial Quantities
LCP Chemicals Brunswick, Georgia

Alternative	Volume Removed (CY)	Mass of Aroclor 1268 Removed (kg)	Mass of Mercury Removed (kg)	Mass of Lead Removed (kg)	Mass of tPAH Removed (kg)
NO ACTION					
Alternative 1	--	--	--	--	--
SMA-1 (48 Acres)					
Alternative 2	153,000	1,730	1,480	15,740	160
Alternative 3	27,000	760	260	910	30
SMA-2 (18 Acres)					
Alternative 4	57,000	980	1,190	12,820	80
Alternative 5	22,000	720	240	730	20
SMA-3 (24 Acres)					
Alternative 6	22,000	720	240	730	20

CY	Cubic yards.
kg	Kilogram(s).
No Action	Remedy alternative 1.
SMA-1	Remedy alternatives 2 and 3.
SMA-2	Remedy alternatives 4 and 5.
SMA-3	Remedy alternatives 6.
tPAH	Total polycyclic aromatic hydrocarbons.

Table 6-3
Remedy Effectiveness for Human Health
LCP Chemicals, Brunswick, Georgia

Domain	SWAC RGO (a, b)	No Action SWAC (mg/kg)	Post-Remediation SWAC (mg/kg)		
			SMA 1	SMA 2	SMA 3
Mercury					
Total Domains (Marsh)	NA	1.7	1.2	1.4	1.3
Total Creek	1-2	2.6	0.9	1.5	1.4
Total Estuary	NA	1.8	1.2	1.4	1.4
Ar-1268					
Total Domains (Marsh)	NA	1.6	1.4	1.5	1.4
Total Creeks	2-4	6.0	1.6	3.3	2.7
Total Estuary	2-4	2.2	1.4	1.7	1.6

NA	Not applicable.
mg/kg	Milligram per kilogram(s).
No Action	Remedy alternative 1.
RGO	Remedial goal option(s).
SMA-1	Remedy alternatives 2 and 3.
SMA-2	Remedy alternatives 4 and 5.
SMA-3	Remedy alternatives 6.
SWAC	Surface weighted average concentration.

(a) The mercury SWAC is based on finfish exposures in the Total Creeks.

(b) The Ar1268 SWAC is based on finfish exposed to the Total Creeks and clapper rail exposed to the Total Estuary.

🟩 Indicates conditions achieve the SWAC RGO.

🟦 Noted that the SWAC RGO is achieved even though the RGO is not directly applicable because the conditions are not directly related to the human health exposures or risks.

Table 6-4
Remedy Alternative Implementation Constraints
LCP Chemicals, Brunswick, Georgia

Implementation Limitation or Constraint	Remedy Alternative 1 (0 acres)	Remedy Alternative 2 (48 acres)	Remedy Alternative 3 (48 acres)	Remedy Alternative 4 (18 acres)	Remedy Alternative 5 (18 acres)	Remedy Alternative 6 (24 acres)
General						
Water-based equipment access and production affected by tide cycles?	NA	Yes	Yes	Yes	Yes	Yes
Land-based equipment access and production affected by tide cycles?	NA	Yes	Yes	Yes	Yes	Yes
Result in temporary short-term ecological impacts to marshes not targeted for remediation?	NA	Substantial	Substantial	Moderate	Moderate	Moderate
Debris removal required for remedy implementation?	NA	Yes	Yes	Yes	Yes	Yes
Requires removal of pier remnants across Purvis Creek?	NA	Yes	Yes	Likely	Likely	Yes
Specialized or non-readily available equipment required?	NA	No	Possibly	No	Possibly	Possibly
Purvis Creek						
Implementation likely to be land-based or water-based?	NA	Water-based	Water-based	NA	NA	Water-based
Staging areas required?	NA	One	One	NA	NA	One
Improvements to the Causeway required?	NA	Possibly	Possibly	NA	NA	Possibly
Result in temporary short-term ecological impacts to marshes?	NA	Substantial	Substantial	NA	NA	Substantial
LCP Ditch and Eastern Creek						
Implementation likely to be land-based or water-based?	NA	Either	Either	Either	Either	Either
Soft sediment conditions present that could affect implementation?	NA	Yes	Yes	Yes	Yes	Yes
Improvements to the Causeway required?	NA	Possibly	Possibly	Possibly	Possibly	Possibly
Construction of temporary roads required to implement land-based remedy?	NA	Possibly	Possibly	Possibly	Possibly	Possibly
Staging areas required?	NA	One	One	One	One	One
Result in temporary short-term ecological impacts to marshes?	NA	Substantial	Substantial	Substantial	Substantial	Substantial
Western Creek						
Implementation likely to be land-based or water-based?	NA	Either	Either	NA	NA	NA
Remedial Areas isolated and discontinuous?	NA	Yes	Yes	NA	NA	NA
Access agreements required for land-based operations?	NA	Yes	Yes	NA	NA	NA
Soft sediment conditions present that could affect implementation?	NA	Yes	Yes	NA	NA	NA
Construction of temporary roads required to implement land-based remedy?	NA	Yes	Yes	NA	NA	NA
Staging areas required?	NA	No	No	NA	NA	NA
Result in temporary short-term ecological impacts to marshes?	NA	Substantial	Substantial	NA	NA	NA
Ecological impact to marshes significantly greater than remedial areas?	NA	Yes	Yes	NA	NA	NA
Domain 3 Creek						
Implementation likely to be land-based or water-based?	NA	Land-based	Land-based	Land-based	Land-based	Land-based
Access agreements required for land-based operations?	NA	Possibly	Possibly	Possibly	Possibly	Possibly
Soft sediment conditions present that could affect implementation?	NA	Yes	Yes	Yes	Yes	Yes
Construction of temporary roads required to implement land-based remedy?	NA	Yes	Yes	Yes	Yes	Yes
Staging areas required?	NA	Multiple	Multiple	Multiple	Multiple	Multiple
Result in temporary short-term ecological impacts to marshes?	NA	Substantial	Substantial	Substantial	Substantial	Substantial
Domain 1A and Domain 2 Marsh						
Implementation likely to be land-based or water-based?	NA	Land-based	Land-based	Land-based	Land-based	Land-based
Soft sediment conditions present that could affect implementation?	NA	Yes	Yes	Yes	Yes	Yes
Large Earthmoving Equipment Required?	NA	Yes	No	Yes	No	No
Construction of temporary roads required to implement land-based remedy?	NA	Yes	Possibly	Yes	Possibly	Possibly
Staging areas required?	NA	Multiple	Some	Multiple	Some	Some
Result in temporary short-term ecological impacts to marshes?	NA	Substantial	Minimal	Substantial	Minimal	Minimal

Table 6-4
Remedy Alternative Implementation Constraints
LCP Chemicals, Brunswick, Georgia

Implementation Limitation or Constraint	Remedy Alternative 1	Remedy Alternative 2	Remedy Alternative 3	Remedy Alternative 4	Remedy Alternative 5	Remedy Alternative 6
Domain 3 Marsh						
Implementation likely to be land-based or water-based?	NA	Land-based	Land-based	NA	NA	NA
Soft sediment conditions present that could affect implementation?	NA	Yes	Yes	NA	NA	NA
Large Earthmoving Equipment Required?	NA	Yes	No	NA	NA	NA
Construction of temporary roads required to implement land-based remedy?	NA	Yes	Possibly	NA	NA	NA
Staging areas required?	NA	Multiple	Some	NA	NA	NA
Result in temporary short-term ecological impacts to marshes?	NA	Substantial	Minimal	NA	NA	NA
Dillon Duck						
Implementation likely to be land-based or water-based?	NA	Land-based	Land-based	Land-based	Land-based	Land-based
Soft sediment conditions present that could affect implementation?	NA	Yes	Yes	Yes	Yes	Yes
Large Earthmoving Equipment Required?	NA	Yes	No	Yes	No	No
Construction of temporary roads required to implement land-based remedy?	NA	Yes	Yes	Yes	Yes	Yes
Staging areas required?	NA	One	One	One	One	One
Result in temporary short-term ecological impacts to marshes?	NA	Substantial	Minimal	Substantial	Minimal	Minimal

Table 6-5
Summary of Remedial Alternative Costs
LCP Chemicals, Brunswick, Georgia

Alternative		Area (Acres)	Total Estimated Indirect Costs (Present Day $MM)	Total Estimated Direct Costs (Present Day $MM)	Total Estimated Recurring Costs (Present Day $MM)	Contingency Costs ($MM)
NO ACTION						
ALT 1	**No Action**	-	$0.0	$0.0	$0.0	$0.0
SMA 1 (48 Acres)						
ALT 2	**Dredge:** All Areas	48	$8.6	$48.6	$0.4	$7.3
ALT 3	**Dredge:** LCP Ditch, Eastern Creek & Western Creek Complex	8	$5.3	$27.9	$1.4	$4.2
	Cap: Domain 3 Creek, Purvis Creek North & Purvis Creek South	16				
	Thin Cover: Domain 1A, Domain 2, Domain 3 and Dillon Duck	23				
SMA 2 (18 Acres)						
ALT 4	**Dredge:** All Areas	18	$4.9	$25.2	$0.3	$3.8
ALT 5	**Dredge:** LCP Ditch & Eastern Creek	7	$3.9	$18.9	$0.5	$2.8
	Cap: Domain 3 Creek	3				
	Thin Cover: Dillon Duck, Domain 1A & Domain 2	8				
SMA 3 (24 Acres)						
ALT 6	**Dredge:** LCP Ditch & Eastern Creek	7	$4.2	$20.7	$0.7	$3.1
	Cap: Domain 3 Creek & Purvis Creek South	6				
	Thin Cover: Dillon Duck, Domain 1A & Domain 2	11				

Note:
Recurring Costs include Operation and Maintenance (O&M) and long-term monitoring.

No Action	Remedy alternative 1.
SMA-1	Remedy alternatives 2 and 3.
SMA-2	Remedy alternatives 4 and 5.
SMA-3	Remedy alternatives 6.

Figures

Note: OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DATE: 02/26/2013

Site Location Map

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-1

PROJECT: 02-27105C

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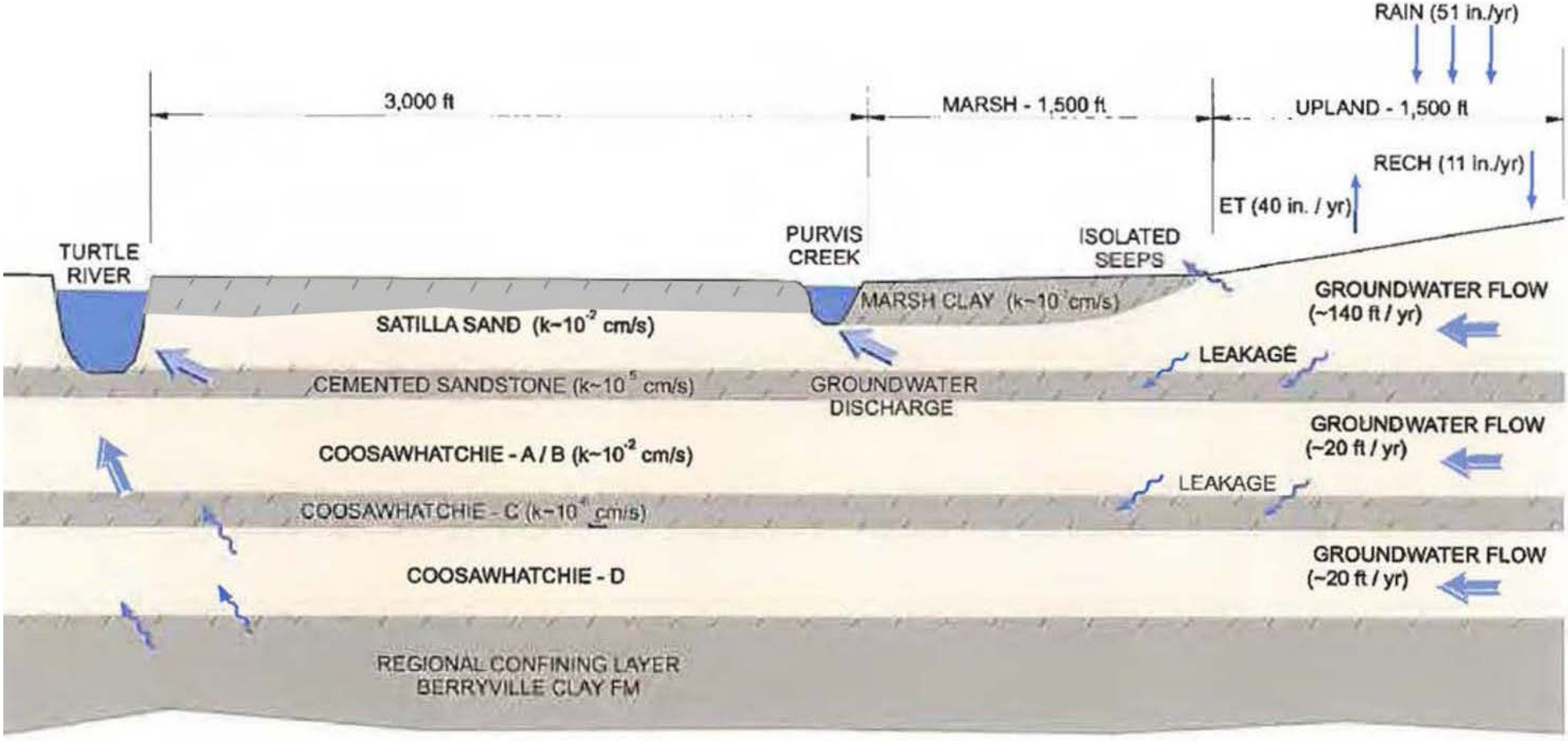

Source: Adapted from Figure 2.1.1 1997 RI Report (GeoSyntec Consultants, 1997)

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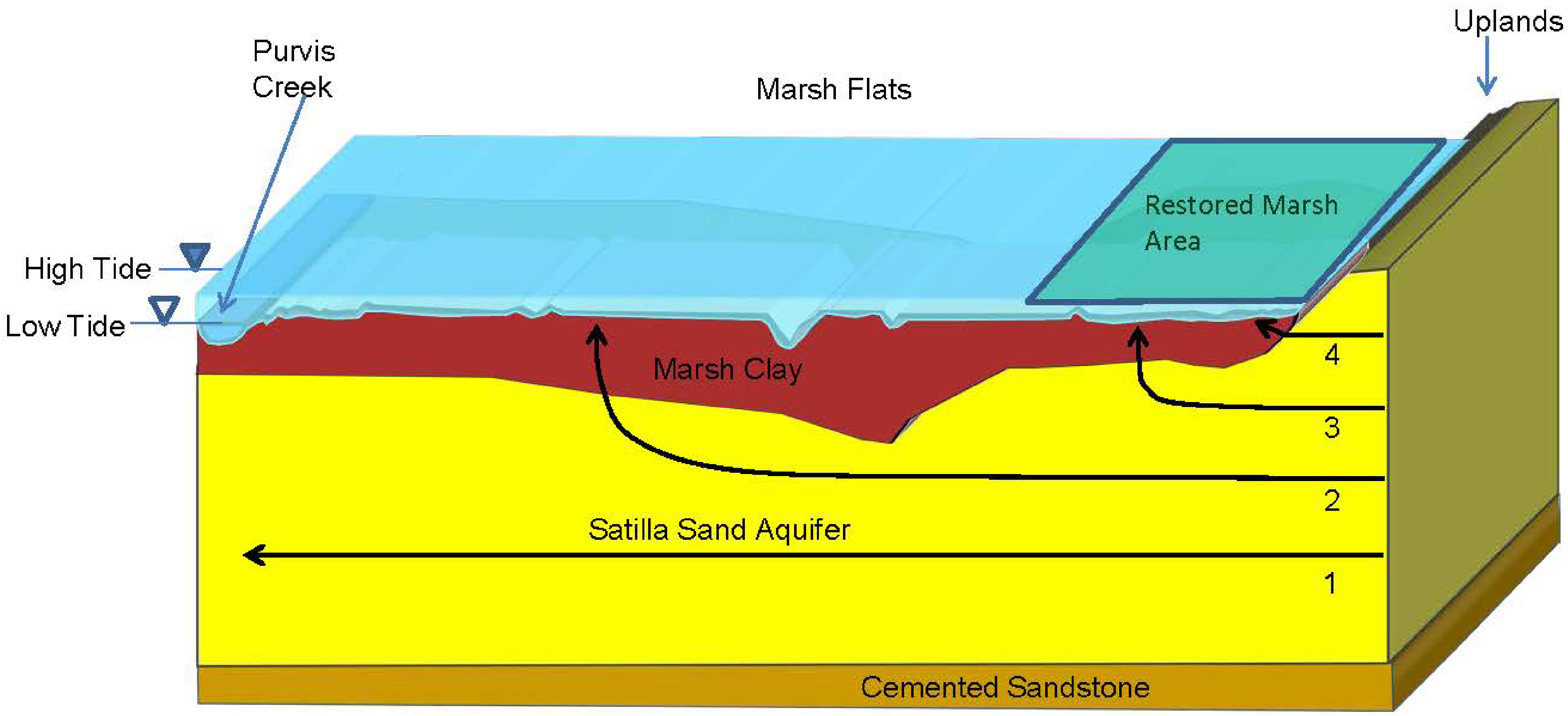
Groundwater Conceptual Site Model:
Flow Paths

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
2-2

DRAFT



1 Flow Path to Purvis Creek and Beyond
2 Flow Path to Marsh Flats and Intertidal Channels
3 Flow Path to Restored Marsh Area
4 Flow Path to Nearshore Seeps

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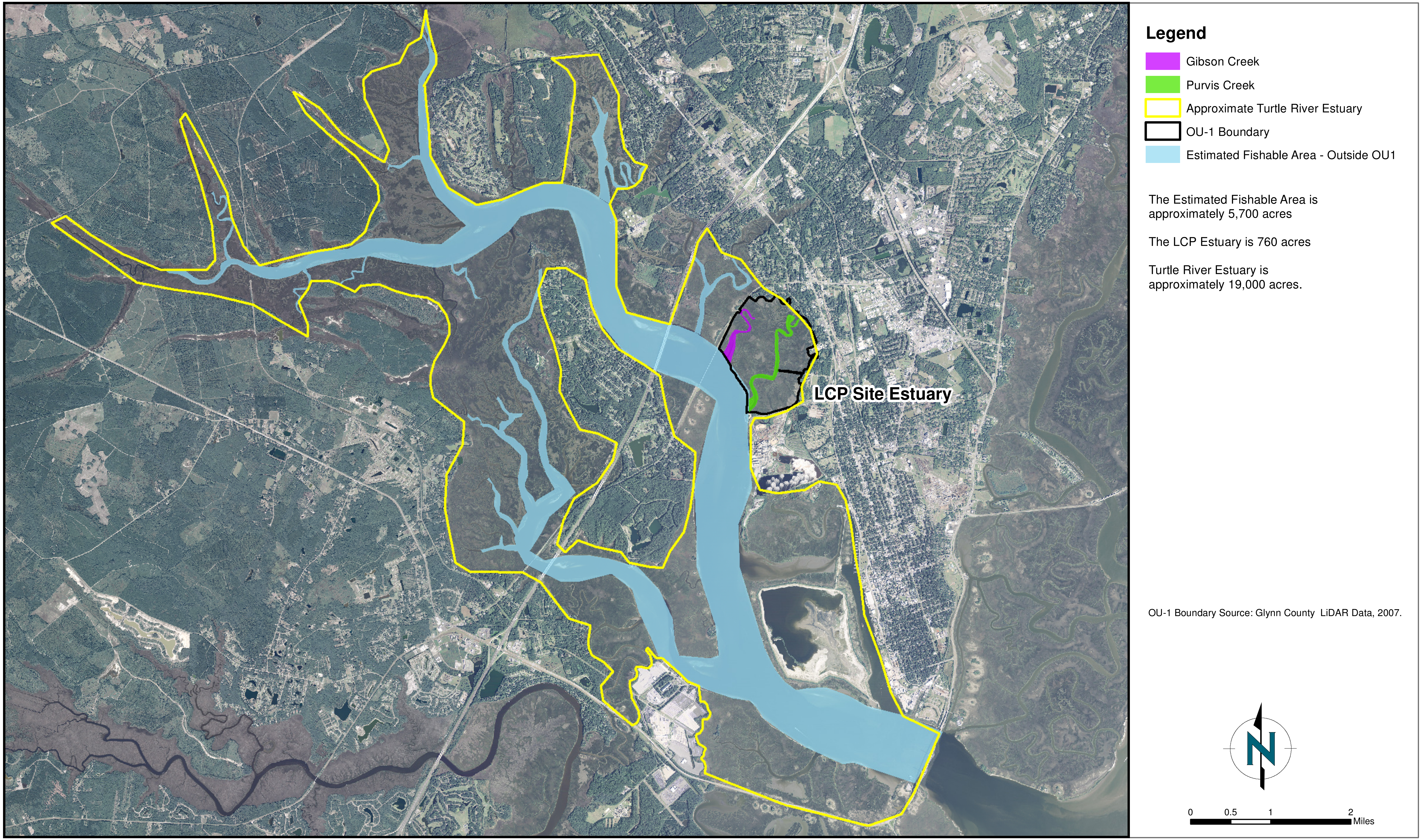
Groundwater Conceptual Site Model:
Flow Paths

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

2-3



The Estimated Fishable Area is approximately 5,700 acres

The LCP Estuary is 760 acres

Turtle River Estuary is approximately 19,000 acres.

OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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Turtle River/ Brunswick Estuary

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure 2-4

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DATE: 03/28/2013

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PROJECT: 02-27105C

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A. Domain 2

This picture is oriented southeast from the northern boundary of Domain 2 at high tide. The LCP Ditch (creek on the left) joins Eastern Creek (creek on the right) and flows west to Purvis Creek (not shown in picture). Domain 1 is in the marsh in the background, and Domain 2 is the marsh in the foreground.

.

B. Domain 2

This picture is of the location described in Figure 2-5A but at low tide.

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LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

FIGURE
2-5

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C. Domain 2

This picture is oriented north and depicts the typical marsh community at Domain 2.

D. Domain 2

This picture is oriented south. Eastern Creek is in the foreground and Domain 2 is the marsh in the background.

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LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

FIGURE
2-5

PROJECT_NO

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E. Domain 1A

This picture is oriented south. LCP Ditch is in foreground and Domain 1A is in background.

F. Domain 1

This picture is oriented south from the northern edge of Domain 1 and is a close-up of the healthy marsh ecosystem found at the site.

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LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

FIGURE
2-5

PROJECT_NO

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G. Healthy Marsh

This picture is oriented west. Purvis Creek is in the foreground and Domain 4 East is in the background.

H. Healthy Marsh

This picture is oriented north along Purvis Creek. Domain 4 East is the marsh on the left of Purvis Creek and Domain 3 is the marsh on the right. Domain 3 Creek is also visible in the background on the right.

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LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

FIGURE
2-5

PROJECT_NO

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I. Dillon Duck

This picture is representative of the western portion of the Dillon Duck area which is east of Domain 3 and in the upland area of the site.

J. Dillon Duck

This picture is representative of the southeastern portion of the Dillon Duck area which is east of Domain 3 and in the upland area of the site.

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LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

FIGURE
2-5

PROJECT_NO

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K. Epibenthic Community

This picture is a close-up of the abundant epibenthic community of fiddler crabs located at the LCP marsh.

L. Die-back Area

This picture is oriented west from the eastern portion of Domain 1, and is representative of a dieback area at the site.

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Photolog

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

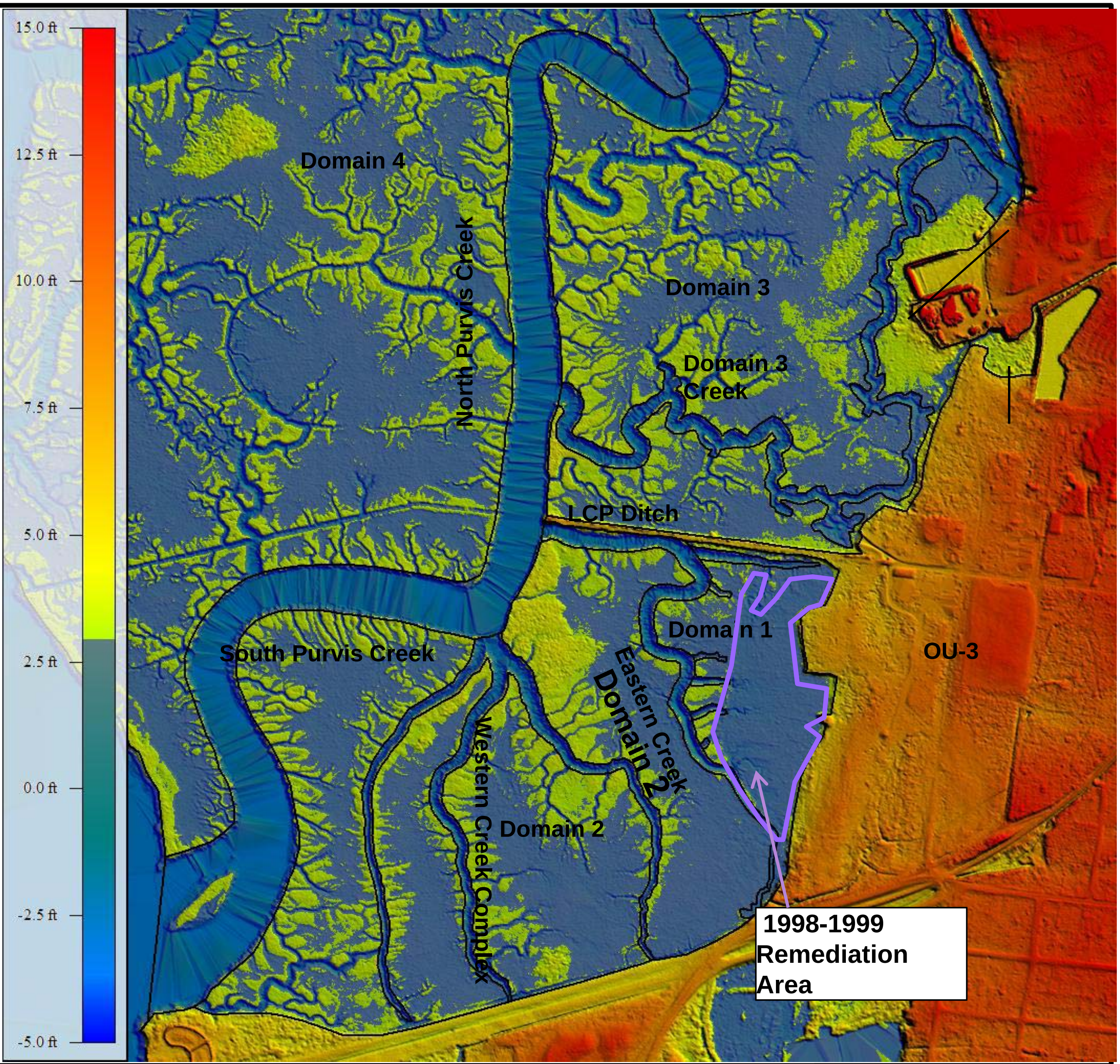
FIGURE
2-5

DRAFTED BY:

DATE: 3/27/2013

PROJECT_NO

Marsh areas in the LCP estuary are only inundated for one to five hours a day depending on the tidal cycle.



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Marsh Inundation – Mean High High Water

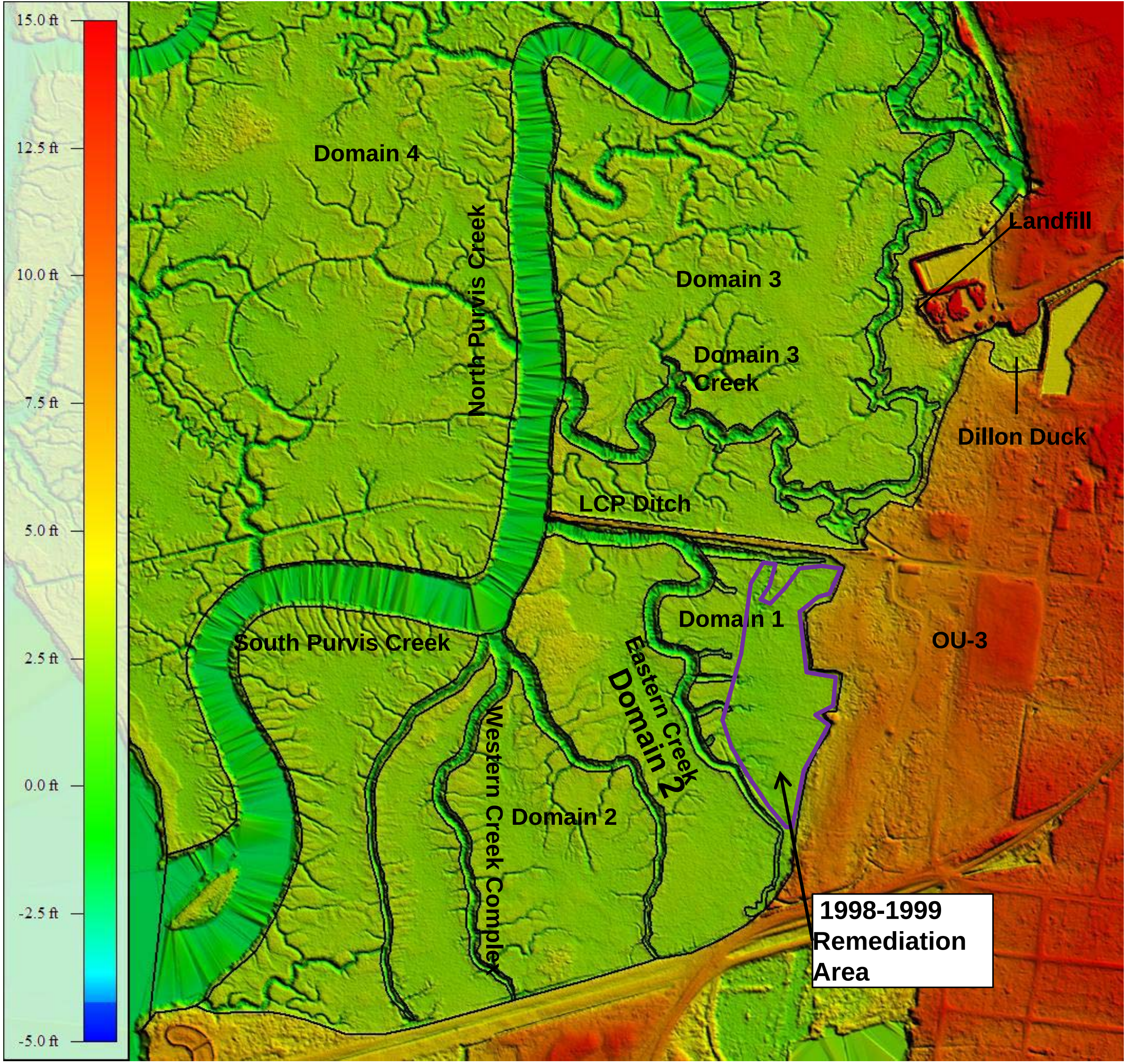
LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

2-6A

DRAFT

Marsh areas in the LCP estuary are only inundated for one to five hours a day depending on the tidal cycle.



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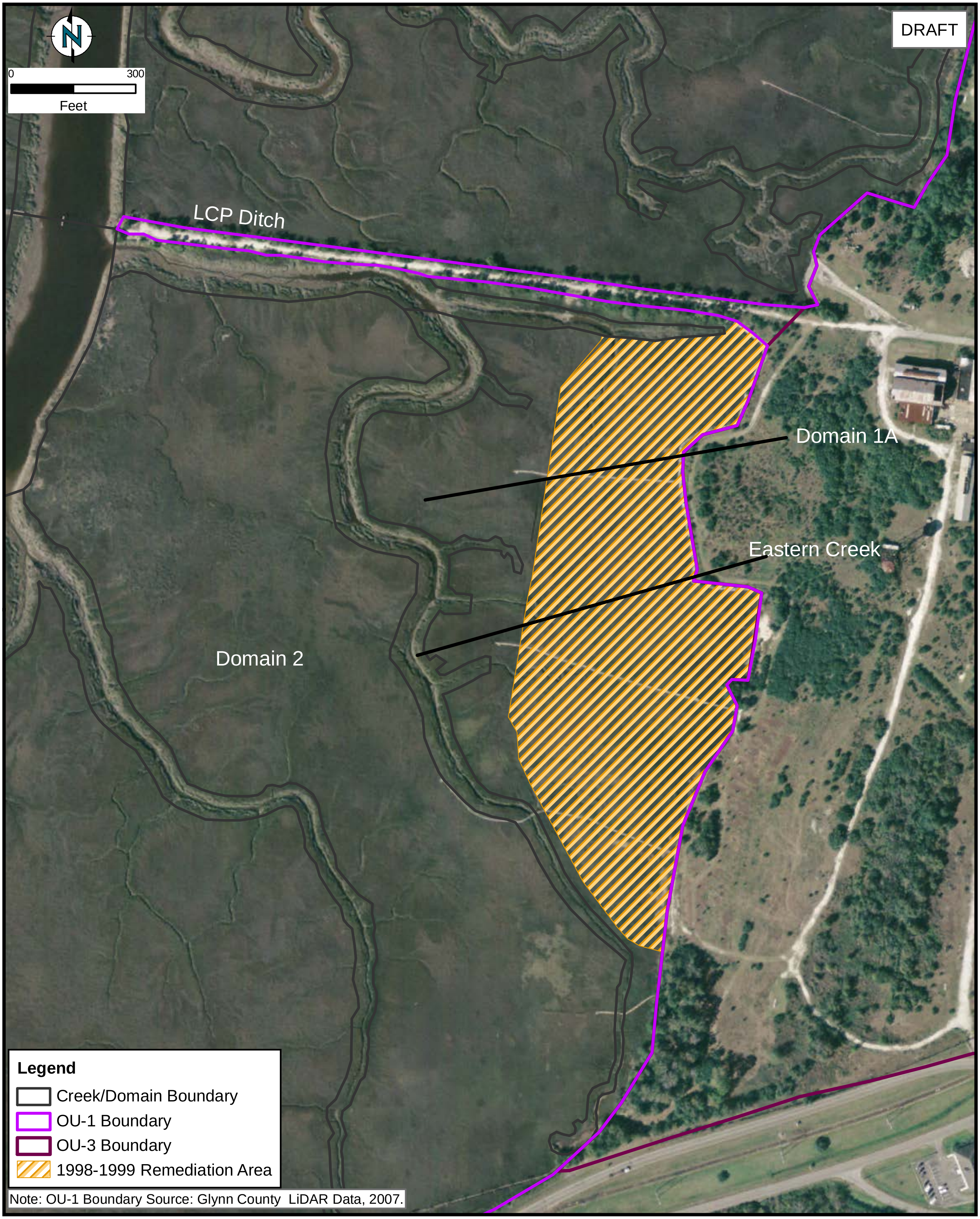
Marsh Inundation – Mean Low Low Water

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
2-6B

DRAFT



Note: OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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Approximate Extent of Remediation Area

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-7

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DATE: 03/28/2013

PROJECT: 02-27105C

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A. Initial Revegetation of Remediated Marsh Flats at the LCP Marsh

B. Aerial Photograph of Marsh Remediation Activities

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DATE: 3/28/2013

Remediation Photographs

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

FIGURE
2-8

PROJECT_NO

DRAFT

C. Revegetation of Remediated Marsh Flats at the LCP Marsh After Two Years

ENVIRON

DRAFTED BY:

DATE: 3/28/2013

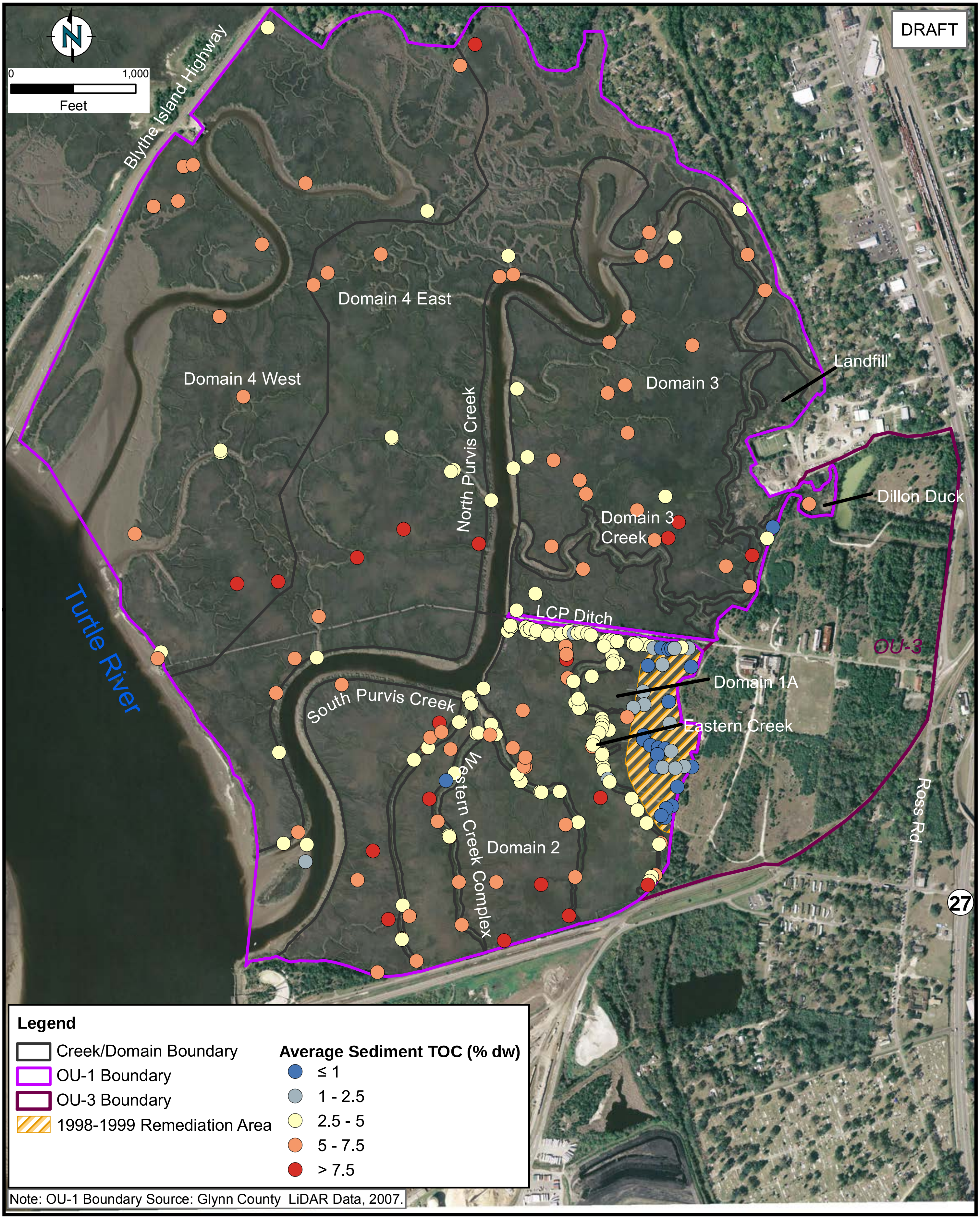
Remediation Photographs

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

FIGURE

2-8

PROJECT_NO



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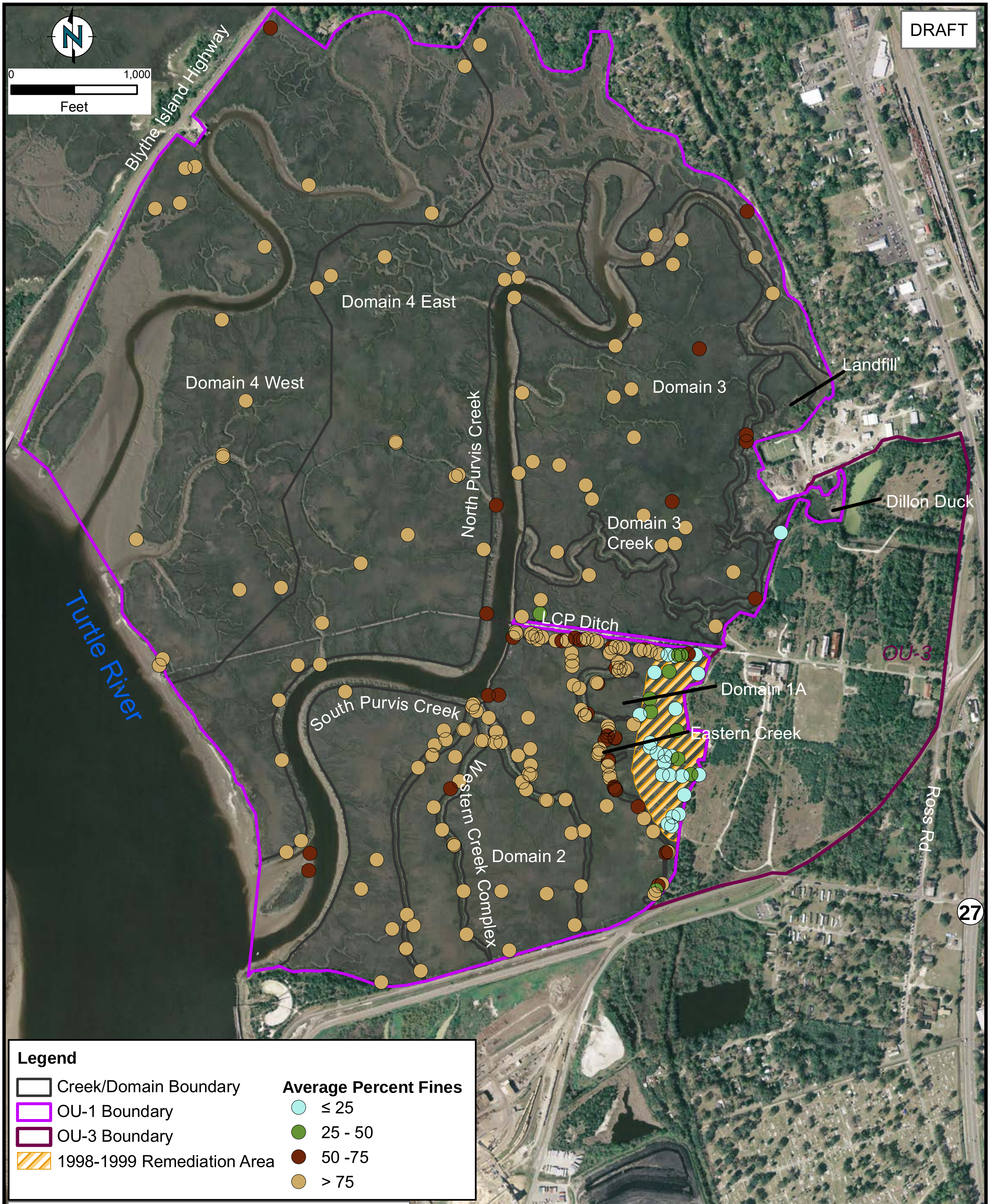
Average Total Organic Carbon in Sediments

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-9

PROJECT: 02-27105C



Note: OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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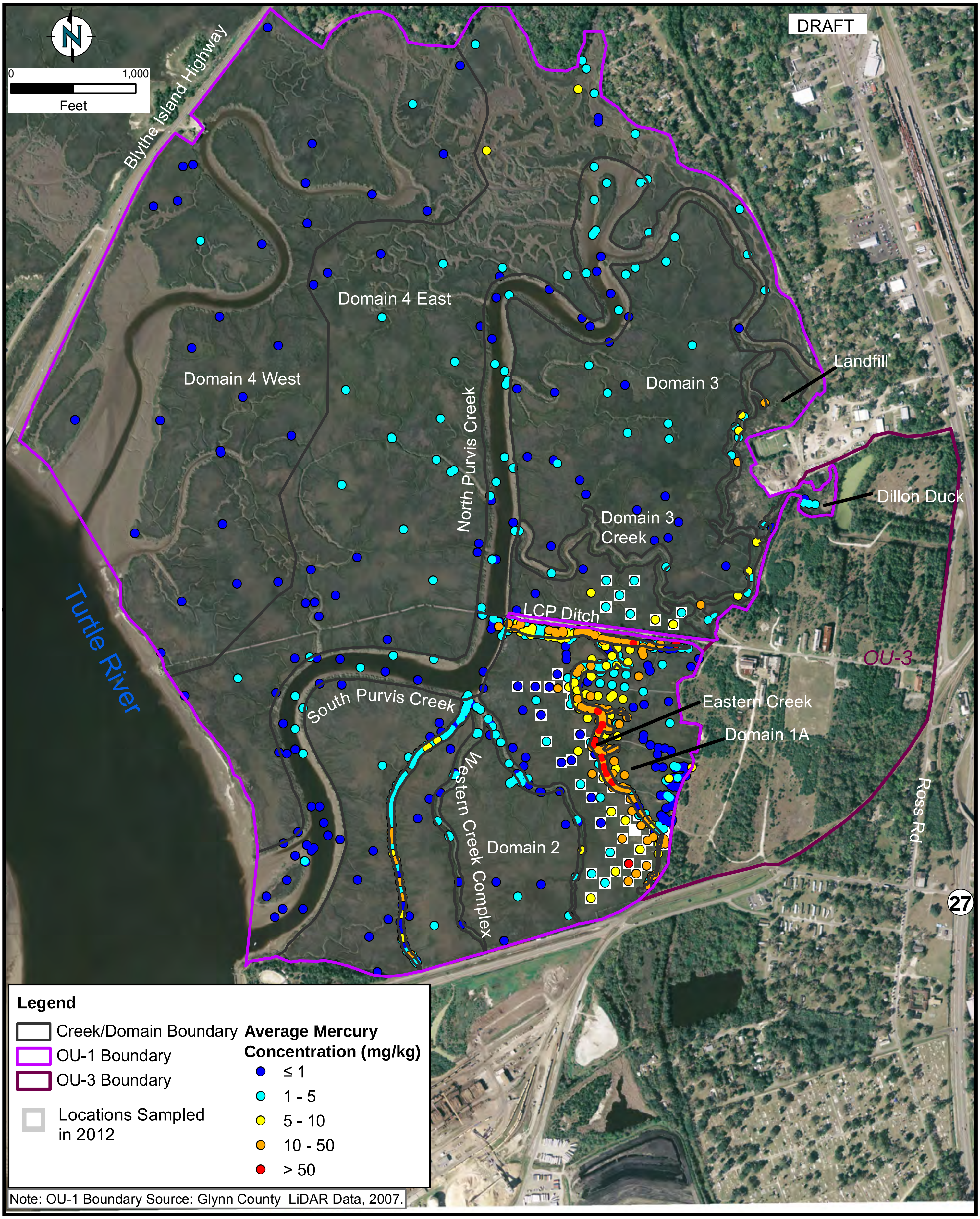
DATE: 03/28/2013

Average Percent Fines

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-10

PROJECT: 02-27105C



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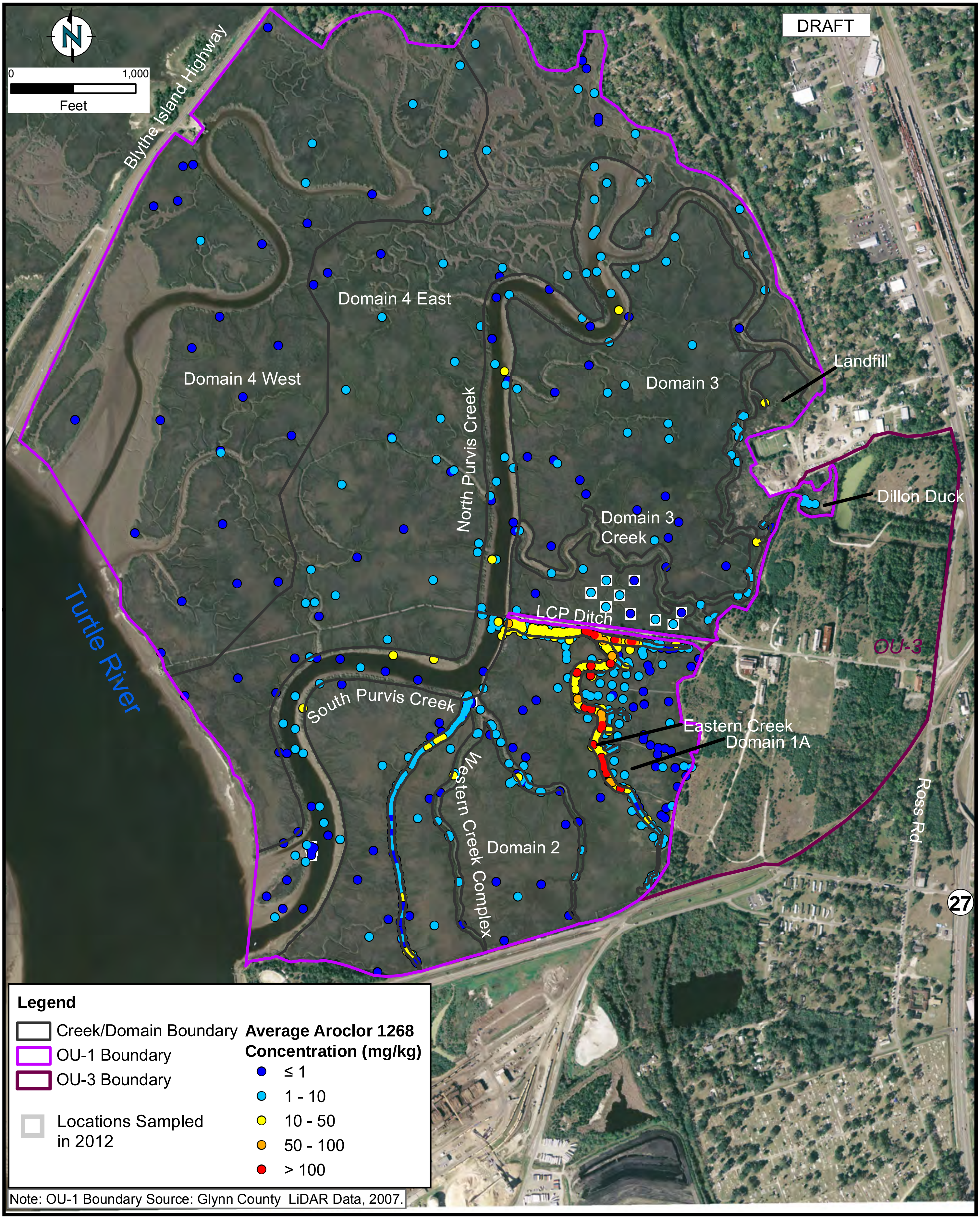
Average Mercury Concentration in OU1 Surface Sediments

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-11

PROJECT: 02-27105C



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Average Aroclor 1268 Concentration in OU1 Surface Sediments

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-12

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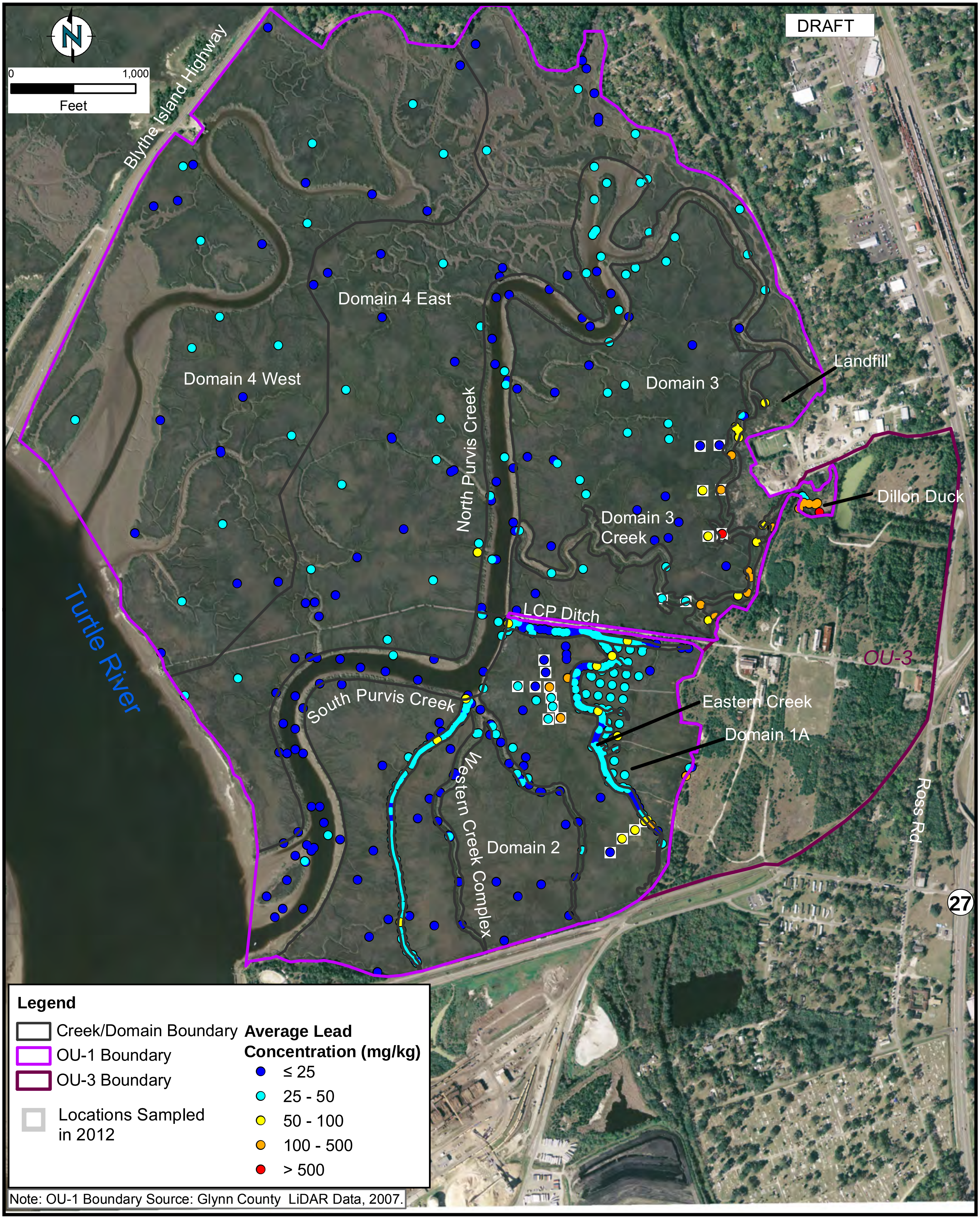
PROJECT: 02-27105C



Average Lead Concentration in OU1 Surface Sediments

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-13

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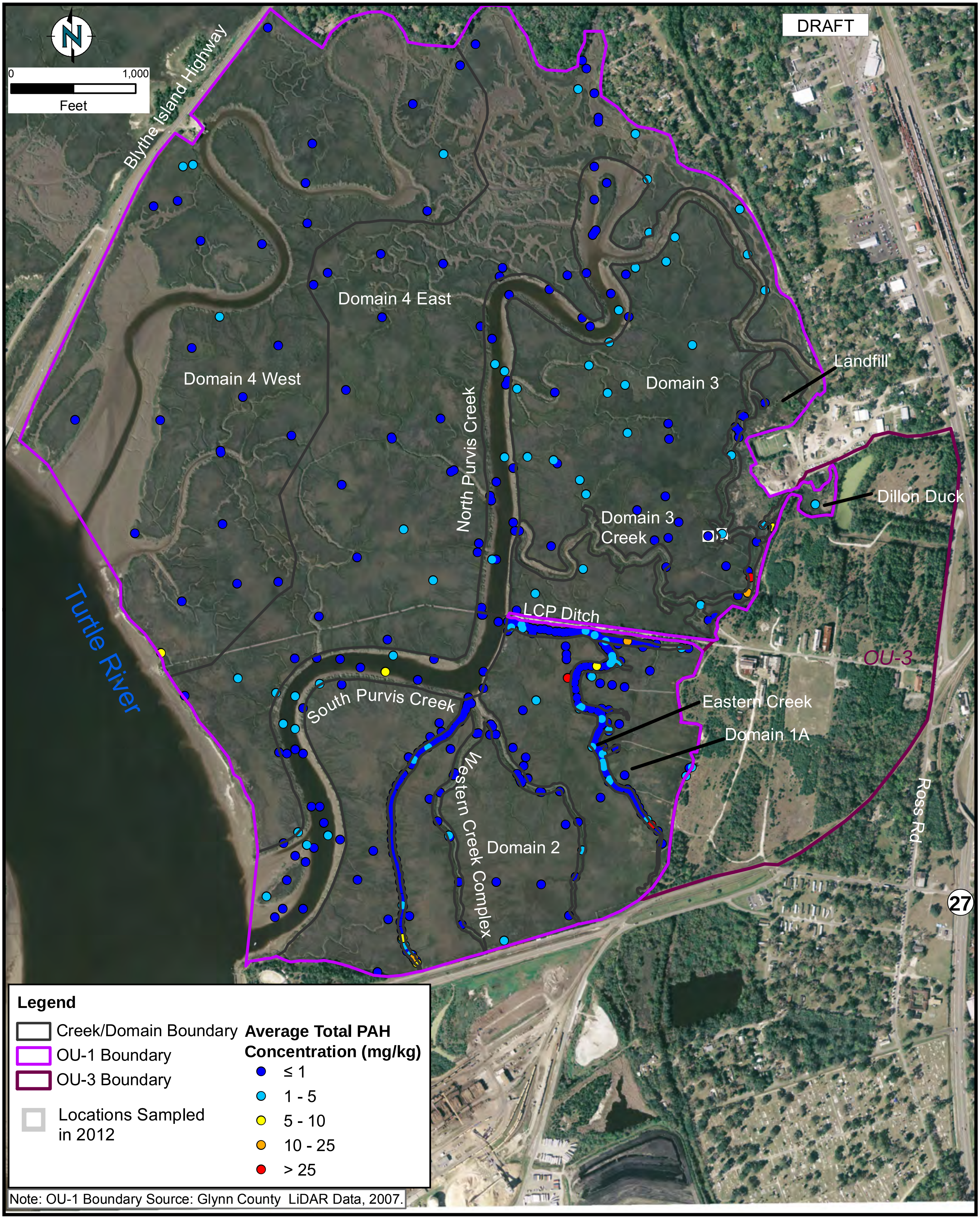

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Average Total PAH Concentration in OU1 Surface Sediments

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-14

PROJECT: 02-27105C

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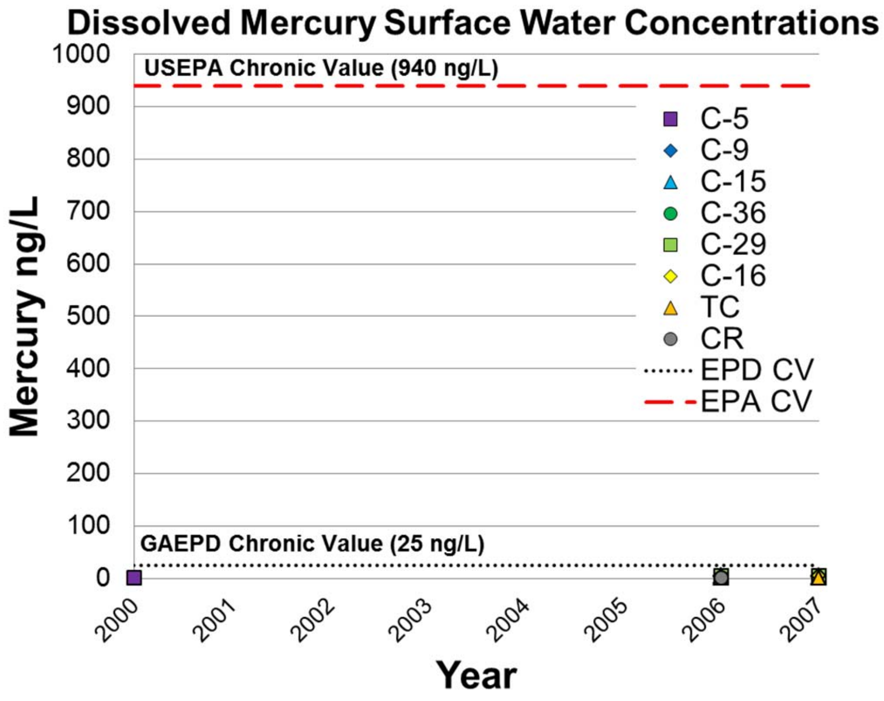

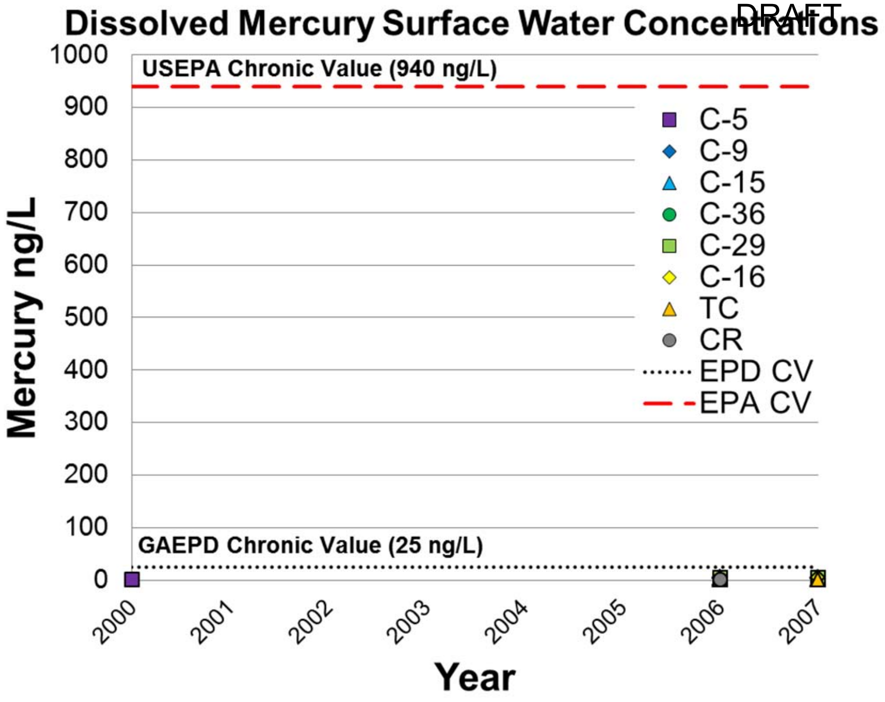

	Mouth of Main Canal	Mouth of Eastern Creek	Mouth of Western Creek	Upper Purvis Creek	Mid-Stretch Purvis Creek	Mouth of Purvis Creek	Troup Creek Control	Crescent River Control
Year	C-5	C-9	C-15	C-36	C-29	C-16	TC	CR
2000	**0.1**	0.94	0.22	0.1	10	0.2	0.036	0.012
2002	--	--	--	0.28	0.15	0.18	0.05	0.043
2003	--	--	--	1.2	1	0.61	0.012	0.012
2004	--	--	--	2.2	1.6	1.6	0.22	0.047
2005	0.59	0.22	0.89	0.35	0.36	0.25	0.088	0.008
2006	**4.4**	**5**	**3.8**	**4.6**	**3.7**	**3.4**	**1**	**0.6**
2007	**4.2**	**3.4**	**2.9**	**3.2**	**4.7**	**3.6**	**1.3**	--

1.0	Dissolved mercury concentration.
1.0	Methyl mercury concentration.
--	No data.

CR	Crescent River (Control)
GAEPD	Environmental Protection Division
ng/L	Nanogram per liter
NRWQC	National Recommended Water Quality Criteria
TC	Troup Creek (Control)
USEPA	Environmental Protection Agency

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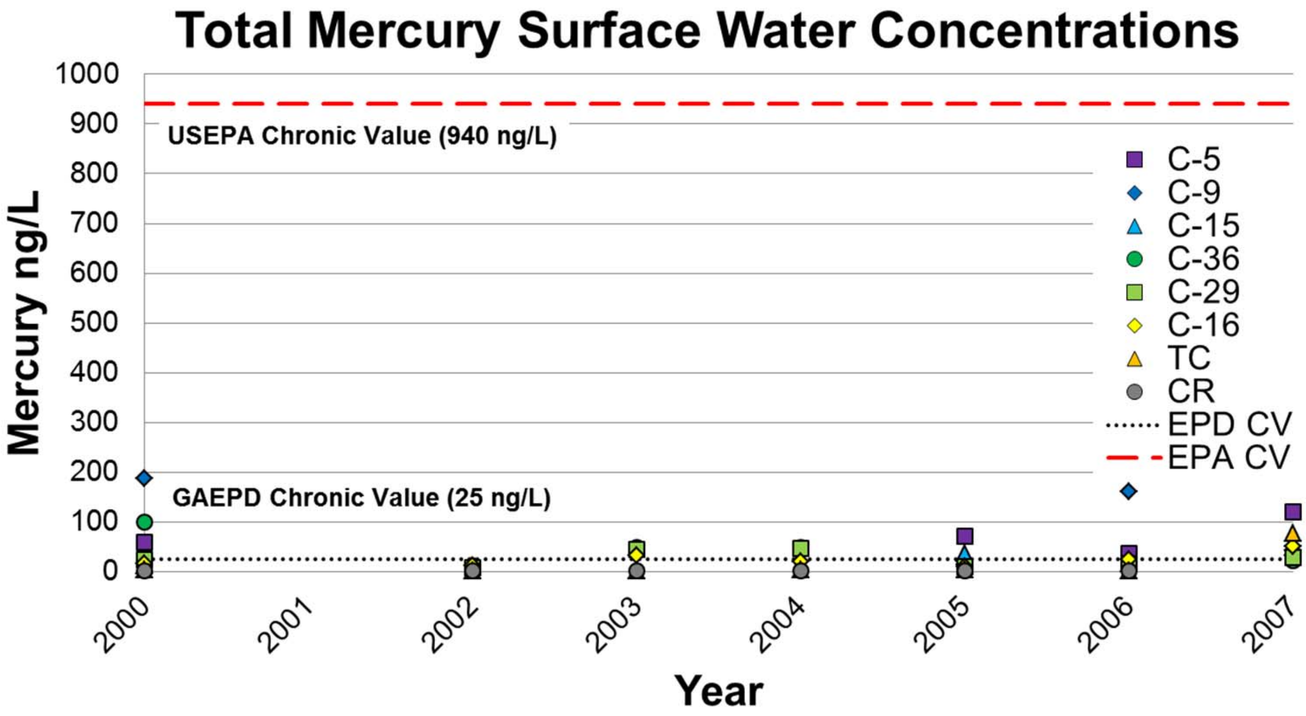
Surface Water Dissolved Total Mercury and Dissolved Methyl Mercury Compared to GA EPD and USEPA NRWQC Chronic Values

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

2-15A

DRAFT



CR	Crescent River (Control)
GAEPD	Georgia Environmental Protection Division
ng/L	Nanogram per liter
NRWQC	National Recommended Water Quality Criteria
TC	Troup Creek (Control)
USEPA	United States Environmental Protection Agency

	Mouth of Main Canal	Mouth of Eastern Creek	Mouth of Western Creek	Upper Purvis Creek	Mid-Stretch Purvis Creek	Mouth of Purvis Creek	TC Control	CR Control
Year	**C-5**	**C-9**	**C-15**	**C-36**	**C-29**	**C-16**	**TC**	**CR**
2000	**59**	**188**	12	**99**	24	16	3.3	1.7
2002	--	--	--	11	8.1	11	1.1	1.2
2003	--	--	--	**48**	**44**	**33**	2.1	1.2
2004	--	--	--	**49**	**46**	21	4.6	1.6
2005	**71**	13	**36**	8.4	9.8	9.6	4.7	1.2
2006	**37**	**160**	15	12	17	25	1.8	0.7
2007	**120**	**43**	**49**	23	**29**	**50**	**78**	--

25 Exceeds GA EPD chronic criterion of 25 ng/L.
1.0 Total mercury concentration.

Yellow highlighted cells exceed the GA EPD chronic Water Quality Standard

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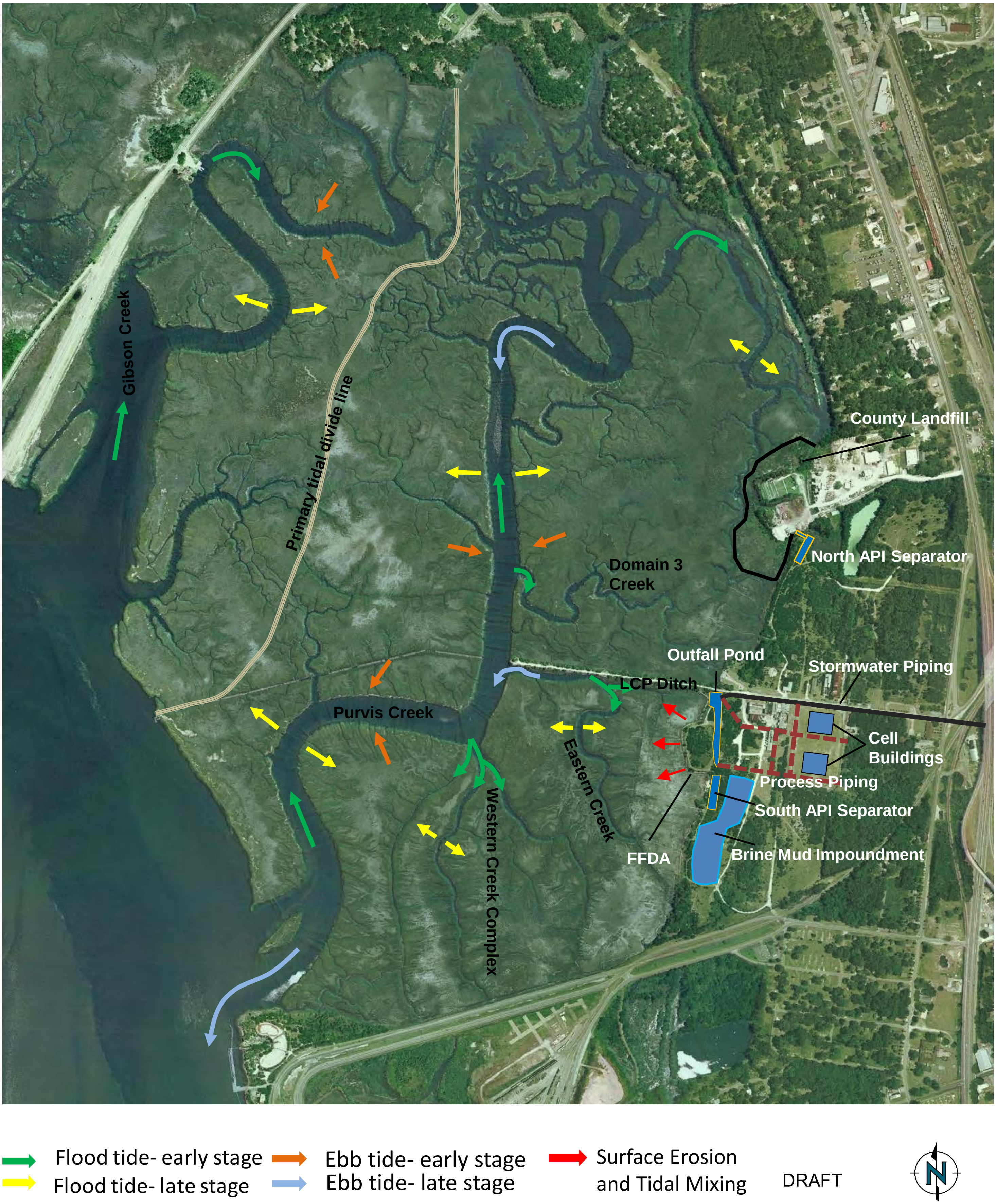
Surface Water Total Mercury Compared to GA EPD and USEPA NRWQC Chronic Values

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
2-15B



Source: Figures 2-2, 7-1 and 7-5 of the Remedial Investigation Report Operable Unit One – Estuary LCP Chemical Site (EPS and ENVIRON, October 2012)

Not to Scale

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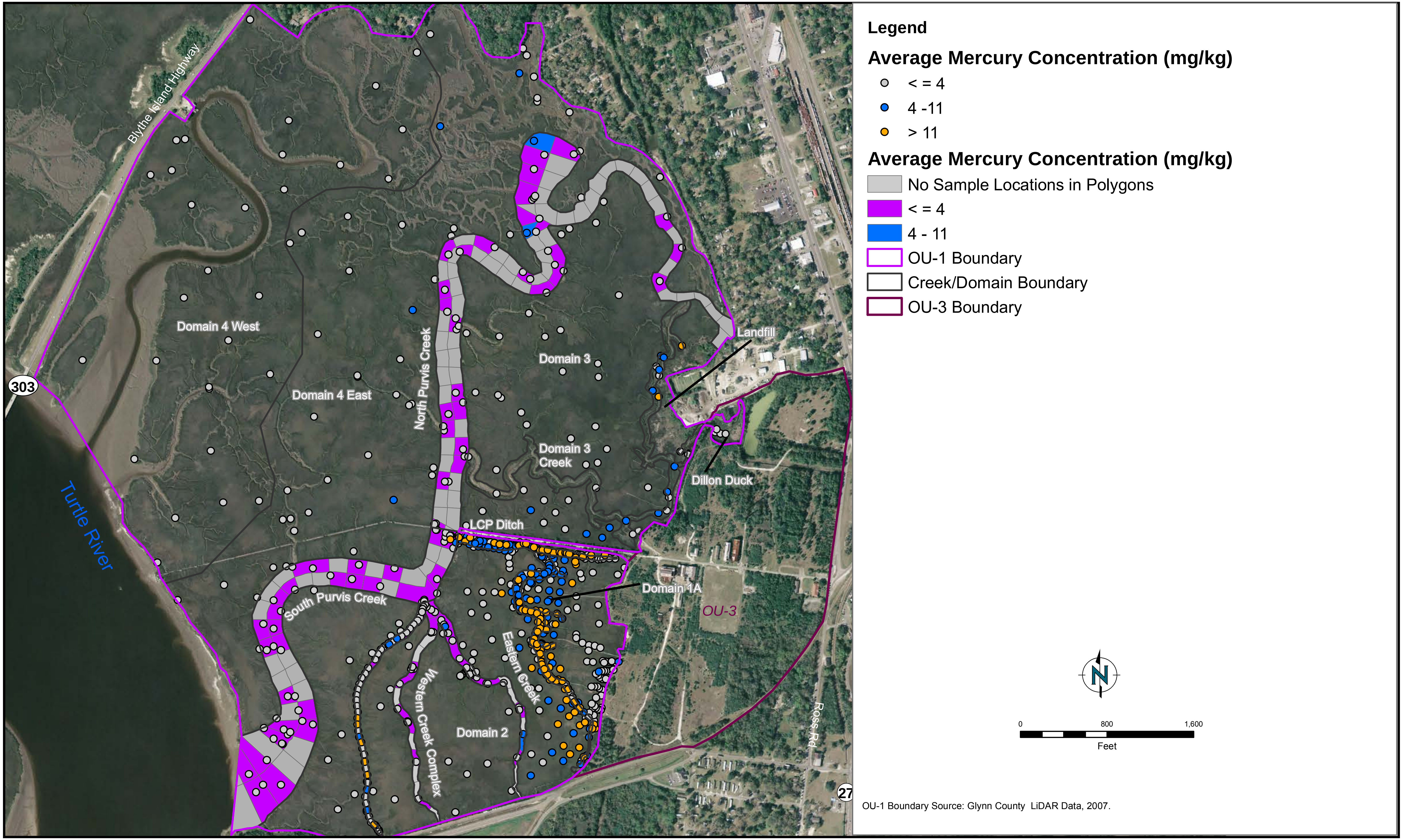
DRAFTED BY: MRJ	DATE: 2/26/2013

Source Areas and
Conceptual Site Description

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
2-16

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

DRAFTED BY: MRJ

DATE: 03/28/2013

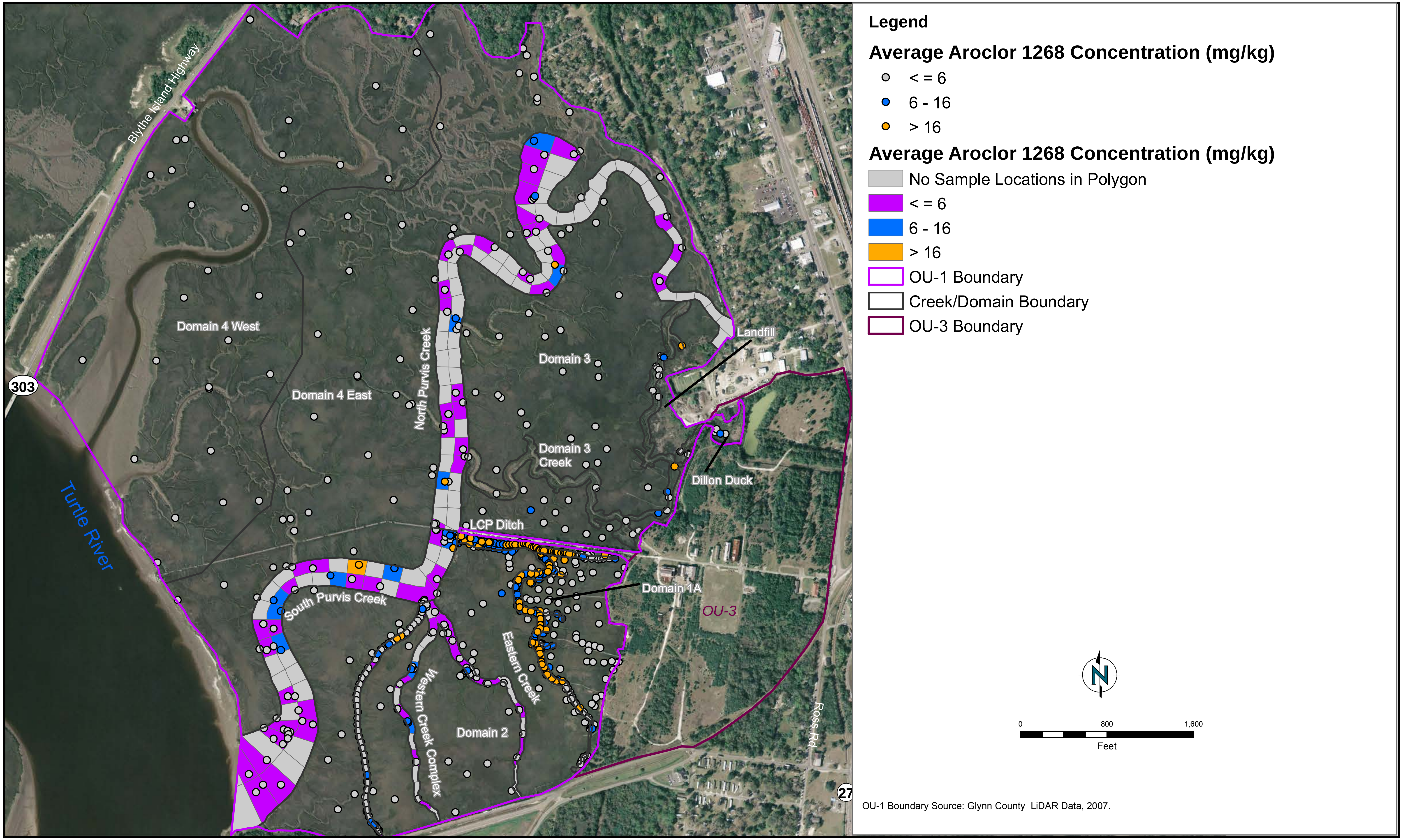
Average Mercury Concentration in OU1 Surface Sediments Compared to Benthic RGOs

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
3-1

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DATE: 03/28/2013

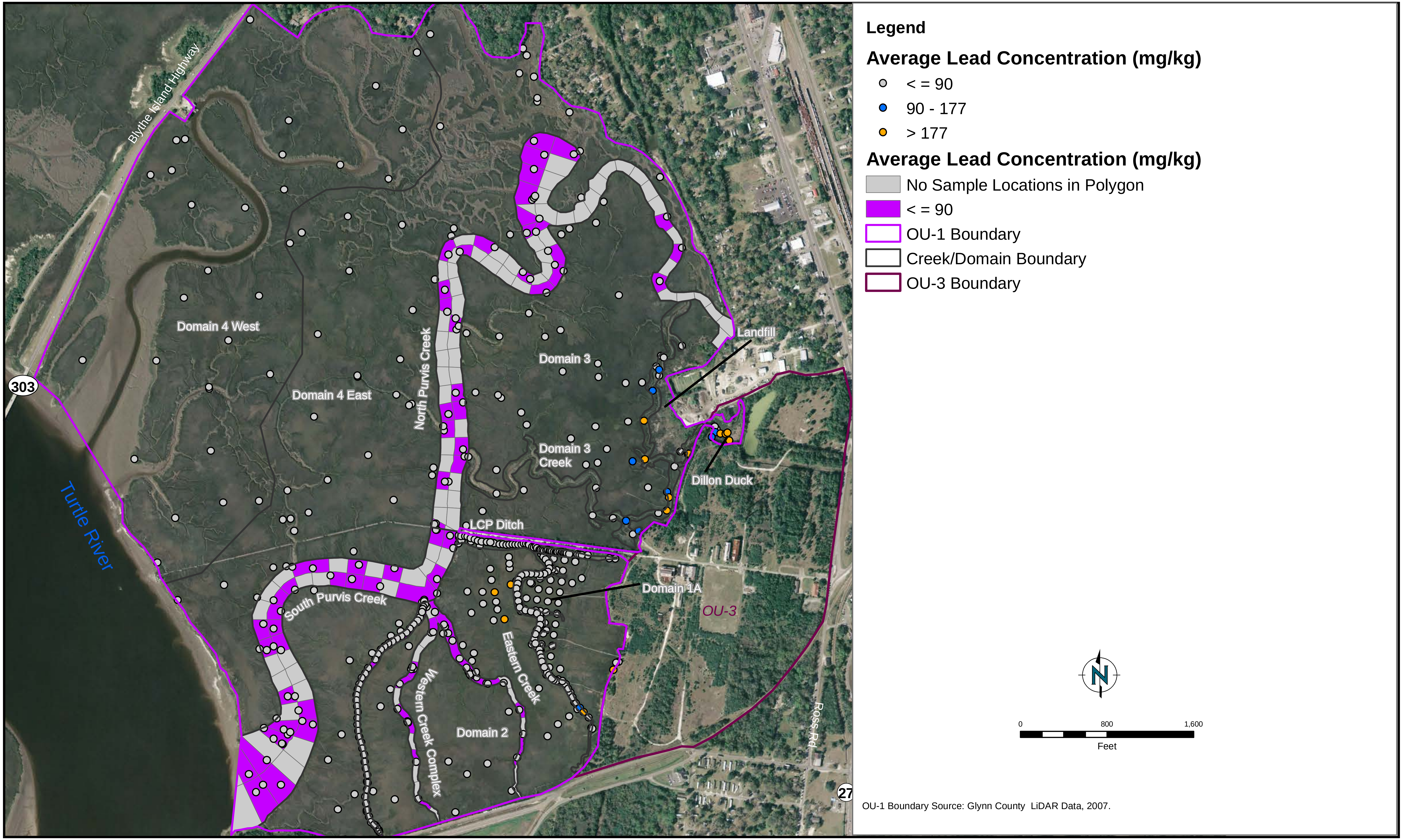
Average Aroclor 1268 Concentration in OU1 Surface Sediments Compared to Benthic RGOs

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
3-2

PROJECT: 02-27105C



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Average Lead Concentration in OU1 Surface Sediments Compared to Benthic RGOs

LCP CHEMICAL SITE
BRUNSWICK, GA

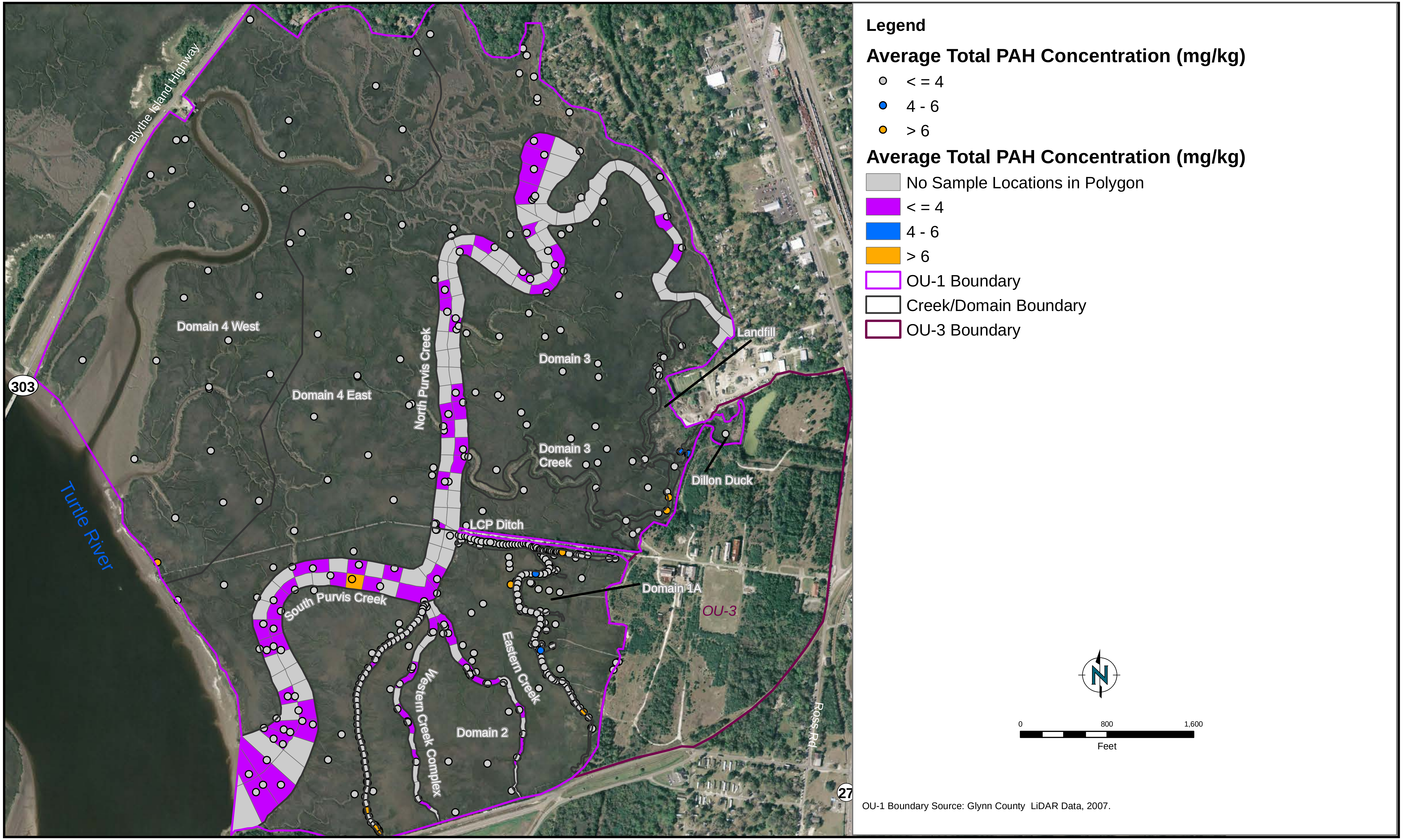
DRAFT

Figure
3-3

DRAFTED BY: MRJ

DATE: 03/28/2013

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

Average Total PAH Concentration in OU1 Surface Sediments Compared to Benthic RGOs

LCP CHEMICAL SITE
BRUNSWICK, GA

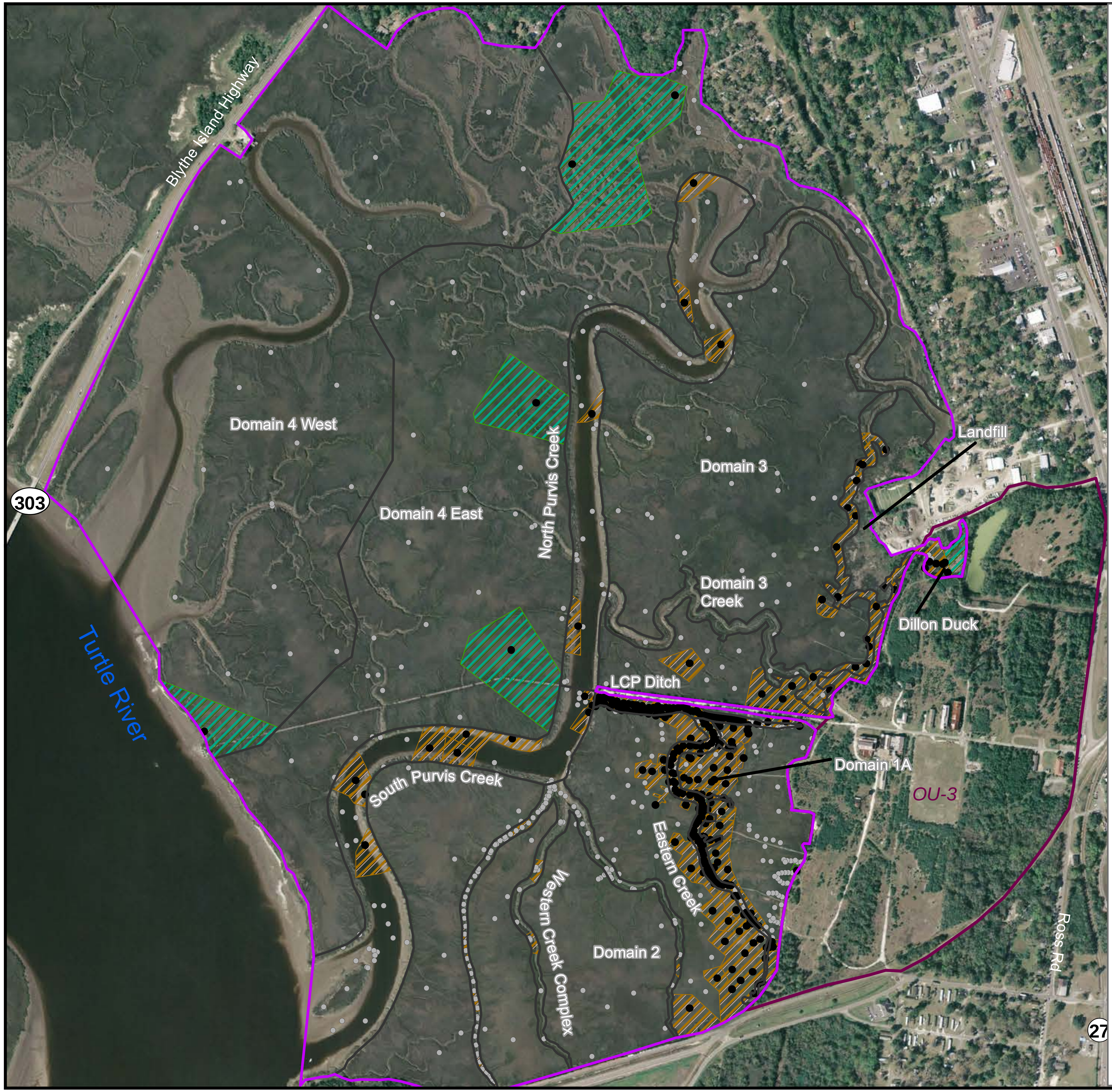
DRAFT

Figure
3-4

DRAFTED BY: MRJ

DATE: 03/28/2013

PROJECT: 02-27105C



Legend

- ● Surface Sample – Exceedance (Any Benthic Community RGO)
- ● Surface Sample – No Exceedance (Any Benthic Community RGO)
- ▨ Remediation Area (48 acres)
- ▨ Risk Management Area (33 acres)
- ☐ OU-1 Boundary
- ☐ Creek/Domain Boundary
- ☐ OU-3 Boundary

Constituent	SWAC RGOs	Benthic Community RGOs
Ar1268	2-4	6
Hg	1-2	4
TPAHs	--	4
Pb	--	90

N

0 800 1,600

Feet

OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DRAFTED BY: MRJ

DATE: 03/28/2013

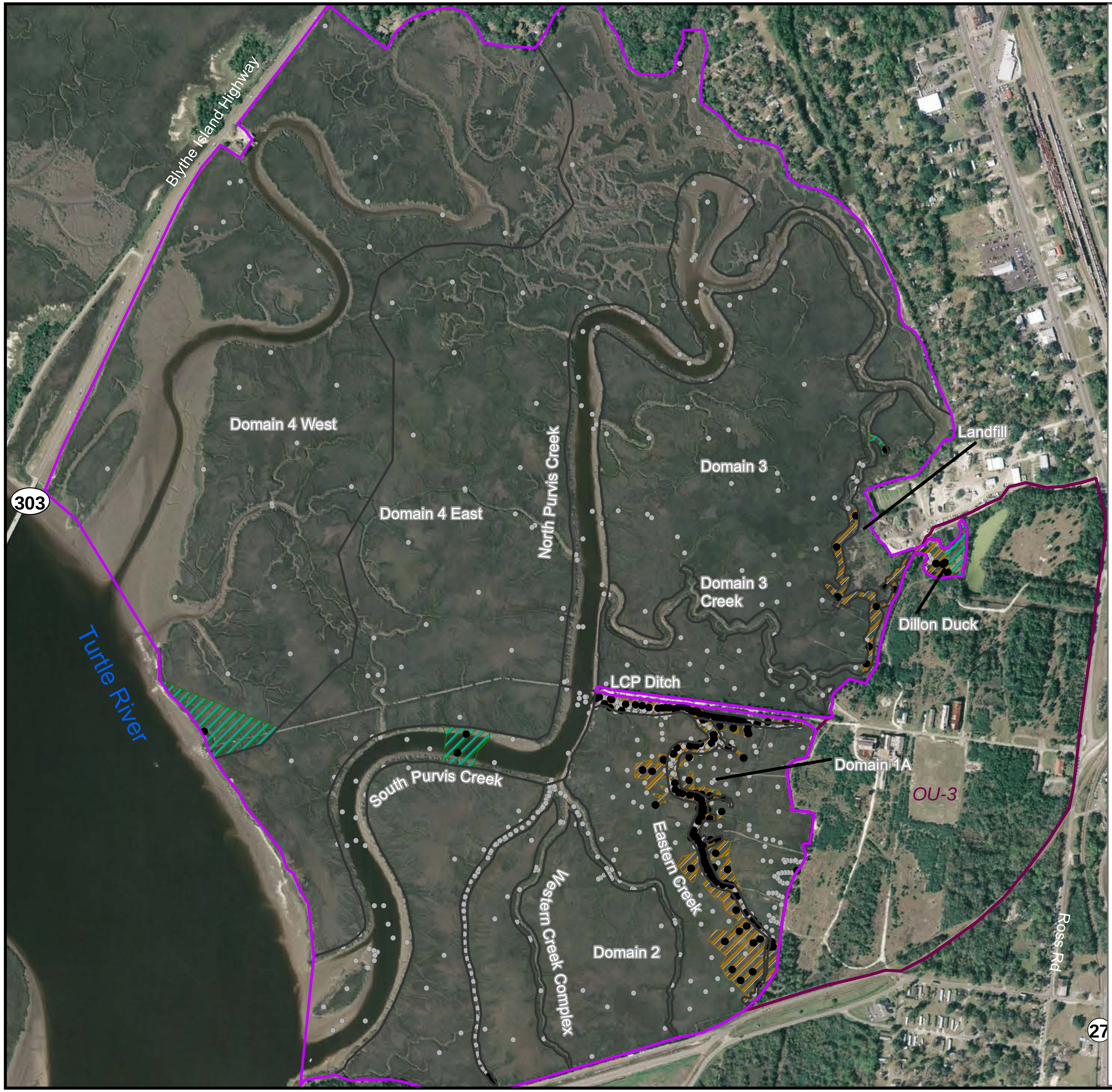
Sediment Management Area 1

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure 3-5

PROJECT: 02-27105C



Legend

- ● Surface Sample – Exceedance (Any Benthic Community RGO)
- • Surface Sample – No Exceedance (Any Benthic Community RGO)
- ▨ Remediation Area (18 acres)
- ▨ Risk Management Area (7 acres)
- ☐ OU-1 Boundary
- ☐ Creek/Domain Boundary
- ☐ OU-3 Boundary

Constituent	SWAC RGOs	Benthic Community RGOs
Ar1268	2-4	6
Hg	1-2	4
TPAHs	--	4
Pb	--	90

N

0 800 1,600
Feet

OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DRAFTED BY: MRJ

DATE: 03/28/2013

Sediment Management Area 2

LCP CHEMICAL SITE
BRUNSWICK, GA

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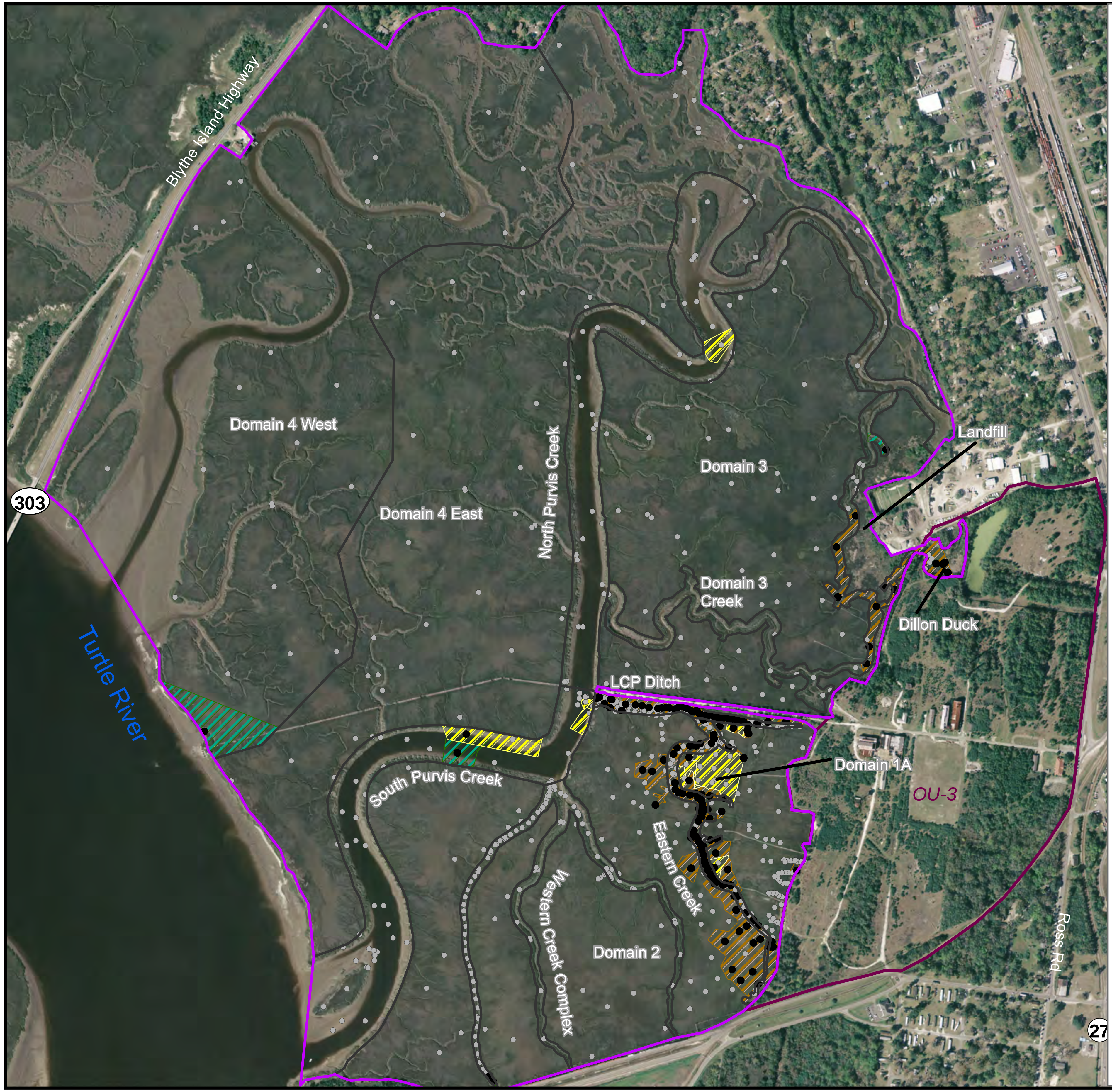
Figure
3-6

PROJECT: 02-27105C



Legend

- ● Surface Sample – Exceedance (Any Benthic Community RGO)
- ● Surface Sample – No Exceedance (Any Benthic Community RGO)
- ▨ Remediation Area (18 acres)
- ▨ Domain 1A and Purvis Creek Addition (6 acres)
- ▨ Risk Management Area (6 acres)
- ☐ OU-1 Boundary
- ☐ Creek/Domain Boundary
- ☐ OU-3 Boundary

Constituent	SWAC RGOs	Benthic Community RGOs
Ar1268	2-4	16
Hg	1-2	11
TPAHs	--	4
Pb	--	177

N

0 800 1,600
Feet

OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DRAFTED BY: MRJ

DATE: 03/28/2013

Sediment Management Area 3

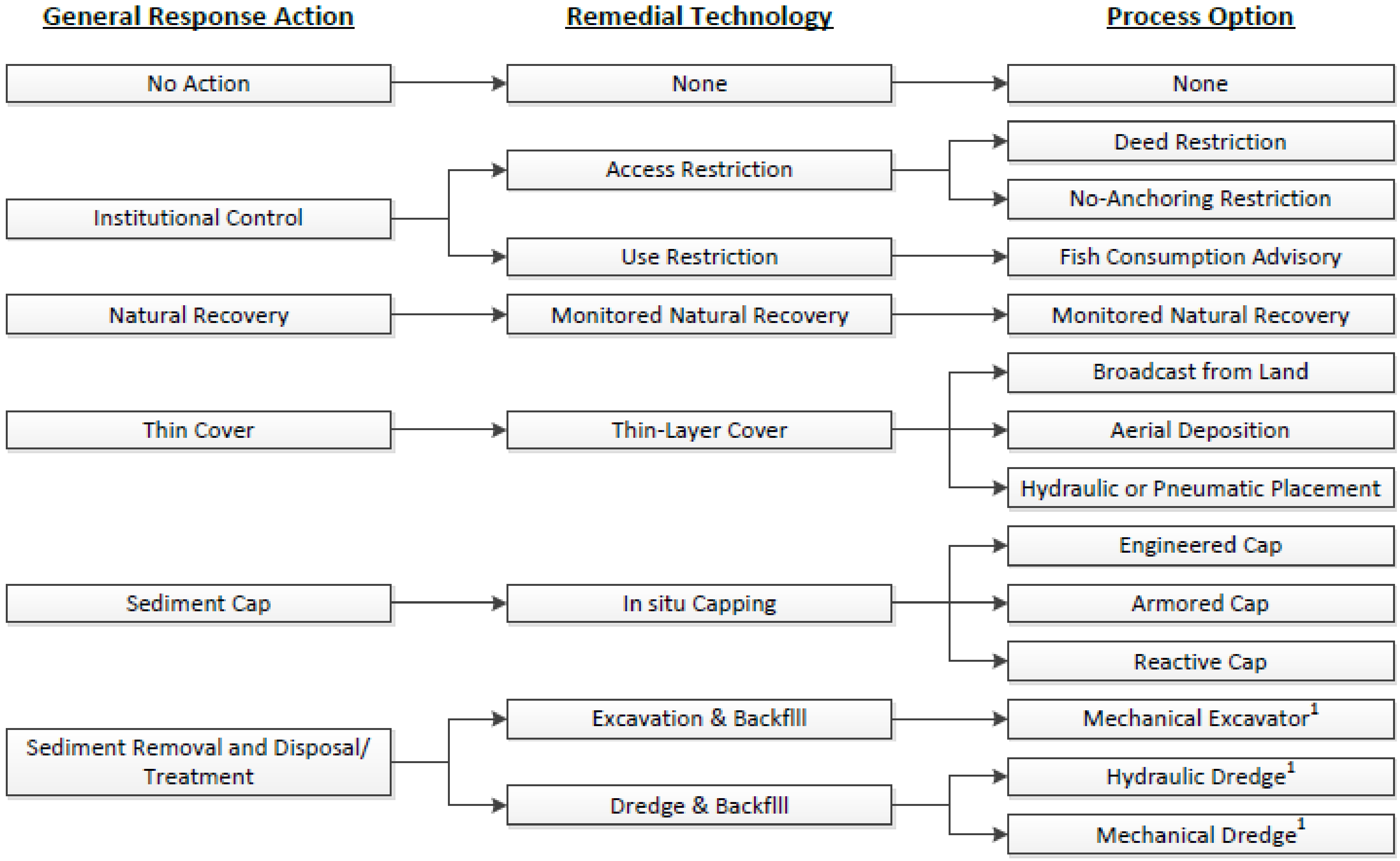
LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
3-7

PROJECT: 02-27105C

DRAFT



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Identification of Technologies

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

4-1

DRAFT

Photo 1.

Telebelt placement of capping material

Photo 2.

Hydraulic dredge spraying a thin layer of dredged material to restore a wetland at the Blackwater Wildlife Refuge, Dorchester County, Maryland.

(Source: USACE, Baltimore District, Baltimore Harbor & Channels, Dredged Material Management Plan. Available at: http://www.nab.usace.army.mil/projects/Maryland/DMMP/photos.html

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Examples of Thin-Layer Cover Placement

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
4-2

DRAFTED BY:

DATE: 3/27/2013

PROJECT_NO

DRAFT

Photo 1.

Mechanical placement of a subaqueous cap with a clamshell

Photo 2.

Hydraulic placement of a subaqueous cap with a spreader barge

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Examples of Engineered Cap Placement

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
4-3

DRAFTED BY:

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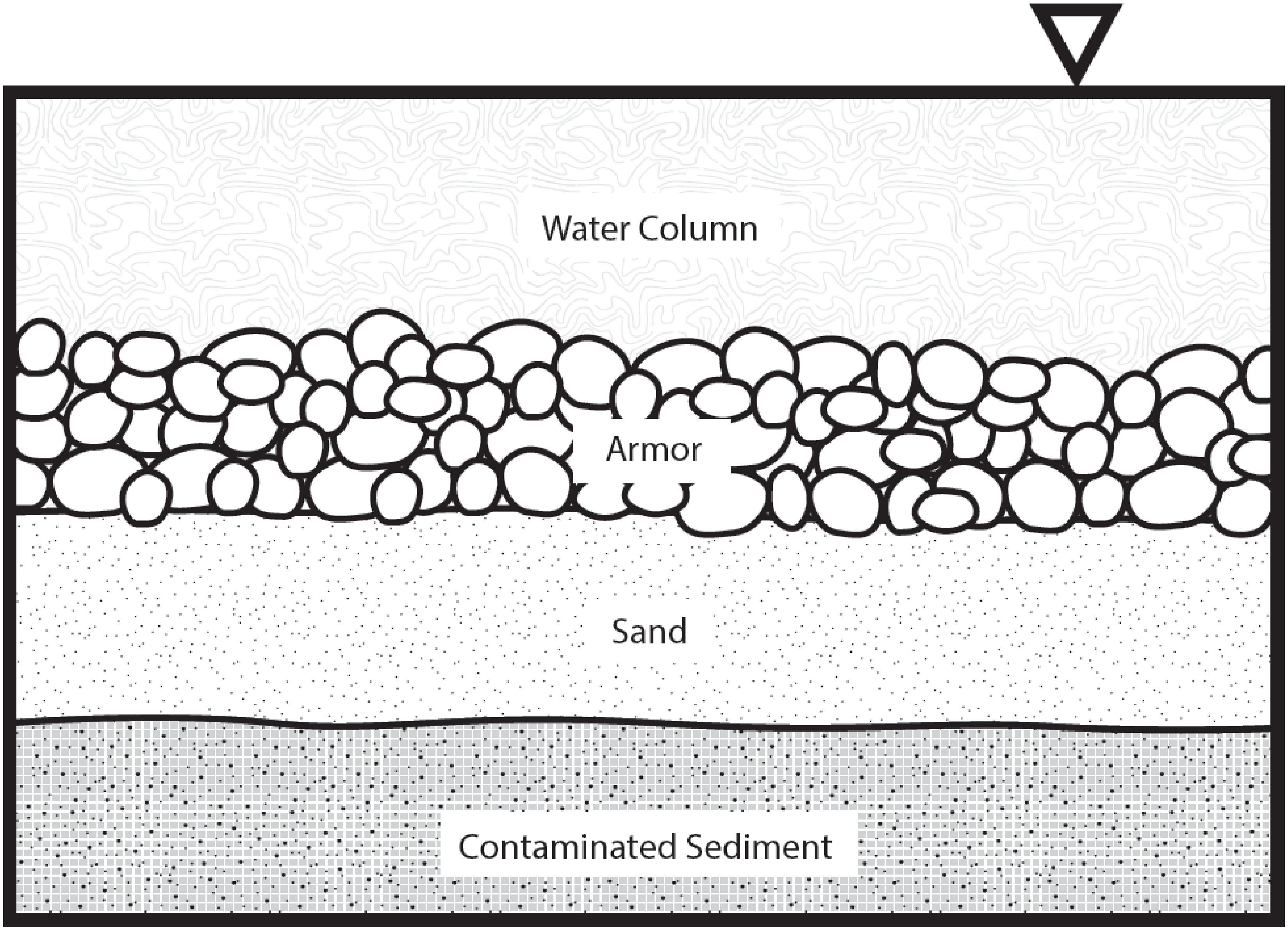

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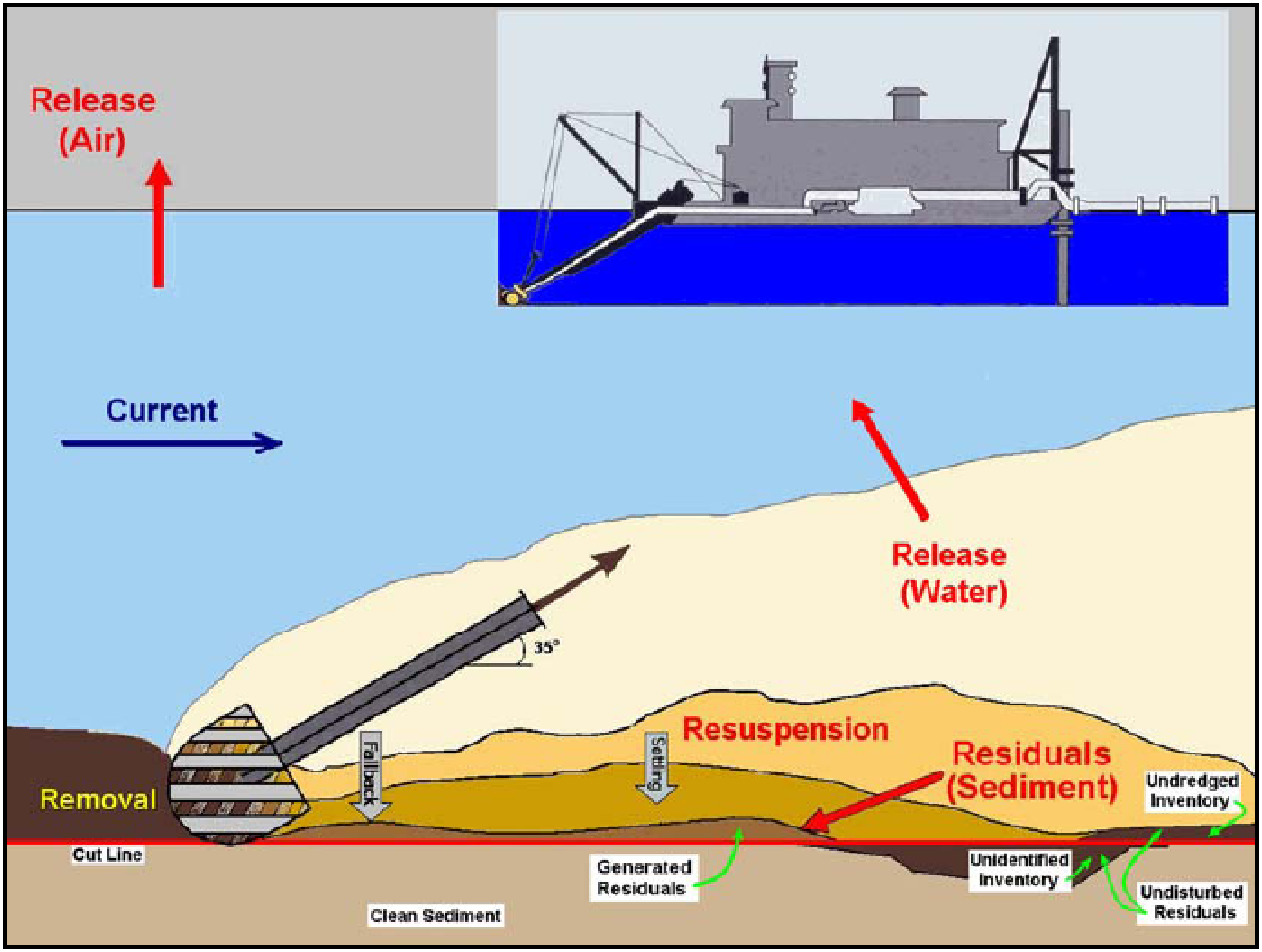
Schematic Cross-Section of Armored Cap

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

4-4

DRAFT



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Conceptual Illustration of Hydraulic Dredging and Processes (USACE 2005)

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

4-5

DRAFT

Photo 1.

Hydraulic Dredging

Photo 2.

Mechanical Dredging

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Examples of Hydraulic and Mechanical Dredging

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
4-6

DRAFTED BY:

DATE: 3/27/2013

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	Remedial Technology / Process Option	Effectiveness	Implementability	Cost	Summary
4.2.1	No Action	–	+	L	R^1
4.2.2	Institutional Controls				
	Deed Restriction	-	+	L	R^2
	No-anchoring Restriction	-	+	L	R^2
	Fish Consumption Advisory	-	+	L	R^2
4.2.3	Monitored Natural Recovery (MNR)	-	+	L	NR
4.2.4	Thin Cover				
	Broadcast from land	O	+	L	R^3
	Aerial Deposition	O	+	M	NR
	Hydraulic or Pneumatic placement	O	+	L	R^3
4.2.5	Sediment Cap				
	Engineered Cap	+	O	M	R
	Armored Cap	+	O	M	R
	Reactive Cap	+	O	H	R
4.2.6	Sediment Removal and Disposal/Treatment				
	Mechanical Excavator	+	+	H	R
	Hydraulic Dredge	+	+	H	R
	Mechanical Dredge	+	+	H	R

Notes:

+ = generally able to meet the evaluation criteria

– = generally unable to meet the evaluation criteria

O = ability to meet the evaluation criteria may dependent on site-specific factors to be evaluated during the detailed development of alternatives

L = low; M = medium; H = high

R = technology/process option retained for further evaluation

R2 = technology would not be effective on its own; must be combined with other technologies to be effective

R3 = technology would be effective on its own in some areas; in other areas it must be combined with other technologies to be effective

NR = technology does not meet the evaluation criteria and is not retained for further consideration

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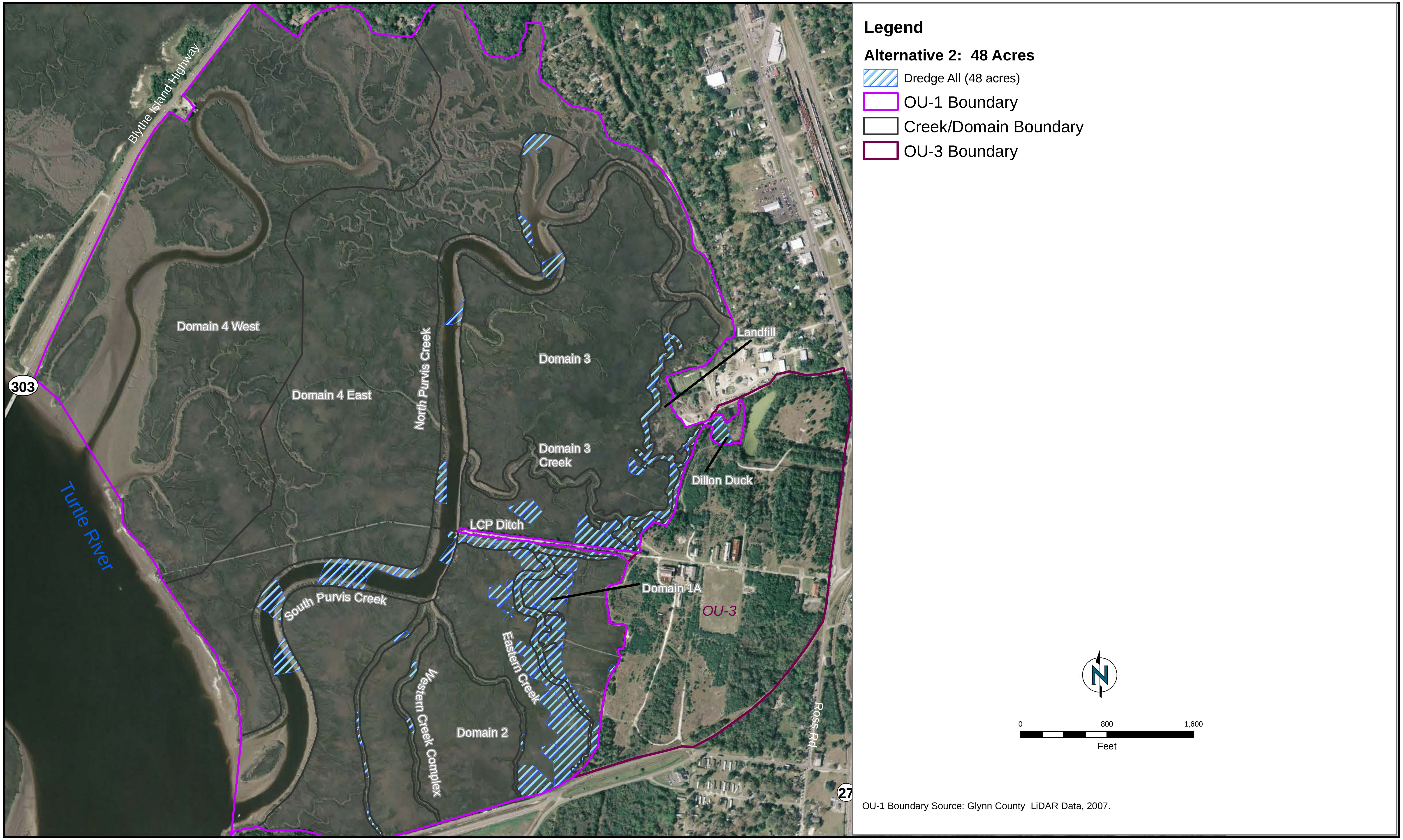
Summary of Feasibility Study Technology Screening Results

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

4-7



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DRAFTED BY: MRJ

DATE: 03/28/2013

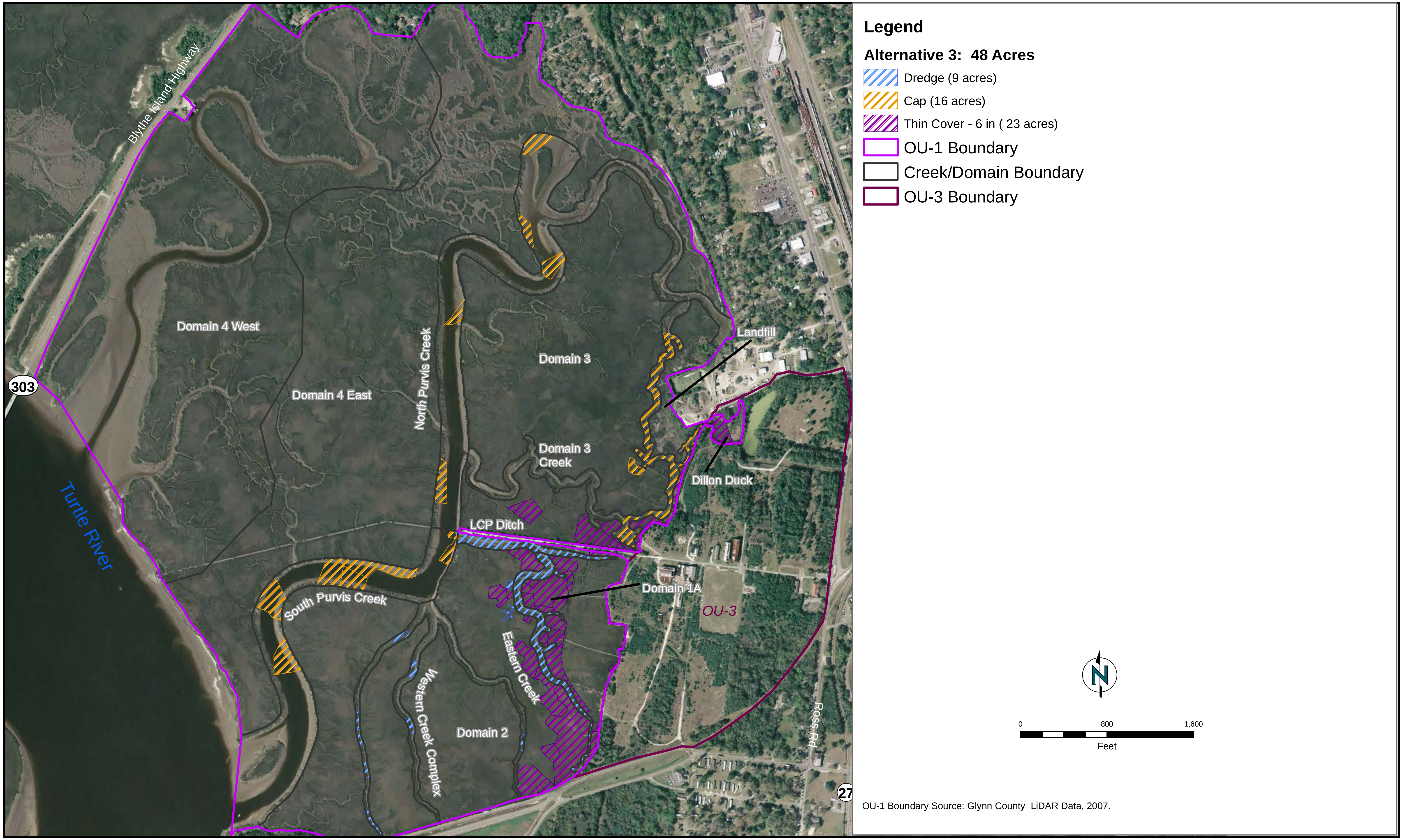
Sediment Remedy Alternative 2: Sediment Removal in SMA-1

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
5-1

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DRAFTED BY: MRJ

DATE: 03/28/2013

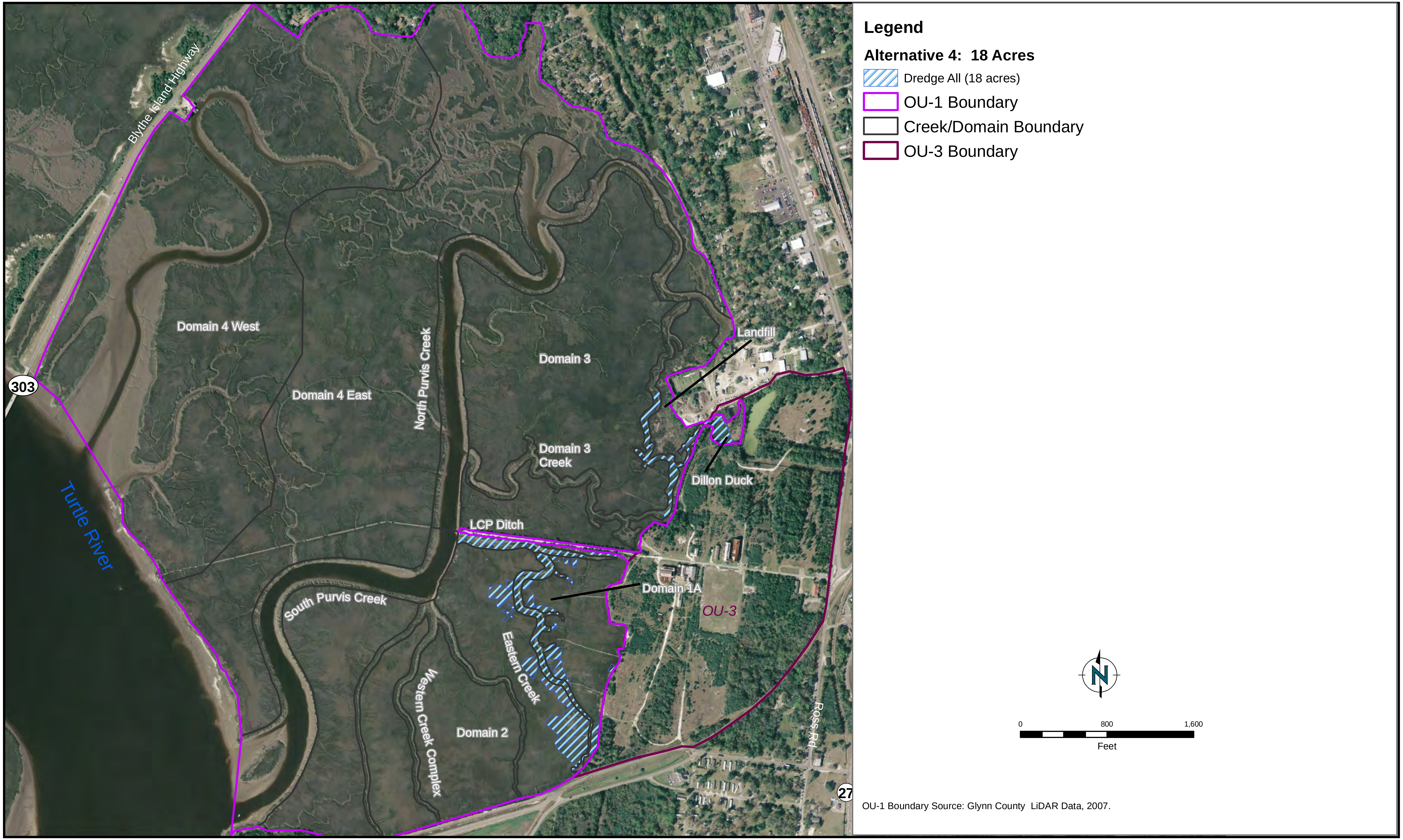
Sediment Remedy Alternative 3: Sediment Removal, Capping and Thin Cover in SMA-1

DRAFT

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
5-2

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

DRAFTED BY: MRJ

DATE: 03/28/2013

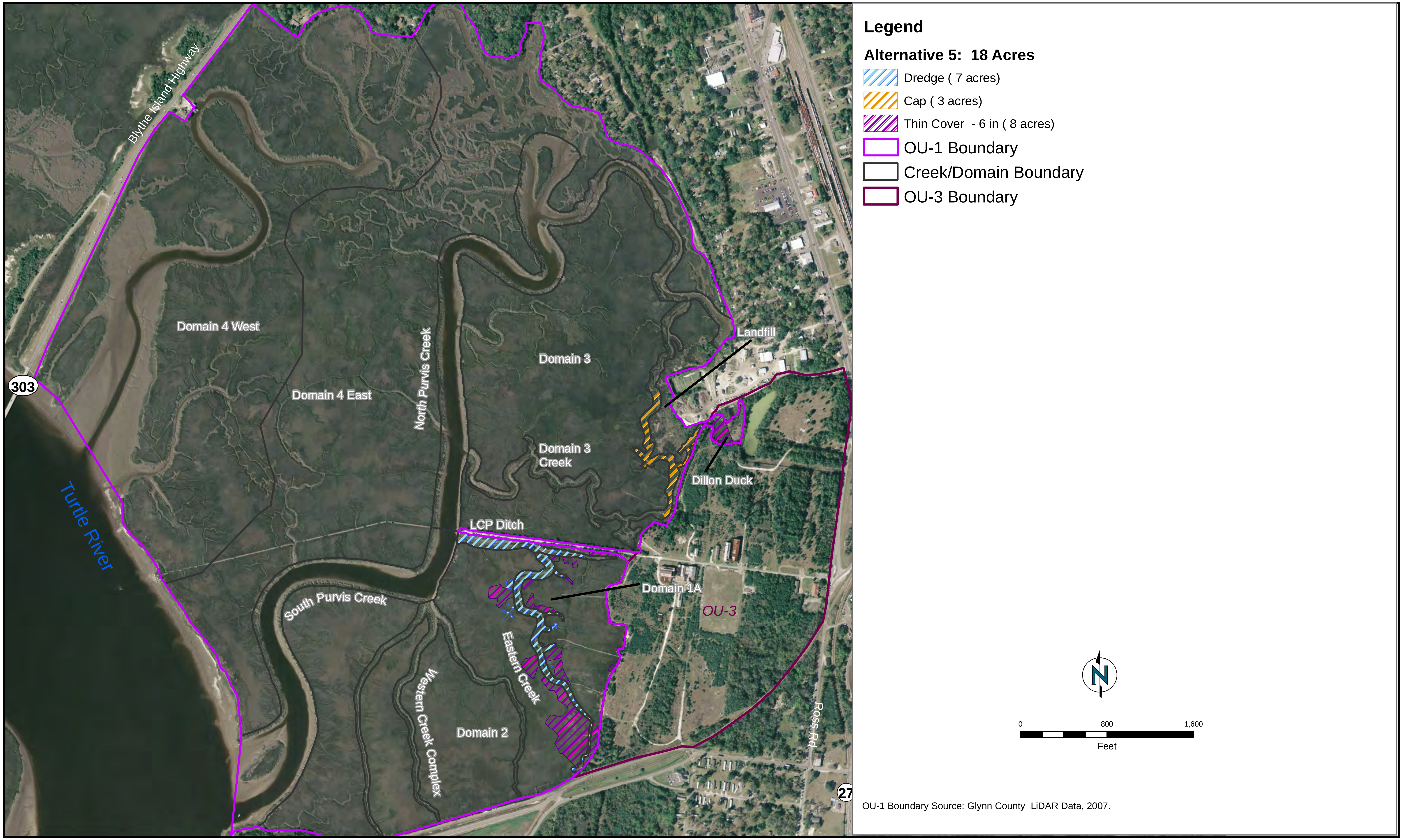
Sediment Remedy Alternative 4: Sediment Removal in SMA-2

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
5-3

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DATE: 03/28/2013

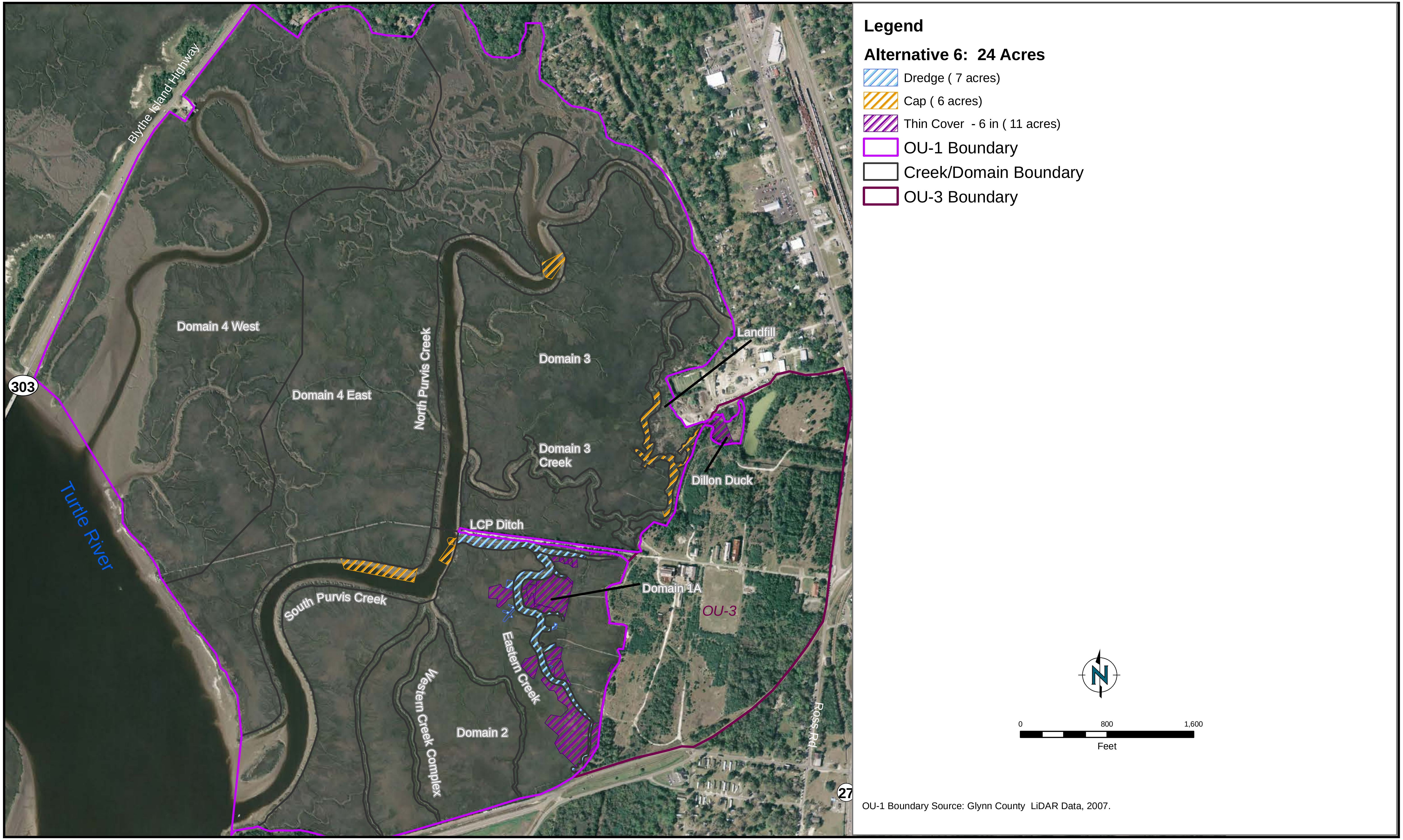
Sediment Remedy Alternative 5: Sediment Removal, Capping and Thin Cover in SMA-2

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
5-4

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DATE: 03/28/2013

Sediment Remedy Alternative 6: Sediment Removal, Capping and Thin Cover in SMA-3

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
5-5

PROJECT: 02-27105C

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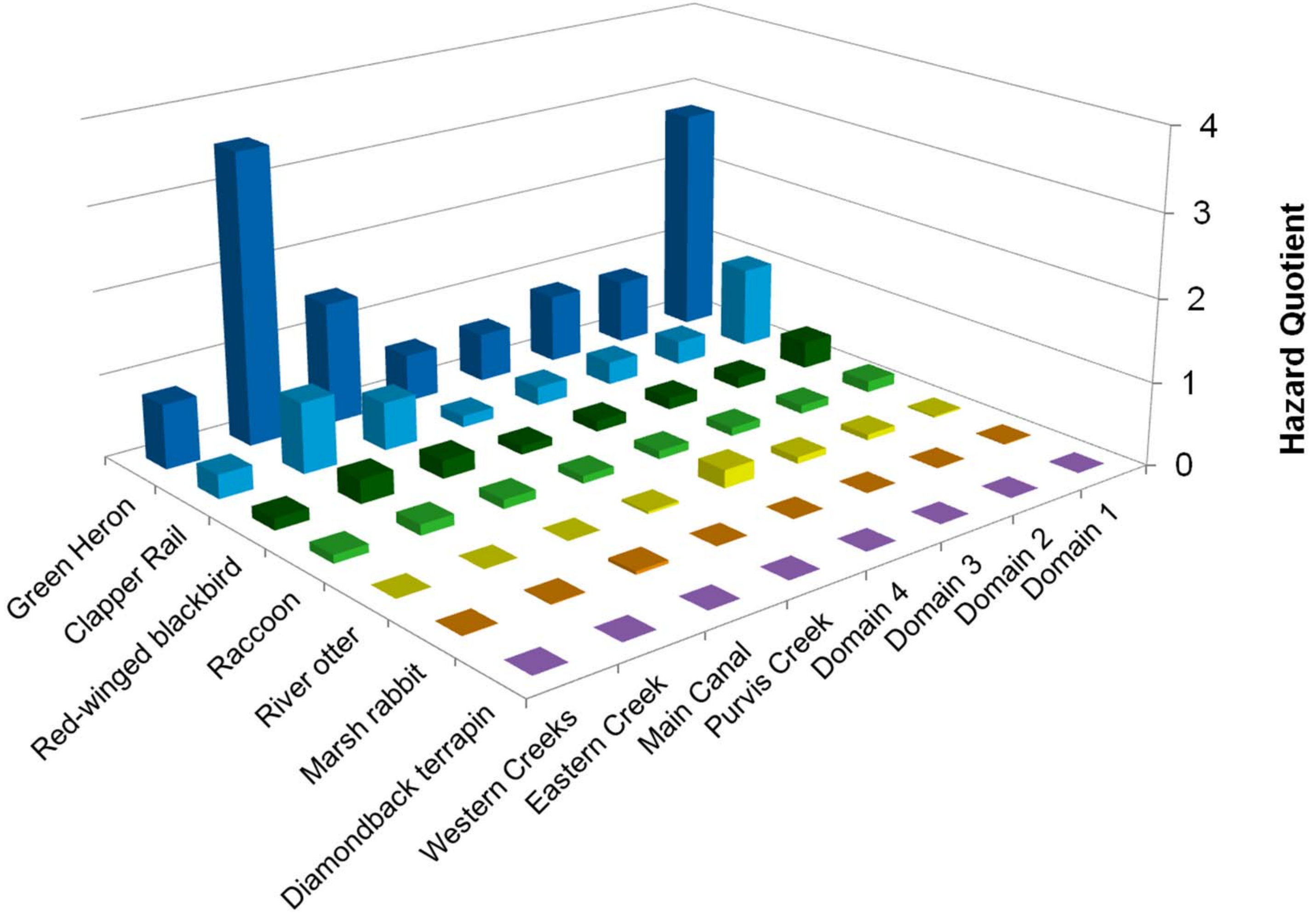

- HQs are based on the lowest observable adverse effects levels upper confidence limit estimates from the BERA (Black & Veatch 2011).
- The results show that HQs are below the level of 1 for all receptors except the green heron.
- The green heron is considered the most sensitive species and is the focus of further discussion related to remedy effectiveness.

BERA Baseline Ecological Risk Assessment.
HQ Hazard quotient.

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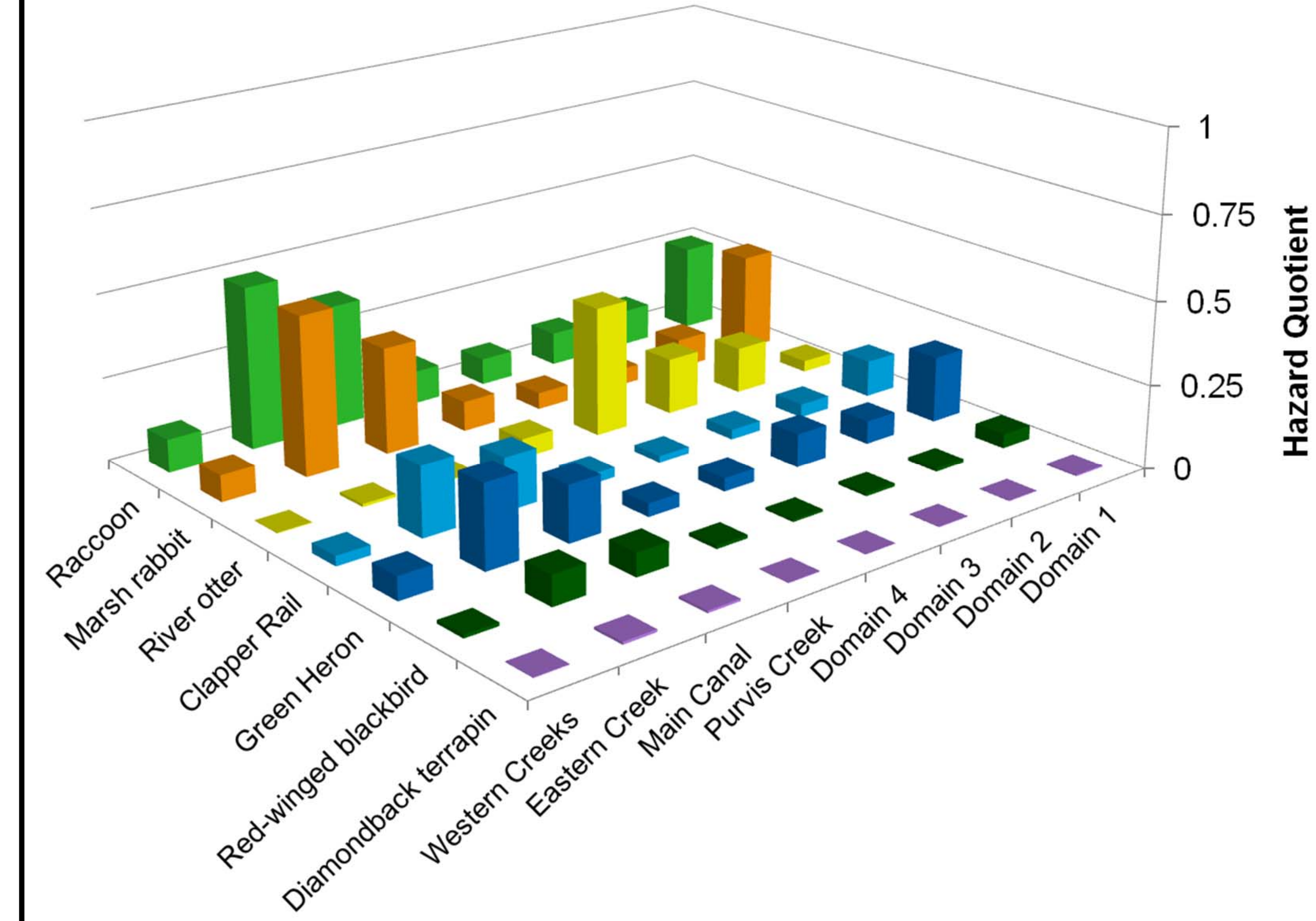
Current Conditions and Baseline Ecological Risk Assessment Findings for Mammals and Birds for Mercury

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

6-1A

DRAFT



- HQs are based on the lowest observable adverse effects levels upper confidence limit estimates from the BERA (Black & Veatch 2011).
- The results show that HQs are below the level of 1 for all receptors.

BERA Baseline Ecological Risk Assessment.
HQ Hazard quotient.

Appendix E2 provides the technical supporting information for this figure.

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Current Conditions and Baseline Ecological Risk Assessment Findings for Mammals and Birds for Aroclor 1268

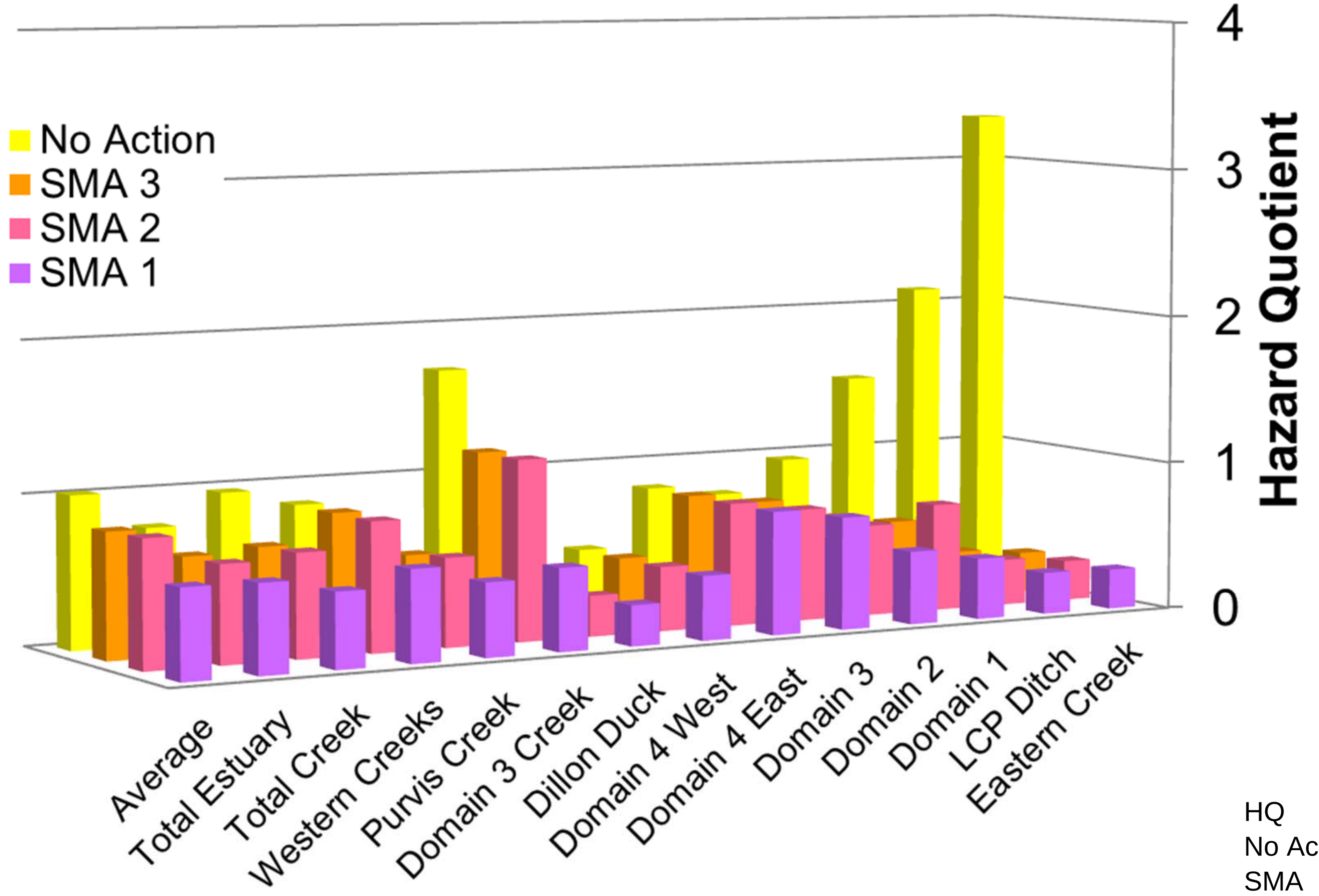
LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

6-1B

DRAFT

Remedy Alternatives 2 through 6 each provide overall protection for green heron populations.



Average = Average of Purvis Creek/ Domain 3/ Domain 3 Creek

- The evaluation shows that for the majority of areas, the starting point for the green heron is below the threshold HQ value of 1.
- Each of the areas with a HQ exceeding the threshold value of 1 are evaluated further on Figure 6-2B.

HQ	Hazard quotient.
No Action	Remedy Alternative 1
SMA	Sediment Management Area.
SMA 1	Remedy Alternatives 2 and 3
SMA 2	Remedy Alternatives 4 and 5
SMA 3	Remedy Alternative 6

Appendix E2 provides the technical supporting information for this figure.

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Remedy Effectiveness Evaluation for the Mercury Exposures and the Green Heron Exposed to All Areas

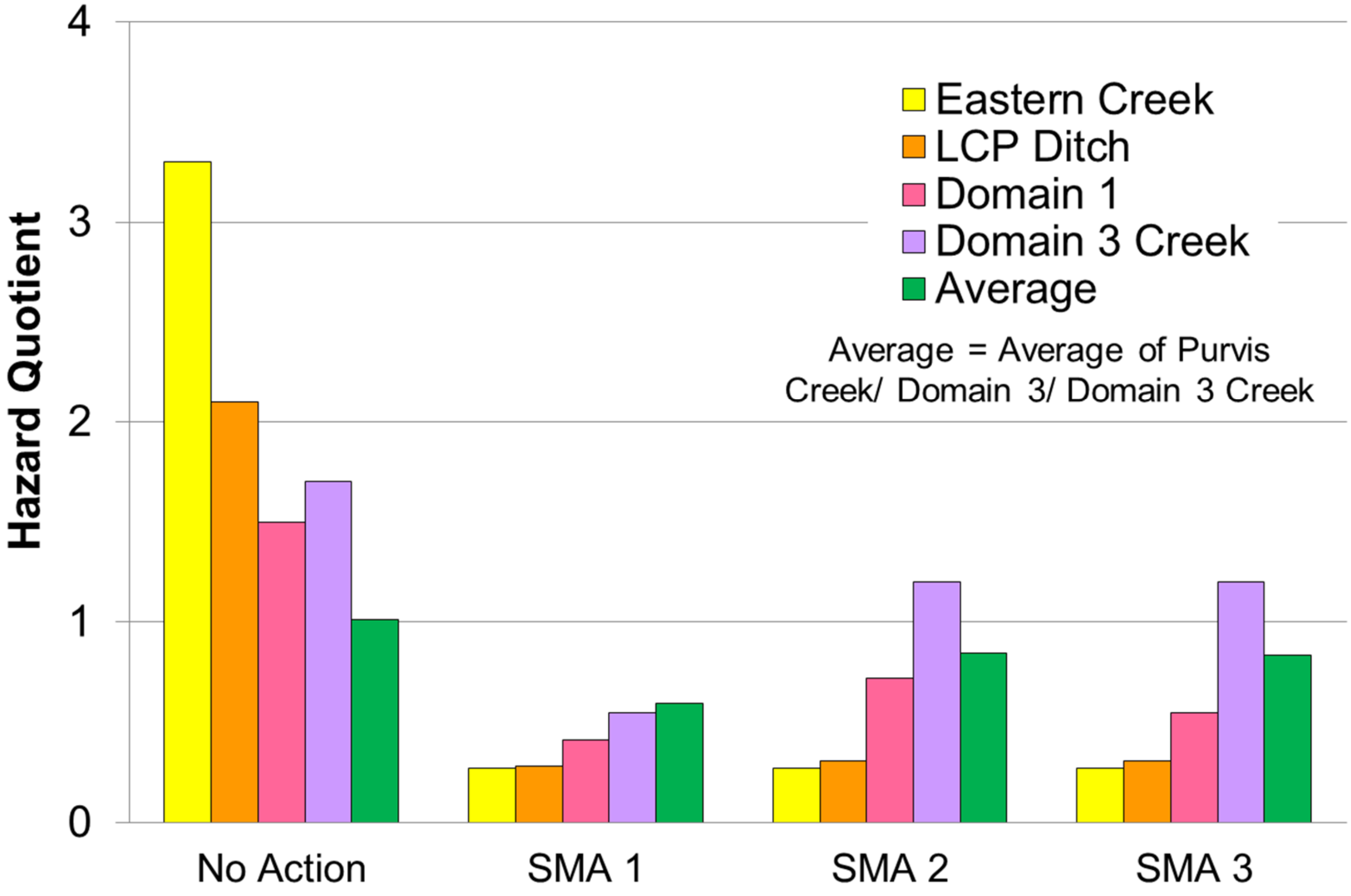
LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

6-2A

DRAFT

Remedy Effectiveness Evaluation for the Green Heron Exposed to Mercury (Focused on HQs>1)



Average = Average of Purvis Creek/ Domain 3/ Domain 3 Creek

Remedy Alternatives 2 through 6 each provide overall protection for Green Heron populations.

Results for this sensitive species indicates Alternatives are protective for all mammal and bird populations.

Appendix E2 provides the technical supporting information for this figure.

No Action	Remedy Alternative 1
SMA	Sediment Management Area.
SMA 1	Remedy Alternatives 2 and 3
SMA 2	Remedy Alternatives 4 and 5
SMA 3	Remedy Alternative 6

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Remedy Effectiveness Evaluation for Mercury and the Green Heron In Areas with HQs Exceeding a Threshold Value of 1

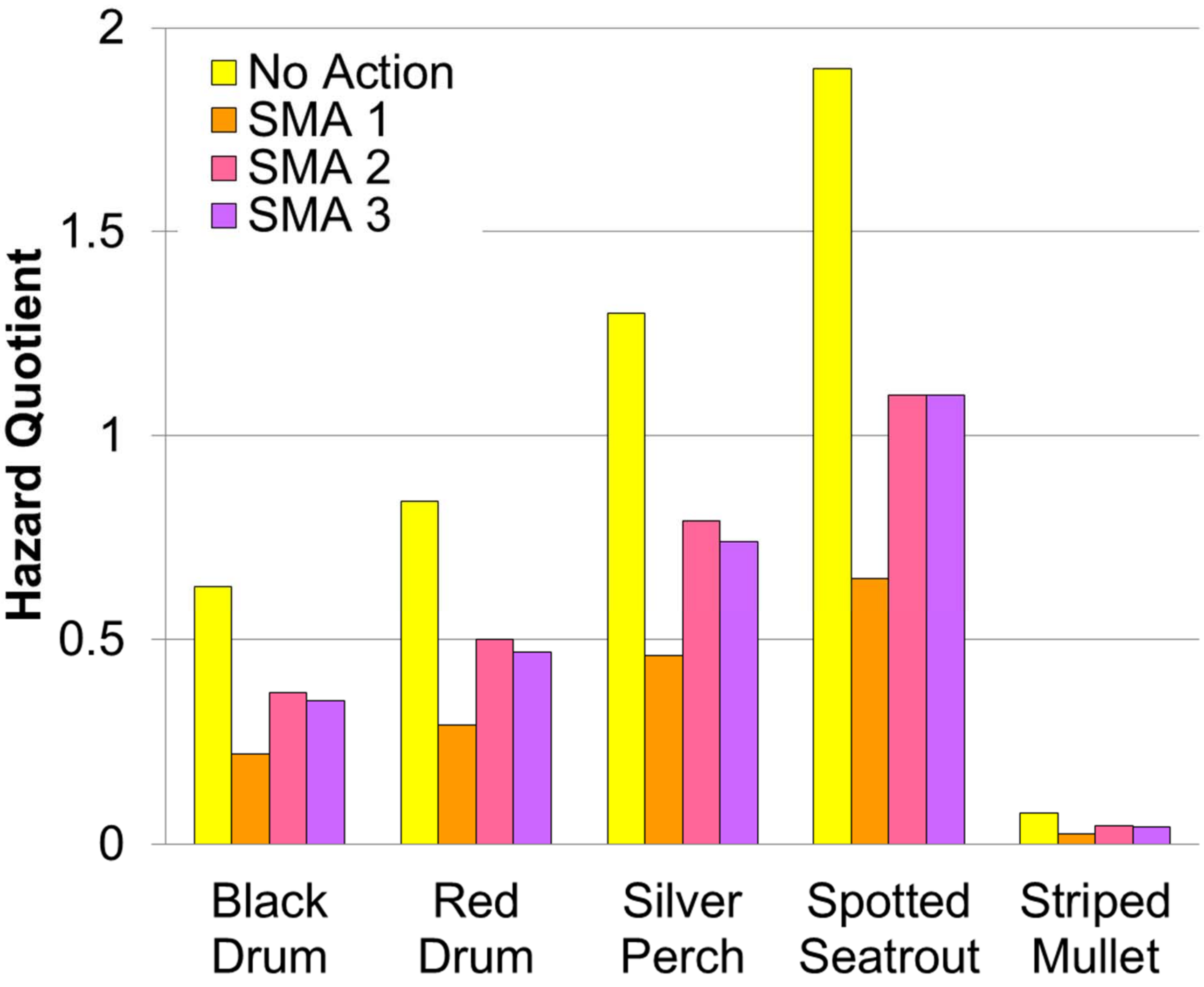
LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

6-2B

DRAFT

Remedy Alternatives 2 through 6 each provide overall protection for Finfish populations.



HQ	Hazard quotient.
No Action	Remedy Alternative 1
SMA	Sediment Management Area.
SMA 1	Remedy Alternatives 2 and 3
SMA 2	Remedy Alternatives 4 and 5
SMA 3	Remedy Alternative 6

Appendix E2 provides the technical supporting information for this figure.

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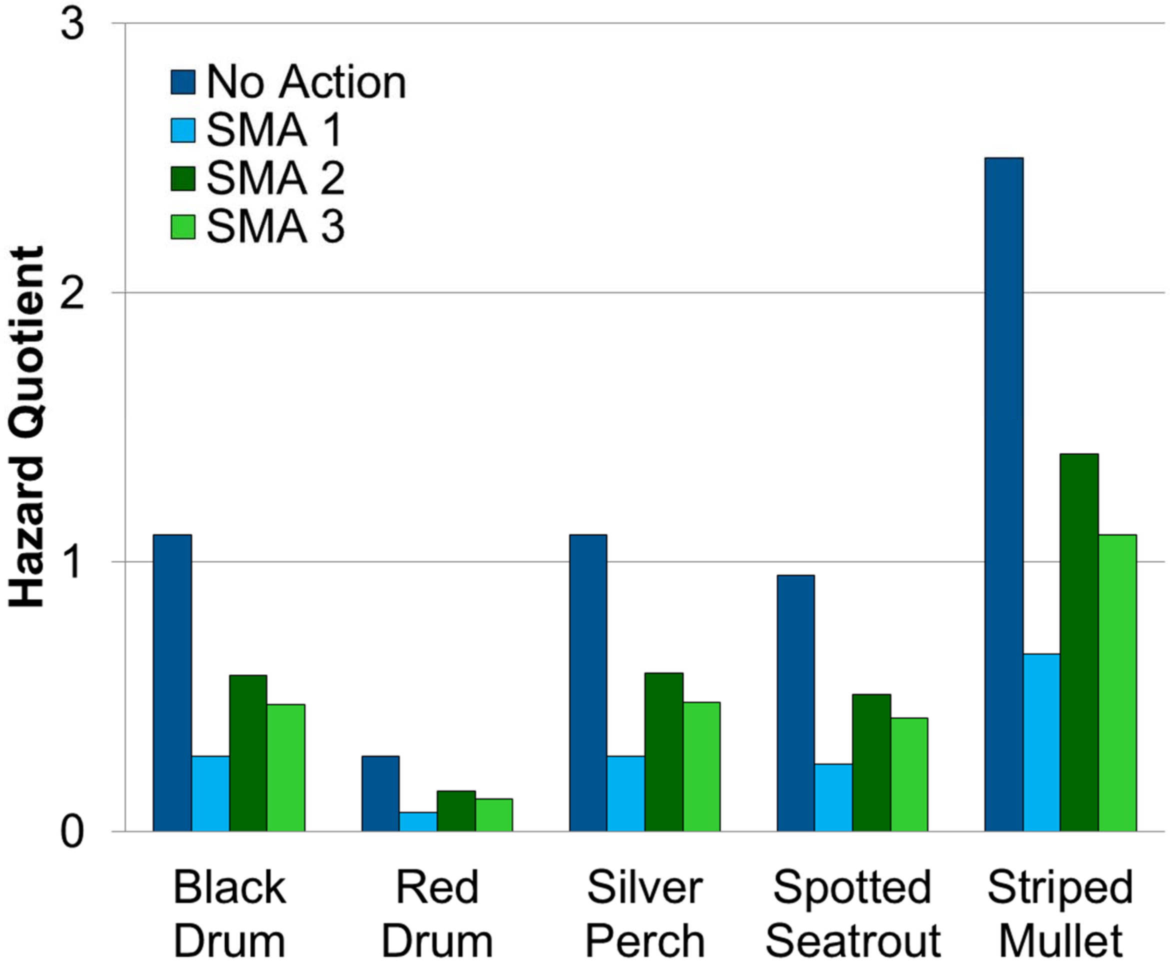
Remedy Effectiveness Evaluation for Mercury and Finfish

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

6-3

DRAFT



Remedy Alternatives 2 through 6 each provide overall protection for Finfish populations.

HQ	Hazard quotient.
No Action	Remedy Alternative 1
SMA	Sediment Management Area.
SMA 1	Remedy Alternatives 2 and 3
SMA 2	Remedy Alternatives 4 and 5
SMA 3	Remedy Alternative 6

- Figure 6-4B shows that striped mullet concentrations from 2011 are even lower than those used in this evaluation.

Appendix E2 provides the technical supporting information for this figure.

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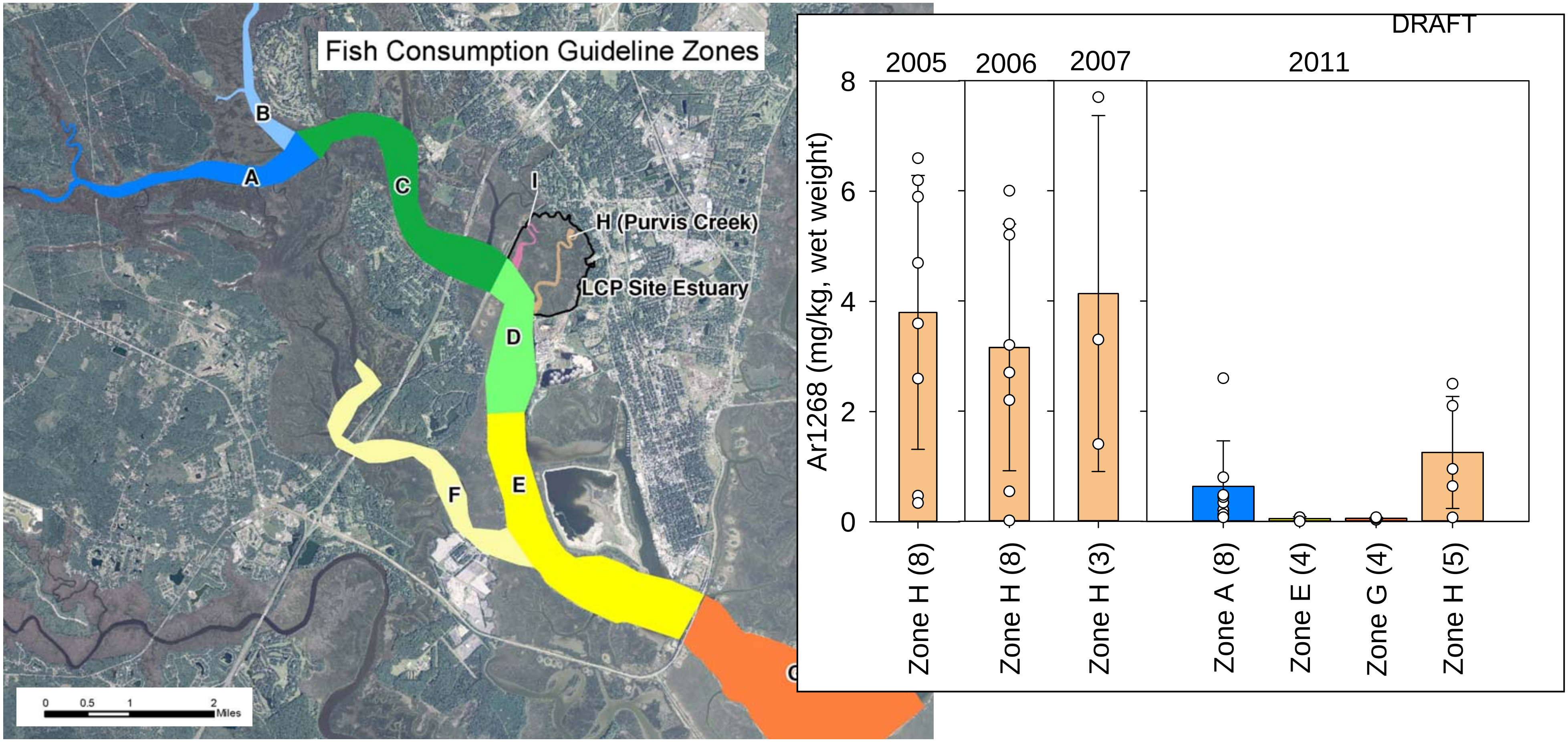
Remedy Effectiveness Evaluation for Aroclor 1268 and Finfish

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

6-4A

DRAFT



- Risk estimates were overestimated because pre-remedy conditions assumes 2005-2007 concentrations and did not include the 2011 fish tissue data set for mullet from Zone H (the LCP Site estuary).
- A full set of fish and crab tissue analytical results is provided graphically in Appendix F.

	Bar	Mean concentration.
	o	Individual sample point.
🟦	Zone A	Turtle River from Hwy 303 to Buffalo River
🟨	Zone E	Turtle River from Channel Marker 9 to Hwy 17
🟧	Zone G	Brunswick River
🟫	Zone H	Purvis Creek

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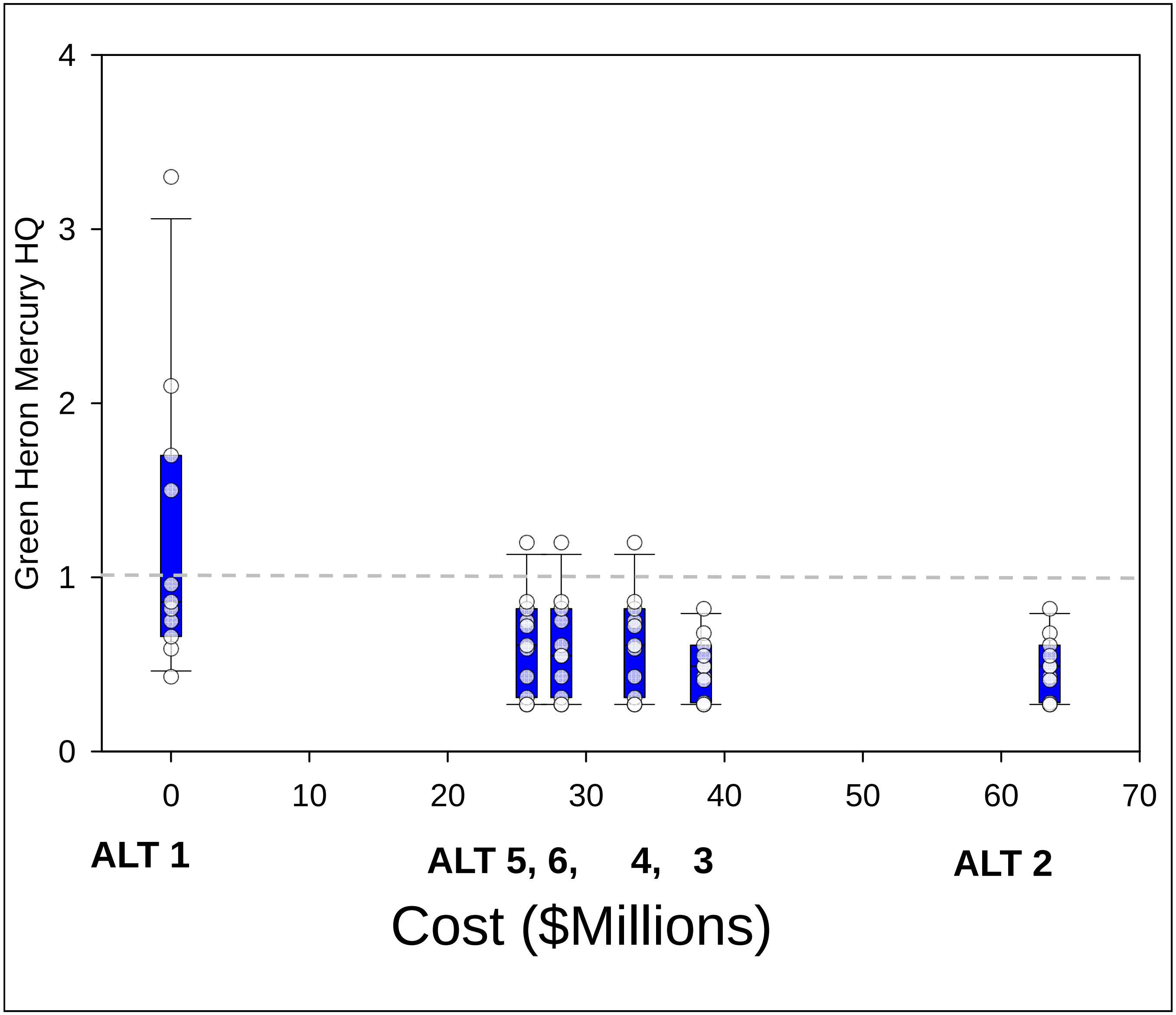
Striped Mullet Aroclor 1268 Fish Tissue Concentrations Over Time

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

6-4B

DRAFT



- Box indicates 25th and 75th percentiles.
- Middle of box is the median.
- Whiskers indicate 10th and 90th percentiles.
- Points indicate Green Heron HQs from the exposure areas on site, as summarized in Section 6 (Figures 6-2A and 6-2B).
- ALT=Alternative.
- HQ =Hazard quotient.

Alternative	Cost in $Mil
ALT 1	$0
ALT 2	$65
ALT 3	$39
ALT 4	$34
ALT 5	$26
ALT 6	$29

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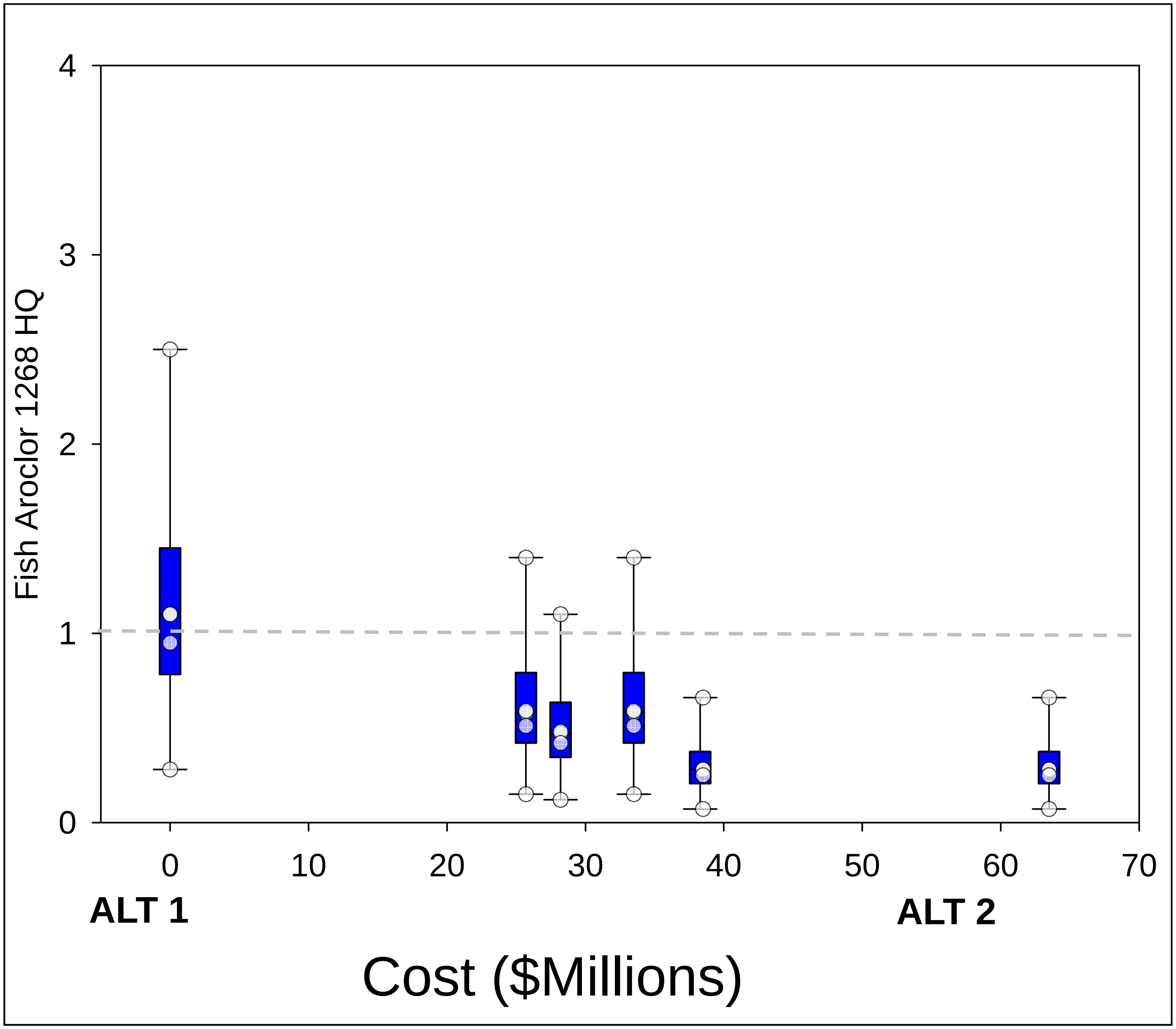
Remedy Alternative Comparison for Green Heron Mercury Risk Reduction by Cost

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

7-1A

DRAFT



- Box indicates 25th and 75th percentiles.
- Middle of box is the median.
- Whiskers indicate 10th and 90th percentiles.
- Points indicate Finfish HQs from Section 6 of the FS (Section 6-3).
- ALT=Alternative.
- HQ =Hazard quotient.

Alternative	Cost in $Mil
ALT 1	$0
ALT 2	$65
ALT 3	$39
ALT 4	$34
ALT 5	$26
ALT 6	$29

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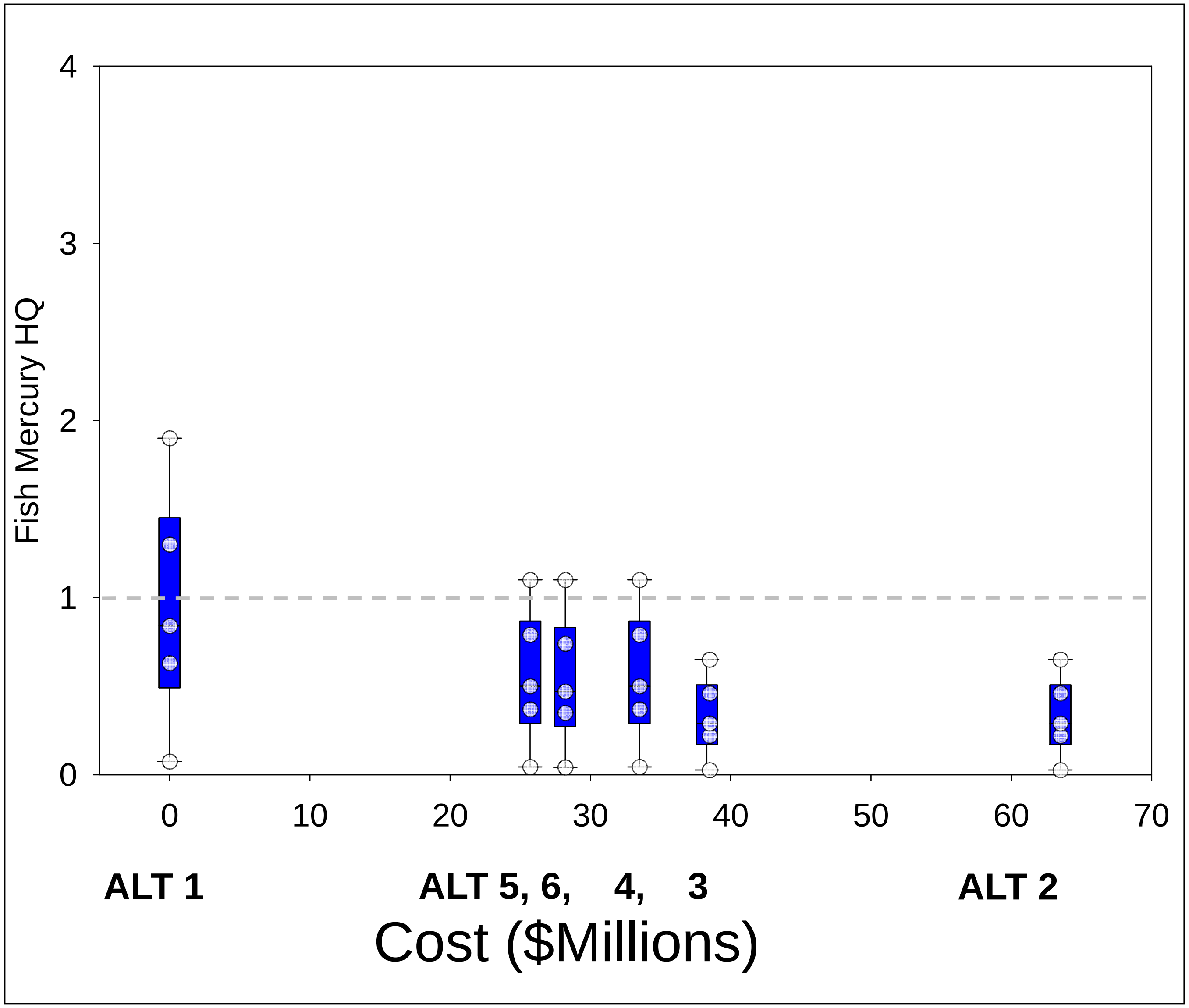
Remedy Alternative Comparison for Finfish Aroclor 1268 Risk Reduction HQs by Cost

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

7-1B

DRAFT



- Box indicates 25th and 75th percentiles.
- Middle of box is the median.
- Whiskers indicate 10th and 90th percentiles.
- Points indicate finfish HQs from Section 6 (Figure 6-4A).
- ALT=Alternative.
- HQ =Hazard quotient.

Alternative	Cost in $Mil
ALT 1	$0
ALT 2	$65
ALT 3	$39
ALT 4	$34
ALT 5	$26
ALT 6	$29

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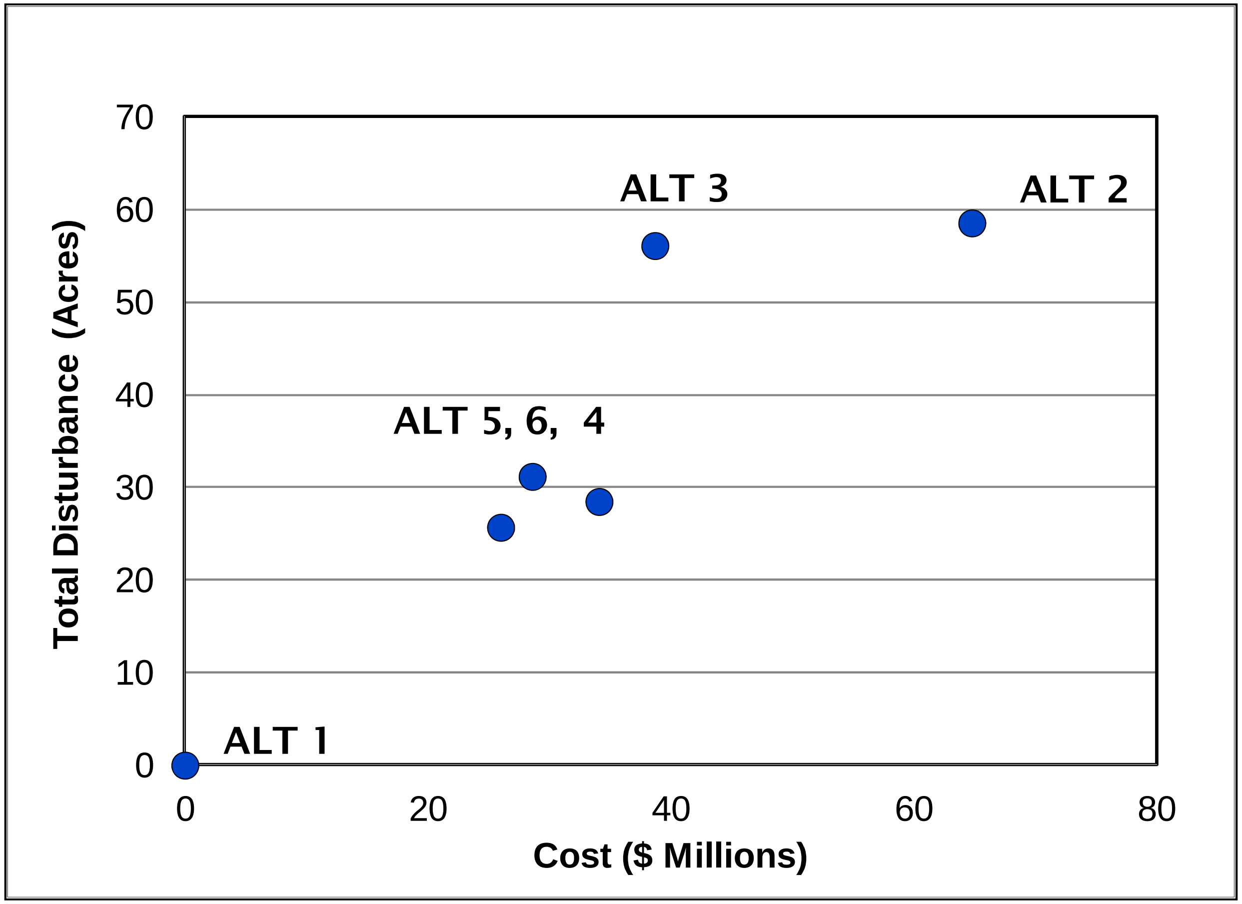
Remedy Alternative Comparison for Finfish Mercury Risk Reduction by Cost

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

7-1C

DRAFT



- Costs were summarized in Table 6-5.
- ALT=Alternative.

Alternative	Cost in $Mil	Remedy Footprint (Acres)	Marsh Disturbance Beyond Footprint (Acres)	Total Acres of Disturbance
ALT 1	$0	0	-	0
ALT 2	$65	48	10.6	59
ALT 3	$39	48	8.1	56
ALT 4	$34	18	10.5	29
ALT 5	$26	18	7.7	26
ALT 6	$29	24	7.2	31

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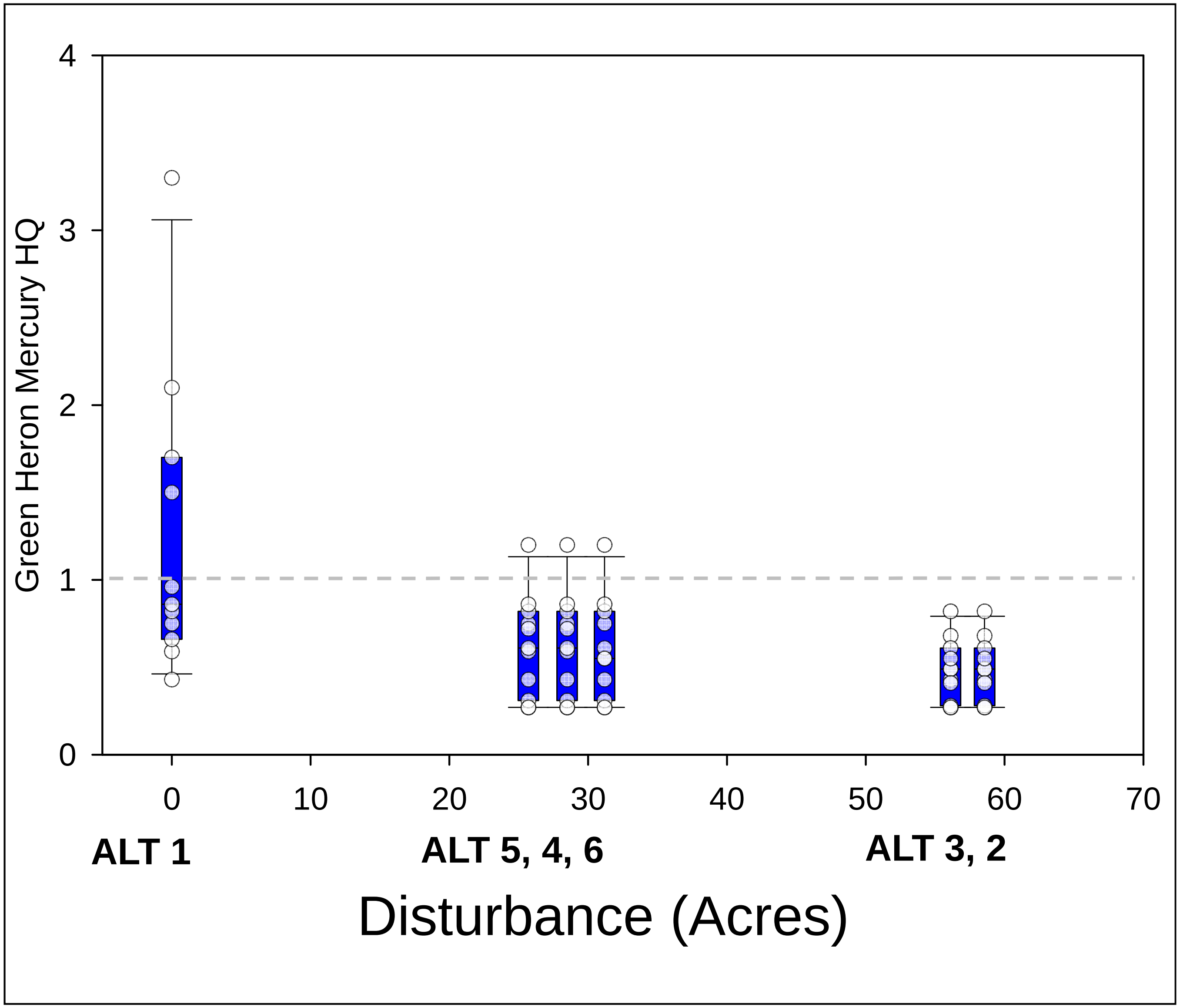
Remedy Alternative Comparison of Cost vs Disturbance

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

7-2

DRAFT



- Box indicates 25th and 75th percentiles.
- Middle of box is the median.
- Whiskers indicate 10th and 90th percentiles.
- Points indicate Green Heron HQs from the exposure areas on site, as summarized in Section 6 (Figures 6-2A and 6-2B).
- ALT=Alternative.
- HQ =Hazard quotient.

Alternative	Disturbance in acres
ALT 1	0
ALT 2	59
ALT 3	56
ALT 4	29
ALT 5	26
ALT 6	31

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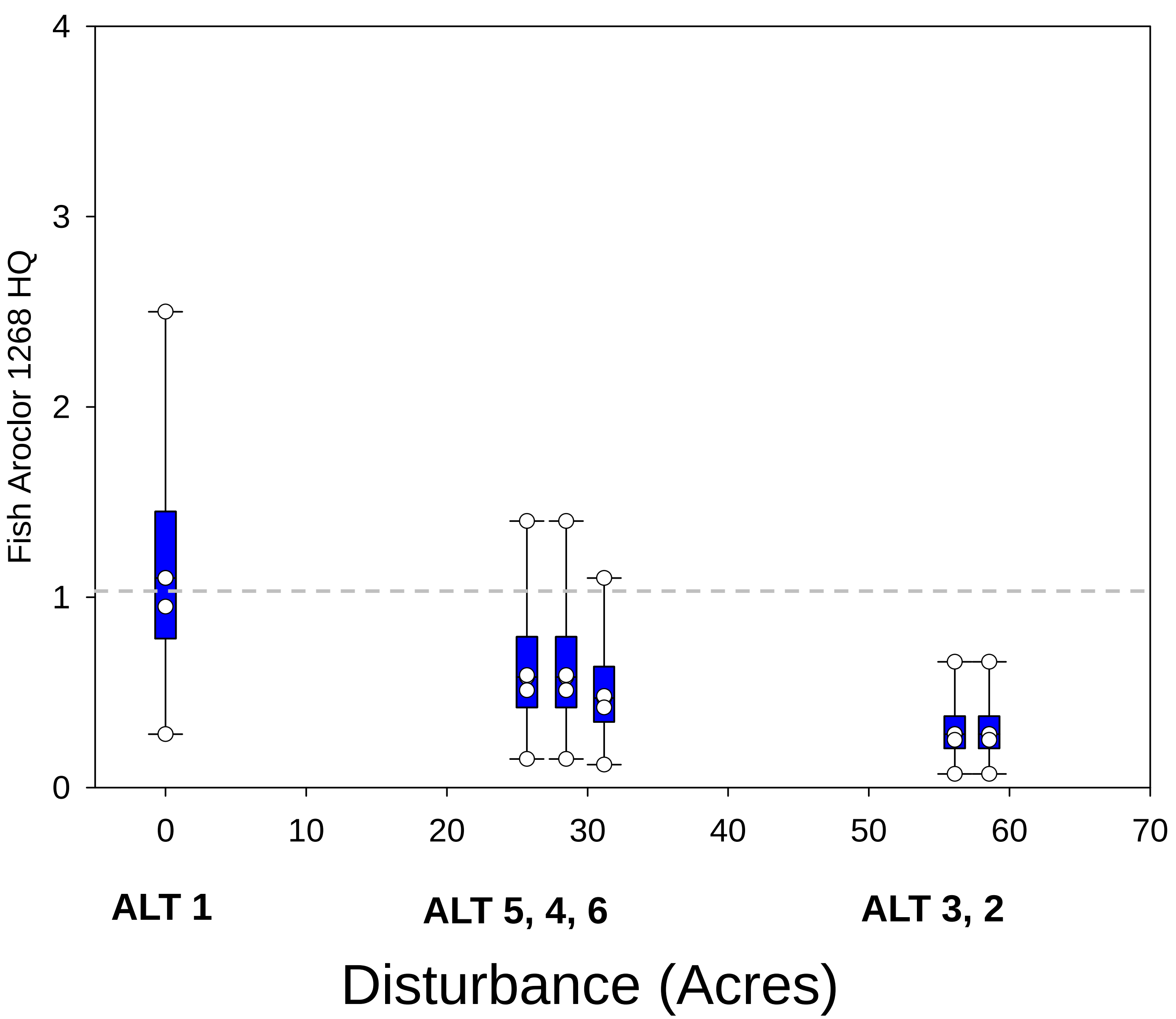
Remedy Alternative Comparison for Green Heron Mercury Risk Reduction by Disturbance (Acres)

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

7-3A



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- Box indicates 25th and 75th percentiles.
- Middle of box is the median.
- Whiskers indicate 10th and 90th percentiles.
- Points indicate Finfish HQs from Section 6 of the FS (Section 6-3).
- ALT=Alternative.
- HQ =Hazard quotient.

Alternative	Disturbance in acres
ALT 1	0
ALT 2	59
ALT 3	56
ALT 4	29
ALT 5	26
ALT 6	31

ENVIRON
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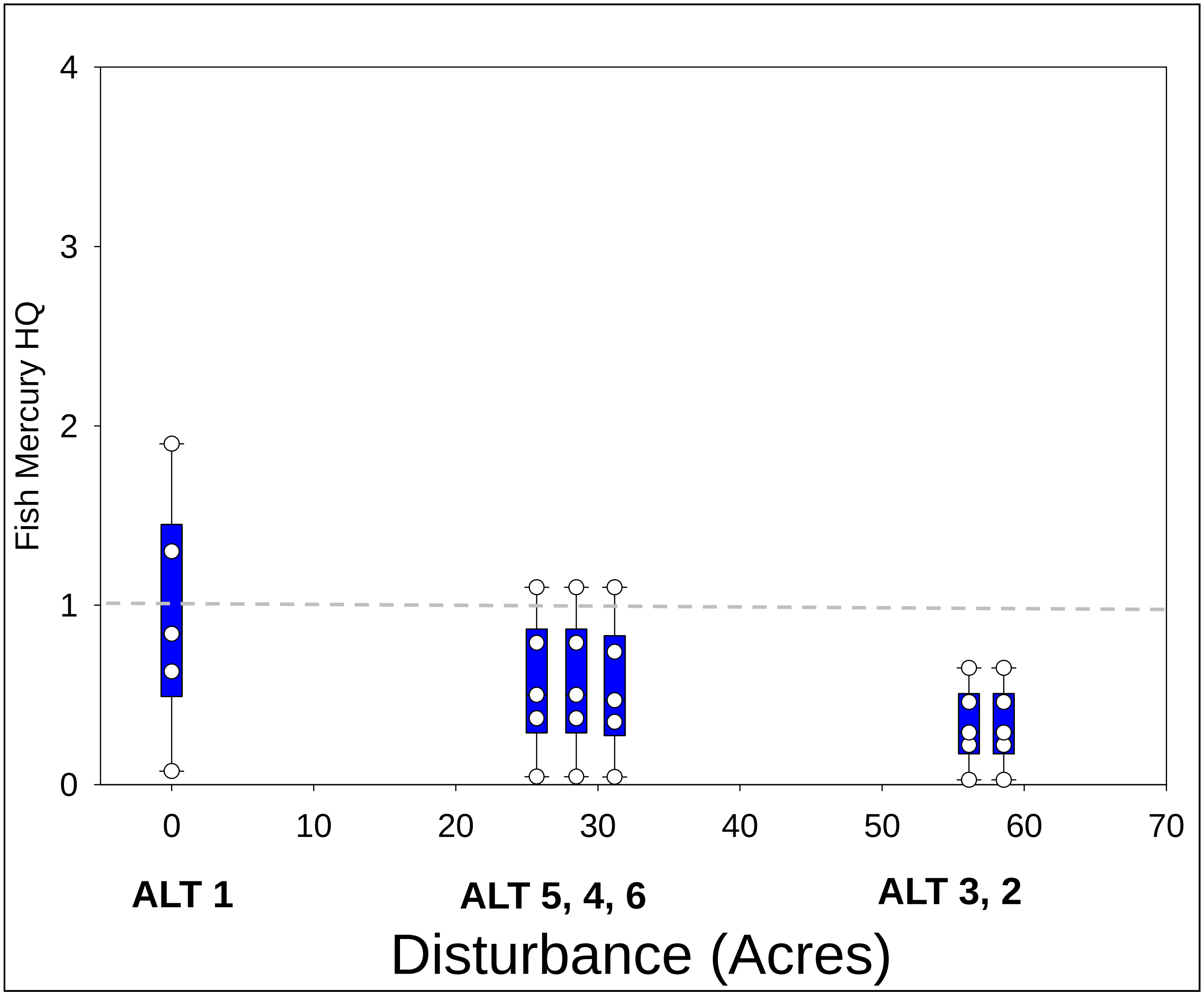
Remedy Alternative Comparison for Finfish Aroclor 1268 Risk Reduction HQs by Disturbance (Acres)

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

7-3B

DRAFT



- Box indicates 25th and 75th percentiles.
- Middle of box is the median.
- Whiskers indicate 10th and 90th percentiles.
- Points indicate finfish HQs from Section 6 (Figure 6-4A).
- ALT=Alternative.
- HQ =Hazard quotient.

Alternative	Disturbance in acres
ALT 1	0
ALT 2	59
ALT 3	56
ALT 4	29
ALT 5	26
ALT 6	31

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Remedy Alternative Comparison for Finfish Mercury Risk Reduction and Disturbance (Acres)

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

7-3C

DRAFT

Appendix A
Groundwater Evaluation

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

Contents

List of Tables

List of Figures

Acronyms and Abbreviations

%	percent
cfs	cubic feet per second
COC	contaminants of concern
CSM	conceptual site model
cm/s	centimeters per second
EPA	US Environmental Protection Agency
ft	feet
ft bgs	feet below ground surface
GAEPD	Georgia Environmental Protection Division
g/d	grams per day
ITRC	Interstate Technology and Regulatory Commission
kg/yr	kilograms per year
mg/kg	milligrams per kilogram
µg/L	micrograms per liter
PAH	polyaromatic hydrocarbons
PCB	polychlorinated biphenyls
ppb	parts per billion
TAL	target analyte list
VOC	volatile organic compounds

1 Introduction

This appendix reports details on the concepts and methods used to calculate mass discharges of mercury, lead, and total PAH towards the marsh sediments through upland groundwater at the LCP Brunswick Site ("Site"). A brief description of the Site hydrogeologic setting is followed by the conceptual model of groundwater flow at the Site. A discussion of the computational framework and software used in the analysis is provided. Details and results of expedited fieldwork conducted at the Site in May 2012 to provide data for the analysis are followed by a discussion of calculated groundwater and mass fluxes at the Site and concluding remarks.

2 Background

The Site is underlain by the Satilla Formation, which is Holocene to Pleistocene in age and about 55-feet (ft) thick in the vicinity of the Site and divided into two general layers. The Upper Satilla sand is the local aquifer and extends to a depth of about 45 ft below ground surface and is composed of uniform very fine to medium sand with thin, discontinuous clay layers. The thin clay layers result in an anisotropic hydraulic conductivity for the formation, in which the vertical hydraulic conductivity of the unit is significantly lower than the horizontal hydraulic conductivity (Geosyntec, 2002). The Lower Satilla is about 10 ft thick and, in the vicinity of the marsh and uplands at the Site, it is variable in texture ranging from clean sand to dense clayey sand. Slug tests conducted in the Upper and Lower Satilla sand indicate a horizontal hydraulic conductivity on the order of 10^{-2} centimeters per second (cm/sec). Beneath the Satilla formation is the cemented sandstone of the Coosawhatchie Formation (approximate hydraulic conductivity of 10^{-5} cm/sec, Geosyntech, 2002), which forms a confining layer between the Satilla sands and underlying aquifers within the Coosawhatchie Formation. **Figure A1** shows a conceptual cross section of the site layering for the local flow system.

Groundwater and surface water interactions at the Site are attenuated by the marsh sediments that overlie the Satilla formation and locally provide confined conditions for groundwater flow. Measured hydraulic conductivities of the marsh clay are consistently low ($1.3x10^{-7}$ to $1.8x10^{-8}$ cm/s) (GeoSyntec, 1997) and texture is consistently fine grained as well. The marsh sediments are typically 7-8 ft thick, though locally it may be thicker, and near the uplands it may be thinner. In isolated locations, the potential for localized groundwater seepage to the surface water exists, as indicated by a thermal infrared (IR) study conducted in 2009 (Stockton Infrared Thermographic Services, 2009; EPS 2012).

The groundwater in the Satilla formation at the Site is non-potable due to naturally occurring high dissolved mineral content. Groundwater within the surficial water bearing zone (upper 50 ft) underlying the Site uplands contains inorganic and organic chemicals associated with past upland disposal practices. Locally groundwater flows from east to west (**Figure A2**) and, based on groundwater level measurements taken during low-tide events, there is an upward gradient through the sediments during low tide. During flood tide, this gradient is reversed, based on measured groundwater head elevations and known tide elevations. Such gradient reversals create a “hyporheic” zone by introducing surface water into the marsh sediment pore water, and potentially beyond the interface with the groundwater aquifer.

Flow from the uplands toward the marsh occurs within the Satilla sand aquifer beneath the marsh and results in discharge to the marsh sediments via seepage and to Purvis Creek, which ultimately discharge to the Turtle River. Groundwater seepage to the surface water may occur as diffuse flow through the marsh sediments, or as focused flow through seeps. It should be noted that, while groundwater seepage is a potential pathway into the upland fringe marsh areas, any transport is likely attenuated by the dense organic rich clay sediments along the marsh.

Groundwater seeps were first noted during the initial site characterization studies in 1995, occurring along the marsh edge, where the marsh clay was absent and the underlying sand exposed. Seepage events are typically brief (on the scale of a few days) and are observed to occur during high water table conditions following extended or intense rainfall events. Depending upon the intensity and duration of the rainfall event, the seepage occurs mostly at isolated locations. Near shore groundwater seeps have been sampled by lysimeters in 2001 and 2003 and groundwater from the seeps is characterized by mercury concentrations of less than 10 micrograms per liter (µg/L) (EPS, 2009).

In order to determine whether preferential groundwater pathways exist that could result in focused groundwater discharge in the marsh, a thermal IR study was conducted on June 15, 2009 (Stockton Infrared Thermographic Services, 2009). This study identified 14 areas of focused groundwater discharge or seeps at the marsh surface, near the marsh shoreline, and along the channel edges. Seeps identified in the thermal IR study show a low intensity of groundwater discharge. The seeps in locations adjacent to contaminated upland wells are isolated and do not form a thermal trace that impacts the temperature in a marsh surface channel.

The presence of seeps raised the concern that the groundwater transport pathway into the marsh, via the seeps, may be significant. To address this concern, a sampling program was designed and implemented to determine whether seeps in the marsh flats represent preferential flow paths for elevated concentrations of contaminants of concern (COC). Seep locations were chosen for the deployment of pore water samplers, or “peepers”. Peepers were placed at two depths within each of the identified seep areas to examine the COC pore water concentrations in the marsh at each location. The peeper investigation targeted locations where the IR imagery results showed the greatest potential for groundwater seepage into the marsh. Thus, the approach was inherently conservative, targeting the greatest potential for contaminant migration into the marsh. The peeper results suggest that transport of mercury, lead, total PAHs, and Aroclor-1268 via focused groundwater pathways in the marsh result in nominal concentrations at the point of discharge. [1]

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[1] Peeper Aroclor 1268 concentrations were non-detect (<0.005 µg/L) in 16 of 18 samples representing 8 seep stations in the marsh; the two detections occurred in near shore peepers, including the peepers at Seep 10D (0.0092 µg/L) and Seep 11S (0.012 µg/L). These results, combined with the observation that Ar1268 concentrations in all groundwater samples supporting this analysis were non-detect, eliminated concern for Ar1268 transport to the marsh via groundwater.

3 Conceptual Site Model of Local Groundwater Flow to the Estuary

The groundwater conceptual site model (CSM) includes local groundwater flow from the uplands into the salt marsh crossing a vertical plane parallel to the marsh boundary along four flow paths, among which the groundwater COC contribution is divided as illustrated in **Figure A3**. Shallow groundwater in the Satilla aquifer, down to the cemented sandstone, migrates towards the marsh, approximately perpendicular to the marsh boundary. COCs that are transported along each flow path encounter a sequence of geochemical conditions that affect the fate of the COCs as they are transported. Each groundwater flow path is discussed next from longest to shortest:

- Flow Path to Purvis Creek and Beyond: The longest flow path is from the uplands to Purvis Creek and beyond. This path is dominated by water that begins near the bottom of the Satilla sand aquifer at the marsh boundary and is transported more than 1000 ft within the Satilla sand. The groundwater enters the marsh sediments from below. Discharge may occur as diffuse-flow through the marsh sediments, or through focused seeps that emanate in Purvis Creek.
- Flow Path to Marsh Flats and Intertidal Channels: This flow path begins with groundwater at depth along the marsh boundary. The groundwater is transported within the aquifer and enters the marsh sediments from below. Discharge through the marsh sediments may occur as diffuse-discharge through the marsh sediments, or through focused seeps.
- Flow Path to Restored Marsh Area: This flow path begins at shallow depths along the marsh boundary; groundwater is transported less than 500 ft from the upland within the aquifer. The groundwater then enters the marsh sediments from below. Discharge through the marsh sediments may occur as diffuse-discharge through the marsh sediments, or through focused seeps.
- Flow Path to Near Shore Seeps: The shortest flow path between the upland groundwater and the marsh leads to near shore seeps, such as those that have been identified and sampled by lysimeters. This transport flow path is dominated by the shallowest groundwater in the aquifer along the marsh boundary. The groundwater may be expressed at the surface after intense rainfall events. The distance of transport within the aquifer is short and the discharge to the surface may be in an area where marsh sediments are thinner than out on the marsh flats.

Each of these flow paths encounters lithologic and biogeochemical zones that affect the fate of the COCs being transported. The major differences between the flow paths are related to the residence time of the groundwater in the various lithologic and biogeochemical zones. Along each flow path, the zones encountered are as follows: the aquifer, the marsh sediments below the root zone, and the marsh sediments within the root zone. Upon discharge to the surface, direct mixing with tidal surface water occurs. The more focused the discharge (i.e., as a seep), the higher the potential COC concentration, but also the greater the influence of surface water dilution at the point of discharge to the surface water. Conversely, diffuse discharges upwelling through the sediment bed will be subject to more attenuation within the sediments, and also are subject to dilution at the point of discharge to the surface water.

4 Computational Framework

In order to evaluate the COC mass being transported by these groundwater pathways, a transect-based mass flux calculation known as the "Transect Method" and outlined by the Interstate Technology and Regulatory Commission (ITRC, 2010) was employed. ITRC is a state-led coalition of regulators, industry experts, citizen stakeholders, academia, and federal partners that work to achieve regulatory acceptance of environmental technologies and innovative approaches. The Transect Method relies on groundwater samples collected along a transect perpendicular to and intersecting a groundwater plume (**Figure A4a**). The transect is divided into any number of sub-areas, each representing a discrete area of uniform concentration and groundwater flow such that the full width and thickness of the plume is defined. Groundwater data are interpolated across the transect to map COC concentrations; the resulting interpolation map represents the COC concentration distribution in the transect at the time of sampling (**Figure A4b-c**).

The mass discharge (mass per unit time) through each sub-area is calculated as:

$$M_i = K_i \times h_i \times C_i \times A_i$$

Where, M_i is the mass discharge, K_i is the hydraulic conductivity, h_i is the hydraulic gradient, C_i is the concentration and A_i is the area of subarea i. The groundwater flow direction and hydraulic gradient for each segment of the transect can be determined from potentiometric surface contour maps. Representative measurements of hydraulic conductivity can be obtained from field tests (e.g., slug or pumping tests). An interpolation is used to fill gaps of concentration and flow data.

The total mass discharge M through the transect then becomes the sum of all individual mass discharges:

$$M = \sum_{i=1}^{n} M_i$$

where n represents the number of all subareas on the transect cross section.

Application of this method to the Site was supported by historic water level maps and historic measurements of hydraulic conductivities based on site-specific slug tests conducted in wells located within the transect. In addition, recent field sampling and drilling was conducted in consultation with the US Environmental Protection Agency (EPA) and Georgia Environmental Protection Division (GAEPD) to gather a current and consistent measure of COC concentrations along the transect.

5 Field Work

5.1 Expedited Field Work

To support the groundwater flux analysis, eleven additional monitoring wells (six locations) were installed between May 14-16, 2012. Locations were selected approximately mid-distance between existing monitoring well cluster locations bordering the marsh, to address potential gaps in the COC concentrations used in the flux analysis. At five of the new well locations (DP-1, DP-2, DP-3, DP-5, DP-6), paired wells were completed, with one set at approximately 14 ft below ground surface (ft bgs), the “A” well, and one set at approximately 28 ft bgs, the “B” well. Location DP-4 was set with a single shallow “A” well at approximately 14 ft bgs to compliment to existing monitoring well cluster MW-104B/C. **Figure A5** shows the sampling transect to which the flux analysis was applied and the monitoring well locations sampled for the purpose of the flux analysis.

5.2 Field and Laboratory Parameters

Following DP well installation and well development all transect wells shown on **Figure A5** were sampled for the following constituents of interest to support the flux analysis:

Potential COCs	Geochemical/Indicator Parameters
target analyte list metals (TAL metals)	silica
mercury	sulfate/sulfide
volatile organic compounds (VOC)	chloride
polyaromatic hydrocarbons (PAH)	total organic carbon
polychlorinated biphenyls (PCB)	pH

The newly installed DP wells exhibited high turbidity during sampling and therefore an additional set of metals samples were collected for filtered sample testing.

5.3 Results of Expedited Field Work

Tables A1 to **A6** provide the groundwater analysis results for all transect wells grouped by parameter type: VOC, PAH, PCB, metals, geochemical indicators and field parameters.

5.3.1 Potentiometric Surface Map

On the day prior to initiating the groundwater sampling, depth-to-water measurements were performed during low tide in all of the monitoring wells on the project site. Due to the high dissolved solids content of the groundwater, the field water level measurements are subsequently adjusted to an equivalent fresh water head value (based on water temperature and Total Dissolved Solids). Field water levels and corrected water levels are provided in **Table A7**. Corrected groundwater levels were used to construct a site potentiometric surface, as shown on **Figure A6**. This potentiometric surface is consistent with past derivations, and shows a westerly groundwater flow direction (from high ground uplands across the marsh).

5.3.2 DP Boring Logs

Boring logs for the DP Series well are included in supplemental figures. In general, all borings exhibited sand, fine to coarse grade, with some silt at all levels, with the exception of DP-5. DP-5 also exhibits several ft of clay inter-bedded with sand.

6 Site Specific Computations of Groundwater Flux and Mass Discharges

The Transect Method was applied to the LCP estuary using groundwater samples from wells located along the upland boundary of the marsh (**Figure A5**). This method allows the mass of COCs migrating in the groundwater at the marsh boundary to be quantified. The groundwater flow pathways describing the flow towards the marsh are discussed in the groundwater CSM. Initial application of this method for mercury was completed using the available chemistry data from upland wells located at the marsh boundary (based on concentrations from 2010 and earlier). That analysis indicated that the mass of mercury transported by the groundwater flow paths toward the restored marsh area was insufficient to account for the measured mercury in the restored marsh. This preliminary finding was consistent with the hypothesis of tidal redistribution of in-channel sediment into the restored marsh.

In May 2012, the upland wells along the plume transect and supplemental temporary groundwater sampling points were installed and sampled. The selection of upland wells, sampling methods, and analytical constituents and methods were reviewed with EPA and GAEPD. The consensus of the review meeting was incorporated into a groundwater monitoring work plan (EPS, 2012). The 2012 groundwater data are used to calculate the mass of COCs being transported by groundwater toward the marsh.

The locations of the wells at the Site that are used to form transects are shown in **Figure A7**. To facilitate interpretation of results, a total of five transects are formed north of the causeway (Transects 4 and 5) and south of the causeway (Transects 1, 2, and 3) along the boundary between the restored marsh area and uplands. **Table A8** lists the transects by number and provides the associated individual wells, well clusters, and temporary points that make up each transect.

Temporary DP series monitoring wells were installed along the upland transect in order to provide additional sampling locations so that better estimates of the mass flux from the uplands could be calculated. These sampling points and their chemistry data were collected during the May 2012 expedited field event.

6.1 Data used in the computation

Hydraulic conductivity values (**Table A9**) at different depths were used in the mass discharge calculations and were determined from slug tests (Geosyntec, 1997). Hydraulic gradient from the uplands towards the marsh is taken from potentiomentric surface maps from the October 2006 and October 2005 sampling events. The most recent potentiometric surface map from the May 2012 water level event (**Figure A6**) is consistent with these previous measurement events. As a simplifying assumption, a value of $3.0x10^{-3}$ feet/feet is used and is considered biased high since the maps represent the hydraulic gradient at low tide (when the hydraulic gradient between the upland and the marsh is at a maximum). Concentration values used in the calculation for mercury, lead, and total PAH at each well location are listed in **Table A10**.

The following conservative assumptions / approaches were used to establish a conservatively-biased flux analysis that is considered highly protective of the marsh.

- For the cases where both filtered and unfiltered sample analyses were available, the concentration for the unfiltered sample was used in the calculation.
- Depth to the water table is used in the Transect Method calculation to provide an upper boundary for the concentration interpolation. The water level depths used in these calculations are provided in **Table A11**, and are taken from the sampling conducted in May 2010, which are consistent with the data from the May 2012 water level event.
- A positive gradient was assumed for 100% of the calculation (i.e., the flux analysis assumed low tide conditions exist at all times).
- The Transect Method calculation assumes that the transects cover the full width and thickness of the plume. As a conservative assumption, the plume is assumed to start at the water table, and the concentration value measured in the upper most well in the cluster is applied uniformly to the area between the water table and the top of the screen.
- At temporary well locations DP-1, DP-2, DP-3, DP-5 and DP-6, there are only two vertical points for the calculation; none of the DP series temporary wells penetrated to the full depth of the aquifer. At each of these temporary wells, an aquifer bottom depth is estimated by interpolating top of sandstone layer from two adjacent wells. The relatively conservative concentration value at the deeper temporary well is applied uniformly down to the estimated aquifer bottom.

6.2 Computation Results

The computations were conducted using the Mass Flux Toolkit developed for the Environmental Security Technology Certification Program (ESTCP) by GSI Environmental (Farhat S. and Newell, C.J., 2011).[2] The computed estimates of mass discharge (kg/yr) towards the marsh through the groundwater pathway are shown in **Table A12**. Vertically, the total mass discharge along each transect is divided among the four groundwater pathways identified in the conceptual site model, and attenuation will occur along each pathway.

The highest mass flux for lead and mercury is found in Transect 1, which contains the wells with the highest concentrations of those substances in shallow groundwater. The flux computed for Transect 1 is 0.35 kilograms per year (kg/yr) mercury, and 0.73 kg/yr lead. Transect 5 shows the largest Total PAH flux of 0.72 kg/yr; the Transect 5 lead flux was 0.62 kg/yr.

6.3 Analysis of Results

Transport of the COCs towards the marsh along a groundwater pathway may have two potential impacts. Surface water quality could be impacted, or contaminants can adsorb onto sediments and thus sediment concentrations could be impacted. In order to assess the potential impact on these media, three analyses were performed. The first analysis compared the potential increase in surface sediment mercury concentrations south of the causeway to measured values over the same period. The second analysis computed the groundwater-surface water dilution that occurs within the marsh south of the causeway based on surface water hydrodynamic modeling results, and the mass flux analysis. The third analysis simply compared the magnitude of the mass

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[2] A full set of live computations was submitted to the Agencies for their technical review prior to submitting this FS.

discharge based on the mass flux analysis to published values to evaluate the magnitude of mercury, lead, and Total PAH discharges and whether those discharges pose concern.

Analysis 1. A 14-acre portion of the marsh was excavated, backfilled with clean soil and re-vegetated with marsh grasses in 1999. Sampling of the surface sediment was conducted across this area approximately four years after the remediation. The average mercury concentration found in the remediated portion of the marsh after this 4 year period was 0.54 mg/kg. At issue is whether the 0.54 mg/kg concentration of mercury in the remediated sediments could be attributed to groundwater transport of mercury.

Mercury transport to the remediated marsh sediments, along the groundwater pathway, can be calculated based on the flux analysis. The maximum possible amount of mercury that could have been transported via the groundwater pathway was computed using the following conservative assumptions:

1) No chemical processes attenuate mercury along the groundwater pathway
2) Transport of mercury accumulates only in the top 1 ft of sediments (i.e., not in deeper sediments)
3) 20% of the mercury mass discharged along transects 1, 2, and 3 south of the causeway is partitioned into the 1 ft of remediated marsh surface sediments. Assumption 3 accounts for the existence of the other transport pathways to portions of the marsh further away from the shoreline.

Based on these assumptions the maximum sediment concentration that could be attributed to a groundwater pathway over the 4 year accumulation period is calculated as follows:

$$Mass\ Accumulation = \frac{Mass\ Flux\ x\ 4\ years}{Sediment\ Mass\ (i.e.,surface\ area\ x\ thickness\ of\ 1\ ft/bulk\ density)}$$

Based on the mass discharge results shown in **Table A12**, an assumed sediment thickness of 1 ft, a remediated surface area of 11 acres, a sediment bulk density of 1.2 grams per cubic centimeter, and four years of mercury accumulation, the estimated maximum groundwater contribution to the average surface sediment bed concentration would be 0.02 milligrams per kilogram (mg/kg). This is over an order of magnitude less than the measured sediment bed concentration of 0.54 mg/kg, and demonstrates that the groundwater pathway is an insignificant contributor to mass accumulation within the sediments. The actual mass transported to the sediments over this time period via groundwater is expected to have been much less than 0.02 mg/kg because conservative assumptions were applied in the flux calculation, attenuation of mercury by chemical processes within the marsh along the groundwater pathway does occur, and the marsh sediment thickness is known to be 7-8 ft in this area.

Analysis 2. The second analysis is based on the dilution that takes place upon groundwater discharge to surface water. Dilution of the groundwater results in attenuation of the groundwater concentrations, and should be considered for evaluating the impact on receptors in the surface water due to in-stream water quality. An estuary system with tidal flushing can be evaluated by the equivalent flow out of the domain (Mitsch and Gosselink 2000). Using the methods reported by Mitsch and Gosselink (2000), the hydrodynamic model was employed to estimate the flow of water through the marsh, south of the causeway, due to tidally influenced flows. These tides equate to an effective flow of 130 cubic feet per second (cfs).

Of the five transects in **Table A8**, the first three are located south of the causeway and were used to compare to the estimated estuarine stream flow calculated in the previous paragraph. The groundwater flows through Transects 1, 2, and 3 are 0.033, 0.018, and 0.022 cfs, respectively. The sum of these groundwater flows into the surface water flow of 130 cfs results in approximately 1800:1 dilution of the flow of groundwater into surface water for the marsh south of the causeway.

Measured or estimated pore water concentrations will experience significant dilution upon discharge to the surface water. Peeper studies that evaluated marsh pore-water concentrations exhibited very low concentrations of COCs. For example, the mercury median (0.0036 parts per billion [ppb]) result and the lead median (<4 ppb) result for the peeper study would be diluted to significantly below non-detect concentrations in the surface water. Even a point computation of the highest mercury concentration from the peeper study (6 ppb mercury measured in the peeper at seep 11-D), when diluted 1800:1 in the surface water, represents a concentration of only 0.003 ppb in surface water. This analysis shows that the low pore-water concentrations of COCs measured in marsh sediments, when further diluted by surface water mixing, will result in no change to in-stream water quality. Groundwater is therefore not a significant contributor to COCs in surface water.

Analysis 3. The third analysis uses the plume classification system of Newell et al. (2011) to provide a sense of the magnitude of the mass fluxes calculated in this appendix. That work classifies the magnitudes of mass discharges and aligns the magnitudes with a surface water (stream flows) or groundwater receptor (pumping rates) size that might be of concern. The classification system is developed from a 40-site database of mass discharge measurements, which span eight orders of magnitude (from 0.00078 grams per day [g/d] to 56,000 g/d).

Both mercury and lead plumes at the Site, based on their estimated total mass discharges of 1.21 g/d and 4.11 g/d through all five transects, are classified as Magnitude 5 plumes (the other COCs would fall into a lower class). Based on the classification system, a magnitude 5 plume would not be a threat to a 1 cfs stream. Based on the hydrodynamic modeling, the comparable stream size for the entire marsh system being evaluated here is approximately 500 cfs.

Based on the mass flux analysis conducted, and the size of the marsh system, the groundwater pathway is not a significant issue for sediment or water quality in the marsh. From the analysis presented, as a transport pathway the groundwater is not a significant contributor to sediment concentrations. In addition, groundwater is not a significant contributor to COCs in surface water. Based on plume magnitude, the size of this groundwater plume is very small compared to the flux necessary to result in a potential threat to general surface water quality at this site.

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Tables

Table A1
Results of 2012 Transect Monitoring Program - Wells Analyzed for Volatile Organic Compounds
LCP Chemical, Brunswick, GA

Location	1,1,1-Trichloroethane	1,1,2,2-Tetrachloroethane	1,1,2-Trichloroethane	1,1-Dichloroethane	1,1-Dichloroethene	1,2-Dichloroethane	1,2-Dichloropropane
DP-1A	<0.075	<0.16	<0.14	0.09	<0.08	<0.08	<0.095
DP-1B	<0.38	<0.8	<0.7	<0.39	<0.4	<0.4	<0.48
DP-2A	<0.75	<1.6	<1.4	<0.77	<0.8	<0.8	<0.95
DP-2B	<0.38	<0.8	<0.7	<0.39	<0.4	<0.4	<0.48
DP-3A	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	<0.095
DP-3B	<0.75	<1.6	<1.4	<0.77	<0.8	<0.8	<0.95
DP-4A	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	<0.095
DP-5A	<0.075	<0.16	<0.14	0.43	<0.08	<0.08	<0.095
DP-5B	<0.075	<0.16	<0.14	0.16	<0.08	<0.08	<0.095
DP-6A	<0.075	<0.16	<2.8	<0.077	<0.08	<0.08	<0.095
DP-6B	<0.38	<0.8	<0.7	<0.39	<0.4	<0.4	<0.48
MW-104B	<0.075	<0.16	<0.14	0.51	0.09	<0.08	<0.095
MW-104C	<0.75	<1.6	<1.4	1.7	<0.8	<0.8	<0.95
MW-110A	<0.15	<0.32	<3.5	<0.16	<0.16	<0.16	<0.19
MW-110B	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	<0.095
MW-110C	<0.075	<0.16	<0.14	0.18	<0.08	<0.08	0.1
MW-111A	<0.75	<1.6	<1.4	3.2	1.4	<0.8	<1.1
MW-111B	<0.75	<1.6	<1.4	1	<0.8	<0.8	<0.95
MW-111C	<0.075	<0.16	<0.14	0.27	<0.08	<0.08	0.27
MW-112A	<0.38	<0.8	<0.7	<0.39	<0.4	<0.4	<0.48
MW-112B	<0.38	<0.8	<0.7	<0.39	<0.4	<0.4	<0.48
MW-112C	<0.38	<0.8	<0.7	<0.39	<0.4	<0.4	<0.48
MW-113A	<0.19	<0.4	<0.35	<0.2	<0.2	<0.2	<0.24
MW-113B	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	<0.095
MW-113C	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	<0.095
MW-114A	<0.075	<0.16	<1.4	<0.077	<0.08	<0.08	<0.095
MW-114B	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	<0.095
MW-114C	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	0.8
MW-354A	<0.075	<0.16	<0.14	0.23	<0.08	<0.08	<0.095
MW-354B	<0.38	<0.8	<0.7	4.8	<0.4	<0.4	<0.48
MW-358A	<0.075	<0.16	<0.14	<0.077	<0.08	<0.08	<0.095
MW-358B	<0.38	<0.8	<0.7	1.3	<0.4	<0.4	<0.48

Table A1
Results of 2012 Transect Monitoring Program - Wells Analyzed for Volatile Organic Compounds
LCP Chemical, Brunswick, GA

Location	2-Butanone (MEK)	2-Hexanone	4-Methyl-2-pentanone	Acetone	Benzene	Bromodichloromethane	Bromoform
DP-1A	<1.9	<2.7	<2.6	<3.3	0.2	<0.091	<0.16
DP-1B	<9.5	<14	<13	<17	<0.31	<0.46	<0.8
DP-2A	<19	<27	<26	<33	6.4	<0.91	<1.6
DP-2B	<9.5	<14	<13	<17	4.4	<0.46	<0.8
DP-3A	<1.9	<2.7	<2.6	17	0.08	<0.091	<0.16
DP-3B	<19	<27	<26	<33	4.6	<0.91	<1.6
DP-4A	<1.9	<2.7	<2.6	6.5	1.5	<0.091	<0.16
DP-5A	<1.9	<2.7	<2.6	<3.3	0.07	<0.091	<0.16
DP-5B	<1.9	<2.7	<2.6	<3.3	0.09	<0.091	<0.16
DP-6A	5.2	<54	<2.6	19	68	<0.091	<3.2
DP-6B	<9.5	<14	<13	18	13	<0.46	<0.8
MW-104B	<1.9	<2.7	<2.6	<3.3	0.29	<0.091	<0.16
MW-104C	<19	<27	<26	<33	1.3	<0.91	<1.6
MW-110A	10	<68	<5.2	41	100	<0.19	<4
MW-110B	<1.9	<2.7	<2.6	<3.3	0.97	<0.091	<0.16
MW-110C	<1.9	<2.7	<2.6	3.5	1	<0.091	<0.16
MW-111A	120	<27	<26	460	14	<0.91	<1.6
MW-111B	<19	<27	<26	<33	5.1	<0.91	<1.6
MW-111C	<1.9	<2.7	<2.6	<3.3	0.57	<0.091	<0.16
MW-112A	<9.5	<14	<13	<19	0.95	<0.46	<0.8
MW-112B	<9.5	<14	<13	<17	1.9	<0.46	<0.8
MW-112C	<9.5	<14	<13	110	4.8	<0.46	<0.8
MW-113A	<4.8	<6.8	<6.5	<12	1.3	<0.23	<0.4
MW-113B	<1.9	<2.7	<2.6	<12	1.2	<0.091	<0.16
MW-113C	12	<2.7	<2.6	120	0.36	<0.091	<0.16
MW-114A	<1.9	<2.7	<2.6	<31	0.15	<0.091	<0.16
MW-114B	<1.9	<2.7	<2.6	<11	<0.062	<0.091	<0.16
MW-114C	<1.9	<2.7	<2.6	<3.3	1.3	<0.091	<0.16
MW-354A	<1.9	<2.7	<2.6	<3.3	1.4	<0.091	<0.16
MW-354B	<9.5	<14	<13	<18	3.8	<0.46	<0.8
MW-358A	<1.9	<2.7	<2.6	<3.3	0.3	<0.091	<0.16
MW-358B	18	<14	<13	190	3.9	<0.46	<0.8

Table A1
Results of 2012 Transect Monitoring Program - Wells Analyzed for Volatile Organic Compounds
LCP Chemical, Brunswick, GA

Location	Bromomethane	Carbon disulfide	Carbon tetrachloride	Chlorobenzene	Chloroethane	Chloroform	Chloromethane
DP-1A	<0.1	1.1	<0.096	<0.11	<0.16	<0.072	<0.068
DP-1B	<0.5	3.8	<0.48	<0.55	<0.8	<0.36	<0.34
DP-2A	<1	0.9	<0.96	<1.1	<1.6	<0.72	<0.68
DP-2B	<0.5	<0.35	<0.48	81	<0.8	<0.36	<0.34
DP-3A	<0.1	0.92	<0.096	<0.11	<0.16	<0.072	<0.068
DP-3B	<1	0.7	<0.96	2.7	<1.6	<0.72	<0.68
DP-4A	<0.1	0.36	<0.096	170	<0.16	<0.072	<0.068
DP-5A	<0.1	0.33	<0.096	0.14	<0.16	<0.072	<0.068
DP-5B	<0.1	0.29	<0.096	0.3	<0.16	<0.072	<0.068
DP-6A	<0.1	1.8	<0.096	<2.2	<0.16	<0.072	<0.068
DP-6B	<0.5	1.1	<0.48	<0.55	<0.8	<0.36	<0.34
MW-104B	<0.1	0.08	<0.096	0.26	<0.16	<0.072	<0.068
MW-104C	<1	<0.69	<0.96	2.3	<1.6	<0.72	<0.68
MW-110A	<0.2	1.2	<0.2	<2.8	<0.32	<0.15	<0.14
MW-110B	<0.1	<0.069	<0.096	<0.11	<0.16	<0.072	<0.068
MW-110C	<0.1	<0.069	<0.096	<0.11	<0.16	<0.072	<0.068
MW-111A	<1	2.1	<0.96	<1.1	<1.6	<0.72	<0.68
MW-111B	<1	0.8	<0.96	<1.1	<1.6	<0.72	<0.68
MW-111C	<0.1	<0.069	<0.096	<0.11	<0.16	<0.072	<0.068
MW-112A	<0.5	<0.35	<0.48	2.3	<0.8	<0.36	<0.34
MW-112B	<0.5	0.7	<0.48	2.1	<0.8	<0.36	<0.34
MW-112C	<0.5	0.75	<0.48	8.1	<0.8	<0.36	<0.34
MW-113A	<0.25	0.45	<0.24	<0.28	<0.4	<0.18	<0.17
MW-113B	<0.1	0.39	<0.096	2.4	<0.16	<0.072	<0.068
MW-113C	<0.1	<0.069	<0.096	0.14	<0.16	<0.072	<0.068
MW-114A	<0.1	<0.069	<0.096	<0.11	<0.16	<0.072	<0.068
MW-114B	<0.1	<0.069	<0.096	<0.11	<0.16	<0.072	<0.068
MW-114C	<0.1	0.21	<0.096	<0.11	<0.16	<0.072	<0.068
MW-354A	<0.1	<0.069	<0.096	38	<0.16	<0.072	<0.068
MW-354B	<0.5	0.9	<0.48	42	<0.8	<0.36	<0.34
MW-358A	<0.1	0.17	<0.096	9.7	<0.16	<0.072	<0.068
MW-358B	<0.5	0.8	<0.48	31	<0.8	<0.36	<0.34

Table A1
Results of 2012 Transect Monitoring Program - Wells Analyzed for Volatile Organic Compounds
LCP Chemical, Brunswick, GA

Location	cis-1,2-Dichloroethene	cis-1,3-Dichloropropene	Dibromochloromethane	Dichloromethane (Methylene chloride)	Ethyl benzene	m&p-Xylene	o-Xylene
DP-1A	0.09	<0.18	<0.14	<0.1	0.82	1	0.29
DP-1B	<0.34	<0.9	<0.7	1.3	<0.25	<0.55	<0.37
DP-2A	<0.67	<1.8	<1.4	2.3	1.2	1.4	1
DP-2B	<0.34	<0.9	<0.7	1.3	1.1	0.9	0.6
DP-3A	<0.067	<0.18	<0.14	<0.1	0.09	0.13	<0.074
DP-3B	<0.67	<1.8	<1.4	2.2	1.4	3.4	1.6
DP-4A	<0.067	<0.18	<0.14	<0.1	0.11	0.4	0.21
DP-5A	0.14	<0.18	<0.14	<0.13	0.06	0.17	0.24
DP-5B	<0.067	<0.18	<0.14	<0.1	0.43	<0.12	0.12
DP-6A	<0.067	<0.18	<2.8	<14	290	290	41
DP-6B	<0.34	<0.9	<0.7	<11	9.2	31	6.6
MW-104B	0.53	<0.18	<0.14	<0.1	<0.05	<0.11	<0.074
MW-104C	1.4	<1.8	<1.4	2	0.5	<1.1	<0.74
MW-110A	<0.14	<0.36	<3.5	<28	550	390	330
MW-110B	<0.067	<0.18	<0.14	<0.1	1.4	<0.11	<0.074
MW-110C	<0.067	<0.18	<0.14	<0.1	0.23	0.74	0.21
MW-111A	<0.67	<1.8	<1.4	5.4	100	90	100
MW-111B	<0.67	<1.8	<1.4	2.7	23	40	30
MW-111C	0.27	<0.18	<0.14	<0.1	<0.05	<0.11	<0.074
MW-112A	<0.34	<0.9	<0.7	1.9	1.4	2	1.2
MW-112B	0.85	<0.9	<0.7	1.8	2.7	1.8	1.3
MW-112C	<0.34	<0.9	<0.7	1.9	8.4	4.4	1.9
MW-113A	1.2	<0.45	<0.35	0.93	0.83	0.6	<0.19
MW-113B	0.99	<0.18	<0.14	<0.16	0.47	0.66	0.59
MW-113C	0.28	<0.18	<0.14	0.1	0.7	1.2	0.28
MW-114A	<0.067	<0.18	<0.14	<0.14	<0.22	1	0.31
MW-114B	<0.067	<0.18	<0.14	<0.12	<0.05	<0.11	<0.074
MW-114C	0.73	<0.18	<0.14	<0.1	6.1	15	3.4
MW-354A	0.24	<0.18	<0.14	0.12	0.13	0.17	0.13
MW-354B	3.2	<0.9	<0.7	2	10	5.2	3.3
MW-358A	0.16	<0.18	<0.14	0.11	<0.05	<0.11	0.08
MW-358B	0.4	<0.9	<0.7	1.7	12	74	19

Table A1
Results of 2012 Transect Monitoring Program - Wells Analyzed for Volatile Organic Compounds
LCP Chemical, Brunswick, GA

Location	Styrene	Tetrachloroethene	Toluene	trans-1,2-Dichloroethene	trans-1,3-Dichloropropene	Trichloroethene	Vinyl chloride
DP-1A	<0.089	<0.099	0.16	<0.072	<0.068	<0.1	<0.075
DP-1B	<0.45	<0.5	<0.27	<0.36	<0.34	<0.5	<0.38
DP-2A	<0.89	<0.99	3.2	<0.72	<0.68	<1	<0.75
DP-2B	<0.45	<0.5	1.2	<0.36	<0.34	<0.5	<0.38
DP-3A	<0.089	<0.099	0.12	<0.072	<0.068	<0.1	<0.075
DP-3B	<0.89	<0.99	<0.54	<0.72	<0.68	<1	<0.75
DP-4A	<0.089	<0.099	0.3	<0.072	<0.068	<0.1	<0.075
DP-5A	<0.089	<0.099	0.14	<0.072	<0.068	<0.1	<0.075
DP-5B	<0.089	<0.099	0.25	<0.072	<0.068	<0.1	<0.075
DP-6A	<1.8	<2	63	<0.072	<1.4	<0.1	<0.075
DP-6B	<0.45	<0.5	15	<0.36	<0.34	<0.5	<0.38
MW-104B	<0.089	<0.099	<0.054	2.1	<0.068	1.3	0.24
MW-104C	<0.89	<0.99	<0.54	3	<0.68	1.4	<0.75
MW-110A	<2.3	<2.5	540	<0.15	<1.7	<0.2	<0.15
MW-110B	<0.089	<0.099	0.3	<0.072	<0.068	<0.1	<0.075
MW-110C	<0.089	<0.099	0.22	<0.072	<0.068	<0.1	<0.075
MW-111A	<0.89	1.7	29	<0.72	<0.68	1.1	<0.75
MW-111B	<0.89	<0.99	15	<0.72	<0.68	<1	<0.75
MW-111C	<0.089	<0.099	<0.054	<0.072	<0.068	<0.1	<0.075
MW-112A	<0.45	<0.5	1.1	<0.36	<0.34	<0.5	<0.38
MW-112B	<0.45	<0.5	0.4	<0.36	<0.34	<0.5	<0.38
MW-112C	<0.45	<0.5	1.3	<0.36	<0.34	<0.5	<0.38
MW-113A	<0.23	<0.25	0.25	3.6	<0.17	0.33	2.3
MW-113B	<0.089	<0.099	0.54	<0.072	<0.068	<0.1	<0.075
MW-113C	<0.089	<0.099	0.37	0.14	<0.068	<0.1	0.18
MW-114A	<0.089	<0.099	0.45	<0.072	<0.068	<0.1	<0.075
MW-114B	<0.089	<0.099	<0.054	<0.072	<0.068	<0.1	<0.075
MW-114C	<0.089	<0.099	3.1	<0.072	<0.068	<0.1	<0.075
MW-354A	<0.089	<0.099	0.12	0.19	<0.068	<0.1	<0.075
MW-354B	<0.45	<0.5	0.35	<0.36	<0.34	<0.5	<0.38
MW-358A	<0.089	<0.099	0.23	<0.072	<0.068	<0.1	<0.075
MW-358B	<0.45	<0.5	1.9	<0.36	<0.34	<0.5	<0.38

Concentrations expressed in µg/L (micrograms per liter)
< denotes non-detect result

Table A2
Results of 2012 Transect Monitoring Program - Wells Analyzed for Polyaromatic Hydrocarbons
LCP Chemical, Brunswick, GA

Location	1,2,4-Trichlorobenzene	1,2-Dichlorobenzene	1,3-Dichlorobenzene	1,4-Dichlorobenzene	2-Methylnaphthalene	Acenaphthene	Acenaphthylene
DP-1A	<0.096	<0.12	<0.1	<0.12	0.11	0.0084	<0.0034
DP-1B	<0.48	<0.6	<0.5	<0.6	2.6	0.77	<0.059
DP-2A	<0.96	<1.2	<1	<1.2	0.18	0.017	<0.007
DP-2B	<0.48	13	800	390	0.82	0.37	<0.048
DP-3A	<0.096	<0.12	0.14	<0.12	0.012	0.0078	<0.0034
DP-3B	<0.96	<1.2	<1	<1.2	0.088	<0.044	<0.034
DP-4A	<0.096	0.23	1.7	3.5	0.011	0.14	0.019
DP-5A	<0.096	<0.12	0.78	2.7	0.74	0.14	<0.016
DP-5B	410	1.1	21	34	0.039	0.35	<0.12
DP-6A	<0.096	<0.12	<0.1	<0.12	72	0.63	<0.18
DP-6B	<0.48	<0.6	1.1	<0.6	0.67	0.77	<0.085
MW-104B	200	1.7	16	15	0.031	0.27	<0.03
MW-104C	150	1.4	76	68	0.033	0.4	<0.067
MW-110A	<0.2	<0.24	0.34	<0.24	6.5	0.87	<0.44
MW-110B	<0.096	<0.12	<0.1	<0.12	2.9	0.36	<0.049
MW-110C	0.32	<0.12	<0.1	<0.12	0.18	0.0089	<0.0037
MW-111A	<1.5	<1.2	<1	<1.2	200	3	<0.24
MW-111B	<0.96	<1.2	<1	<1.2	62	1	<0.23
MW-111C	<0.096	<0.12	<0.1	<0.12	0.011	<0.0088	<0.0068
MW-112A	<0.48	2.2	1.2	0.85	1.1	0.38	<0.11
MW-112B	<0.48	4.1	<0.5	<0.6	0.26	<0.044	<0.034
MW-112C	<0.48	31	<0.5	1.4	0.081	<0.044	<0.034
MW-113A	<0.24	<0.3	<0.25	<0.3	0.37	1.3	<0.11
MW-113B	<0.096	4.3	<0.1	<0.12	0.99	0.29	<0.037
MW-113C	<0.096	<0.12	<0.1	<0.12	0.29	<0.043	<0.0034
MW-114A	<0.096	<0.12	<0.1	<0.12	0.91	0.42	<0.07
MW-114B	<0.096	<0.12	<0.1	<0.12	0.017	0.16	<0.0052
MW-114C	<0.096	<0.12	<0.1	<0.12	0.011	<0.0093	<0.0035
MW-354A	<0.096	20	0.59	9.4	0.015	0.24	<0.17
MW-354B	<0.48	85	0.55	12	0.47	0.25	<0.055
MW-358A	<0.096	0.47	<0.1	0.34	0.018	<0.0063	<0.0093
MW-358B	<0.48	280	1.6	38	1.8	0.13	<0.034

Table A2
Results of 2012 Transect Monitoring Program - Wells Analyzed for Polyaromatic Hydrocarbons
LCP Chemical, Brunswick, GA

Location	Anthracene	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(g,h,i)perylene	Benzo(k)fluoranthene
DP-1A	0.016	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
DP-1B	0.1	<0.013	<0.022	<0.012	<0.015	<0.013
DP-2A	0.072	<0.0054	0.016	<0.0047	0.0065	<0.0052
DP-2B	0.091	0.11	0.036	0.036	0.015	<0.013
DP-3A	<0.0036	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
DP-3B	<0.052	<0.026	<0.043	<0.023	<0.029	<0.025
DP-4A	0.013	<0.0052	<0.0086	<0.0046	<0.0058	<0.005
DP-5A	<0.012	<0.0052	<0.0086	<0.0046	<0.0058	<0.005
DP-5B	0.032	<0.013	<0.022	<0.012	<0.015	<0.013
DP-6A	0.052	<0.026	<0.043	<0.023	<0.029	<0.025
DP-6B	<0.049	<0.013	<0.022	<0.012	<0.015	<0.013
MW-104B	0.024	<0.0056	<0.0093	<0.005	<0.0063	<0.0054
MW-104C	0.076	<0.006	<0.0098	0.013	<0.0066	<0.0057
MW-110A	0.065	<0.014	<0.023	<0.013	<0.016	<0.014
MW-110B	0.027	<0.015	<0.024	<0.013	<0.016	<0.014
MW-110C	<0.0039	<0.0028	<0.0046	<0.0025	<0.0031	<0.0027
MW-111A	<1.7	<0.052	<0.086	<0.046	<0.058	<0.05
MW-111B	<0.17	<0.026	<0.022	0.042	<0.015	<0.013
MW-111C	<0.0072	<0.0052	<0.0086	<0.0046	<0.0058	<0.005
MW-112A	1.3	1.4	0.58	0.39	0.22	0.085
MW-112B	0.086	<0.026	0.066	0.09	0.029	<0.025
MW-112C	0.1	0.59	0.34	0.34	0.16	<0.025
MW-113A	0.63	0.045	0.0065	0.012	0.0074	<0.0025
MW-113B	0.025	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
MW-113C	<0.0036	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
MW-114A	0.036	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
MW-114B	0.021	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
MW-114C	0.0094	<0.0027	<0.0044	<0.0024	<0.003	<0.0026
MW-354A	0.04	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
MW-354B	<0.15	<0.0054	0.017	0.018	0.016	0.017
MW-358A	<0.013	<0.0026	<0.0043	<0.0023	<0.0029	<0.0025
MW-358B	0.2	<0.026	<0.043	0.072	<0.029	<0.025

Table A2
Results of 2012 Transect Monitoring Program - Wells Analyzed for Polyaromatic Hydrocarbons
LCP Chemical, Brunswick, GA

Location	Chrysene	Dibenzo(a,h)anthracene	Dibenzofuran	Fluoranthene	Fluorene	Hexachlorobutadiene	Indeno(1,2,3-cd) pyrene
DP-1A	<0.0034	<0.0025	0.0065	<0.0056	0.013	<0.11	<0.0026
DP-1B	<0.017	<0.013	0.23	0.03	0.51	<0.55	<0.013
DP-2A	<0.007	0.01	0.016	0.058	0.043	<1.1	<0.0054
DP-2B	0.14	<0.013	0.21	0.069	0.33	<0.55	<0.013
DP-3A	<0.0034	<0.0025	<0.0046	<0.0044	0.0059	<0.11	<0.0026
DP-3B	<0.034	<0.025	<0.046	<0.044	<0.038	<1.1	<0.026
DP-4A	<0.0068	<0.005	<0.0092	<0.0088	0.027	<0.11	<0.0052
DP-5A	<0.0068	<0.005	0.047	0.022	0.091	<0.11	<0.0052
DP-5B	<0.017	<0.013	0.38	<0.022	0.53	<0.11	<0.013
DP-6A	<0.034	<0.025	0.66	<0.044	0.75	<0.11	<0.026
DP-6B	<0.017	<0.013	<0.13	<0.022	0.15	<0.55	<0.013
MW-104B	<0.0074	<0.0054	0.042	<0.0095	0.087	<0.11	<0.0056
MW-104C	<0.0078	<0.0057	0.15	<0.01	0.17	<1.1	<0.006
MW-110A	<0.019	<0.014	0.52	<0.024	0.68	<0.22	<0.014
MW-110B	<0.019	<0.014	0.11	<0.024	0.23	<0.11	<0.015
MW-110C	<0.0037	<0.0027	0.0055	<0.0047	<0.0041	<0.11	<0.0028
MW-111A	<0.068	<0.05	<1.1	<0.088	0.35	<1.1	<0.052
MW-111B	<0.017	<0.013	1.2	<0.022	1.7	<1.1	<0.013
MW-111C	<0.0068	<0.005	<0.0092	<0.0088	<0.0076	<0.11	<0.0052
MW-112A	1.4	0.063	0.17	1.1	0.15	<0.55	0.11
MW-112B	<0.034	<0.025	<0.046	<0.044	0.078	<0.55	0.038
MW-112C	0.69	0.049	<0.046	0.17	<0.038	<0.55	0.09
MW-113A	0.033	<0.0025	1	0.15	1.3	<0.28	0.0055
MW-113B	<0.0034	<0.0025	0.099	<0.0044	0.24	<0.11	<0.0026
MW-113C	<0.0034	<0.0025	<0.0046	<0.0044	<0.0038	<0.11	<0.0026
MW-114A	<0.0034	<0.0025	0.19	0.0048	0.44	<0.11	<0.0026
MW-114B	<0.0034	<0.0025	0.05	<0.0044	0.12	<0.11	<0.0026
MW-114C	<0.0035	<0.0026	<0.0047	0.0068	<0.0091	<0.11	<0.0027
MW-354A	<0.0034	<0.0025	0.039	<0.0044	0.07	<0.11	<0.0026
MW-354B	<0.007	<0.0052	<0.056	<0.009	<0.094	<0.55	0.017
MW-358A	<0.0034	<0.0025	0.01	<0.0044	<0.011	<0.11	<0.0026
MW-358B	<0.034	<0.025	<0.046	<0.044	0.1	<0.55	<0.026

Table A2
Results of 2012 Transect Monitoring Program - Wells Analyzed for Polyaromatic Hydrocarbons
LCP Chemical, Brunswick, GA

Location	Naphthalene	Phenanthrene	Pyrene
DP-1A	0.21	0.028	0.012
DP-1B	1.2	0.67	0.042
DP-2A	0.86	0.11	0.093
DP-2B	1.2	0.31	0.34
DP-3A	0.034	0.0052	<0.0035
DP-3B	0.53	<0.2	<0.035
DP-4A	0.095	<0.01	0.03
DP-5A	1.2	<0.029	0.1
DP-5B	0.51	0.036	0.026
DP-6A	260	0.72	0.077
DP-6B	5.6	<0.076	0.024
MW-104B	0.33	0.015	<0.0076
MW-104C	0.22	<0.025	0.028
MW-110A	110	0.78	0.038
MW-110B	26	0.12	<0.02
MW-110C	0.55	<0.0054	<0.0038
MW-111A	150	<2.2	<0.07
MW-111B	47	<0.13	0.028
MW-111C	0.053	<0.01	<0.007
MW-112A	0.49	0.86	5
MW-112B	2.3	0.12	0.063
MW-112C	6.4	0.12	1.1
MW-113A	0.9	1.1	0.42
MW-113B	0.43	0.15	0.0052
MW-113C	0.68	<0.34	<0.0035
MW-114A	0.55	0.029	0.0095
MW-114B	0.2	0.013	0.0046
MW-114C	0.065	0.01	0.012
MW-354A	0.099	0.01	<0.0035
MW-354B	7	<0.11	0.073
MW-358A	0.033	<0.012	<0.0035
MW-358B	19	0.057	0.045

Concentrations expressed in μg/L (micrograms per liter)
< denotes non-detect result

Table A3
Results of 2012 Transect Monitoring Program - Wells Analyzed for TAL Metals
LCP Chemical, Brunswick, GA

Location	Aluminum	Aluminum, dissolved	Antimony	Antimony, dissolved	Arsenic	Arsenic, dissolved	Barium	Barium, dissolved	Beryllium	Beryllium, dissolved
DP-1A	4750	353	0.48	0.51	3.74	2.73	586	621	0.11	<0.08
DP-1B	59400	2110	0.18	0.24	40.1	12.5	112	6.22	1.88	0.23
DP-2A	3930	582	1.01	1.78	18.6	15.7	34	19.4	0.34	0.27
DP-2B	150000	14500	0.78	1.48	49.2	21.9	494	103	4.96	1.4
DP-3A	7340	75.5	0.58	0.15	4.39	0.83	137	120	0.45	<0.04
DP-3B	3260	2310	0.18	0.71	16.9	14.3	131	128	8.02	7.01
DP-4A	2310	296	0.14	0.4	4.86	3.98	282	272	0.09	<0.04
DP-5A	14.4	4.2	0.88	0.14	2.61	1.99	177	170	<0.16	<0.16
DP-5B	176	52.2	0.05	0.03	0.35	0.28	6.05	5.65	0.01	0.01
DP-6A	179	67.4	0.07	0.1	1.61	1.79	233	211	0.01	0.01
DP-6B	7830	598	0.07	0.42	28.7	7.64	240	40.3	0.16	0.03
MW-104B	733	-	0.05	-	1.34	-	23.5	-	1.15	-
MW-104C	22200	-	0.49	-	15.9	-	411	-	24	-
MW-110A	45.4	-	0.04	-	5.17	-	6.72	-	0	-
MW-110B	118	-	<0.003	-	0.12	-	17	-	0.13	-
MW-110C	10.2	-	0.58	-	0.61	-	529	-	<0.08	-
MW-111A	159000	-	1.52	-	129	-	3910	-	12.9	-
MW-111B	46200	-	0.65	-	46.5	-	1170	-	10.1	-
MW-111C	2	-	0.09	-	0.39	-	94.5	-	<0.04	-
MW-112A	23500	-	0.66	-	9.83	-	191	-	1.13	-
MW-112B	4610	-	0.36	-	35.4	-	282	-	17.7	-
MW-112C	1710	-	1.37	-	66.8	-	137	-	12.3	-
MW-113A	80700	-	0.86	-	27.1	-	145	-	1.85	-
MW-113B	20400	-	0.07	-	6.77	-	99.1	-	1.55	-
MW-113C	105	-	1.81	-	2.03	-	7160	-	<0.16	-
MW-114A	1340	-	0.07	-	1.54	-	9.31	-	0.09	-
MW-114B	12400	-	0.05	-	5.09	-	67	-	1.58	-
MW-114C	221	-	<0.15	-	3.09	-	96.8	-	1.95	-
MW-354A	847	-	0.1	-	1.84	-	9.77	-	0.4	-
MW-354B	18000	-	1.69	-	29	-	712	-	15.7	-
MW-358A	233	-	0.06	-	0.51	-	5.76	-	0.79	-
MW-358B	7540	-	0.36	-	46.6	-	59.8	-	36.2	-

Table A3
Results of 2012 Transect Monitoring Program - Wells Analyzed for TAL Metals
LCP Chemical, Brunswick, GA

Location	Cadmium	Cadmium, dissolved	Calcium	Calcium, dissolved	Chromium	Chromium, dissolved	Chromium, hexavalent	Cobalt	Cobalt, dissolved	Copper	Copper, dissolved
DP-1A	<0.14	<0.14	602000	578000	19	8.53	-	1.27	0.67	1.26	<0.4
DP-1B	0.95	0.07	2360	1050	56.7	13.6	-	29.7	4.81	6.82	1.29
DP-2A	<0.07	<0.07	96800	79800	38.7	30	-	2.4	3.43	9.41	8.02
DP-2B	1.29	0.12	25500	14800	243	87.7	-	25	10.1	24.9	14
DP-3A	0.12	0.07	166000	247000	26.8	1.24	-	2.62	2.07	5.59	0.28
DP-3B	<0.14	<0.14	77000	71300	393	371	-	1.77	2.62	13.3	13.4
DP-4A	0.11	<0.07	211000	206000	5.91	2.87	-	0.51	0.29	0.82	0.24
DP-5A	<0.28	<0.28	333000	342000	<1.2	<1.2	-	<0.36	<0.36	0.93	<0.8
DP-5B	<0.007	<0.007	24800	24600	2.45	2.01	-	0.08	0.03	0.18	0.11
DP-6A	0.01	<0.007	60800	61300	1.75	1.55	-	0.26	0.26	0.29	0.19
DP-6B	4.99	0.2	18300	12700	34.7	10.4	-	33.2	2.91	61.8	4.66
MW-104B	<0.007	-	5250	-	6.88	-	-	0.13	-	0.18	-
MW-104C	0.08	-	31500	-	137	-	-	1.63	-	5.46	-
MW-110A	<0.007	-	83800	-	1.74	-	<40	0.04	-	9.21	-
MW-110B	<0.007	-	2620	-	0.57	-	-	<0.009	-	0.09	-
MW-110C	<0.14	-	625000	-	5.96	-	-	<0.18	-	<0.4	-
MW-111A	2.8	-	8540	-	1420	-	<40	24.8	-	43	-
MW-111B	0.83	-	5160	-	438	-	-	9.31	-	15.7	-
MW-111C	<0.07	-	273000	-	0.35	-	-	<0.09	-	<0.2	-
MW-112A	0.22	-	144000	-	72.1	-	-	1.15	-	12.7	-
MW-112B	0.43	-	50200	-	1350	-	-	5.21	-	56.9	-
MW-112C	1.08	-	48400	-	2660	-	<40	9.24	-	231	-
MW-113A	0.29	-	21500	-	138	-	-	4.54	-	19.7	-
MW-113B	0.41	-	1110	-	26.2	-	-	1.98	-	1.77	-
MW-113C	<0.28	-	4430000	-	8.84	-	-	<0.36	-	4.98	-
MW-114A	0.03	-	3060	-	6.69	-	-	0.14	-	0.35	-
MW-114B	0.13	-	2710	-	40.1	-	-	0.51	-	0.39	-
MW-114C	<0.35	-	84900	-	65.9	-	-	<0.45	-	9.29	-
MW-354A	<0.07	-	3640	-	11.1	-	-	0.35	-	0.83	-
MW-354B	<0.28	-	13600	-	717	-	-	4.2	-	40.1	-
MW-358A	<0.07	-	29200	-	8.79	-	-	0.2	-	2.39	-
MW-358B	0.28	-	9740	-	1220	-	<40	3.08	-	31	-

Table A3
Results of 2012 Transect Monitoring Program - Wells Analyzed for TAL Metals
LCP Chemical, Brunswick, GA

Location	Iron	Iron, dissolved	Lead	Lead, dissolved	Magnesium	Magnesium, dissolved	Manganese	Manganese, dissolved	Mercury	Mercury, dissolved
DP-1A	1500	710	4.82	0.11	446000	432000	474	469	0.88	0.09
DP-1B	32200	1880	10.6	1.05	3560	69.5	181	7.6	20.2	3.27
DP-2A	1590	839	11.7	6.15	18800	16300	132	89.1	8.56	4.96
DP-2B	33000	5460	51.7	8.78	8040	2180	176	44.1	7.08	2.21
DP-3A	15900	6270	5.91	<0.02	103000	68400	907	1110	0.01	<0.02
DP-3B	2390	363	3.58	3.35	61500	56100	188	166	0.76	0.72
DP-4A	13000	11000	0.56	0.11	76200	75700	609	615	0.06	<0.02
DP-5A	928	32.9	<0.08	<0.08	793000	787000	212	210	0	<0.02
DP-5B	5730	5140	0.13	0.05	7330	7030	238	230	0	<0.02
DP-6A	2510	2260	0.45	0.02	8310	8500	307	321	0	<0.02
DP-6B	9750	752	51	4.02	4740	3140	106	42.9	0.02	<0.02
MW-104B	274	-	0.1	-	1340	-	15	-	0.04	-
MW-104C	6290	-	6.78	-	4810	-	182	-	2.54	-
MW-110A	282	-	0.28	-	6150	-	126	-	0.01	-
MW-110B	1940	-	<0.002	-	848	-	25.4	-	0	-
MW-110C	64500	-	<0.04	-	59100	-	1900	-	0.04	-
MW-111A	3360	-	165	-	989	-	16.9	-	6.36	-
MW-111B	6900	-	26	-	1400	-	24.6	-	3.72	-
MW-111C	9720	-	<0.02	-	51800	-	556	-	0	-
MW-112A	2710	-	20.6	-	127000	-	645	-	4.96	-
MW-112B	1160	-	9.05	-	4760	-	153	-	7.72	-
MW-112C	7430	-	7.63	-	172	-	110	-	15	-
MW-113A	11800	-	66.8	-	68100	-	48.8	-	27.6	-
MW-113B	6830	-	3.47	-	1180	-	25.8	-	3.44	-
MW-113C	17.4	-	0.32	-	18.7	-	0.4	-	69.1	-
MW-114A	5110	-	1.42	-	399	-	28.2	-	0.1	-
MW-114B	8470	-	5.58	-	785	-	46	-	0.28	-
MW-114C	336	-	<0.1	-	3280	-	18.8	-	0.48	-
MW-354A	13.8	-	0.15	-	346	-	11.6	-	0.03	-
MW-354B	593	-	5.33	-	1820	-	30.7	-	0.53	-
MW-358A	18	-	0.14	-	54500	-	25.9	-	0	-
MW-358B	1050	-	3.22	-	348	-	48.4	-	12.5	-

Table A3
Results of 2012 Transect Monitoring Program - Wells Analyzed for TAL Metals
LCP Chemical, Brunswick, GA

Location	Nickel	Nickel, dissolved	Potassium	Potassium, dissolved	Selenium	Selenium, dissolved	Silver	Silver, dissolved	Sodium	Sodium, dissolved
DP-1A	6.06	3.33	72500	70700	<5	<5	0.33	0.22	4500000	4360000
DP-1B	33.2	13.3	4060	949	<5	6.5	0.13	0.04	160000	149000
DP-2A	41.7	27.5	15300	14200	7.6	5.7	0.22	0.12	2340000	2260000
DP-2B	45.2	15.5	7740	3780	12.9	12.1	0.17	0.08	477000	425000
DP-3A	17.2	14.2	53400	37600	<5	<5	0.1	<0.05	1280000	1000000
DP-3B	33.2	30.7	24900	22700	<5	6.3	0.13	0.15	5010000	4260000
DP-4A	4.02	2.87	30900	30800	<5	<5	0.05	<0.05	857000	848000
DP-5A	<0.4	<0.4	241000	243000	<5	<5	<0.2	<0.2	6610000	6450000
DP-5B	0.23	0.23	3000	2930	<5	<5	0	<0.005	46900	45800
DP-6A	0.97	0.89	2620	2630	<5	<5	0.01	<0.005	17800	17600
DP-6B	17.2	2.55	3110	1890	7.1	<5	0.04	0.01	92500	83900
MW-104B	0.53	-	1320	-	5.6	-	<0.005	-	112000	-
MW-104C	13.6	-	3110	-	5.8	-	<0.05	-	839000	-
MW-110A	0.45	-	5480	-	<5	-	<0.005	-	119000	-
MW-110B	0.04	-	2250	-	<5	-	<0.005	-	94500	-
MW-110C	0.47	-	9990	-	<5	-	0.56	-	3980000	-
MW-111A	128	-	1340	-	16.7	-	0.42	-	1810000	-
MW-111B	45.7	-	969	-	10.5	-	0.3	-	1210000	-
MW-111C	<0.1	-	2960	-	<5	-	0.15	-	850000	-
MW-112A	13.9	-	21000	-	11.9	-	<0.05	-	2360000	-
MW-112B	145	-	12200	-	13.1	-	<0.1	-	63100000	-
MW-112C	339	-	19900	-	23.2	-	<0.2	-	10900000	-
MW-113A	41	-	18000	-	12.2	-	0.08	-	2290000	-
MW-113B	4.12	-	2040	-	<5	-	<0.005	-	236000	-
MW-113C	16.3	-	15800	-	10.3	-	<0.2	-	1750000	-
MW-114A	0.44	-	577	-	<5	-	<0.005	-	67100	-
MW-114B	1.03	-	1690	-	6.6	-	<0.005	-	184000	-
MW-114C	8.02	-	55900	-	<5	-	<0.25	-	17500000	-
MW-354A	1.5	-	4440	-	5.2	-	<0.05	-	383000	-
MW-354B	94.4	-	8510	-	11.6	-	<0.2	-	9680000	-
MW-358A	0.76	-	29300	-	<5	-	<0.05	-	846000	-
MW-358B	112	-	3510	-	10.4	-	<0.2	-	8770000	-

Table A3
Results of 2012 Transect Monitoring Program - Wells Analyzed for TAL Metals
LCP Chemical, Brunswick, GA

Location	Thallium	Thallium, dissolved	Vanadium	Vanadium, dissolved	Zinc	Zinc, dissolved
DP-1A	<0.008	<0.008	12	9	5.6	15.9
DP-1B	0.47	<0.0008	64.3	7.4	170	1.7
DP-2A	<0.004	<0.004	357	302	6.4	6.3
DP-2B	0.44	<0.004	360	252	167	11.9
DP-3A	0.05	<0.004	16.2	2.8	20.8	10.1
DP-3B	<0.008	<0.008	734	688	10.4	6.7
DP-4A	<0.004	<0.004	9.6	6.1	2.9	2
DP-5A	<0.016	<0.016	4.7	4.6	<0.7	<0.7
DP-5B	<0.0004	<0.0004	2.1	2.6	4.8	<0.7
DP-6A	<0.0004	<0.0004	2.9	2	0.9	<0.7
DP-6B	1.25	0.04	24.2	9.5	180	6.9
MW-104B	0	-	19	-	0.7	-
MW-104C	<0.02	-	295	-	6.2	-
MW-110A	<0.0004	-	3	-	4.2	-
MW-110B	<0.0004	-	9.8	-	<0.7	-
MW-110C	<0.008	-	7.3	-	1.3	-
MW-111A	0.54	-	2010	-	66.1	-
MW-111B	0.21	-	654	-	39	-
MW-111C	<0.004	-	1.1	-	1.2	-
MW-112A	0.02	-	140	-	21.7	-
MW-112B	<0.008	-	2790	-	33.6	-
MW-112C	<0.016	-	6680	-	62	-
MW-113A	0.12	-	155	-	49	-
MW-113B	0.04	-	82.2	-	35.2	-
MW-113C	<0.016	-	16.6	-	13.1	-
MW-114A	0	-	10.9	-	4.9	-
MW-114B	0	-	117	-	9.5	-
MW-114C	<0.02	-	240	-	7.7	-
MW-354A	<0.004	-	34.8	-	4.1	-
MW-354B	<0.016	-	1350	-	24.7	-
MW-358A	<0.004	-	25.1	-	9.3	-
MW-358B	<0.016	-	2310	-	30	-

Concentrations expressed in mg/L (milligrams per liter)
< denotes non-detect result
- denotes parameter not sampled

Table A4
Results of 2012 Transect Monitoring Program - Wells Analyzed for Polychlorinated Biphenyls
LCP Chemical, Brunswick, GA

Location	Aroclor-1016	Aroclor-1221	Aroclor-1232	Aroclor-1242	Aroclor-1248	Aroclor-1254	Aroclor-1260	Aroclor-1268
DP-1A	<0.049	<0.057	<0.049	<0.049	<0.11	<0.049	<0.049	<0.049
DP-1B	<0.049	<0.3	<0.049	<0.049	<0.049	<0.067	<0.049	<0.049
DP-2A	<0.051	<0.051	<0.051	<0.051	<0.051	<0.051	<0.051	<0.051
DP-2B	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
DP-3A	<0.049	<0.064	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
DP-3B	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49
DP-4A	<0.049	<0.089	<0.23	<0.049	<0.049	<0.049	<0.049	<0.049
DP-5A	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
DP-5B	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
DP-6A	<0.049	<0.47	<0.08	<0.049	<0.049	<0.049	<0.049	<0.049
DP-6B	<0.062	<0.2	<0.11	<0.059	<0.049	<0.049	<0.049	<0.049
MW-104B	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-104C	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MW-110A	<0.49	<9.8	<0.49	<0.49	<0.49	<0.49	<0.49	<0.49
MW-110B	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-110C	<0.049	<0.096	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-111B	<0.049	<0.16	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-111C	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-112A	<0.055	<0.055	<0.055	<0.055	<0.055	<0.055	<0.055	<0.055
MW-112B	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-112C	<0.057	<0.057	<0.057	<0.057	<0.057	<0.057	<0.057	<0.057
MW-113A	<0.056	<0.056	<0.056	<0.056	<0.056	<0.056	<0.056	<0.056
MW-113B	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-113C	<0.13	<1.5	<0.9	<0.15	<0.093	<0.049	<0.049	<0.049
MW-114A	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049	<0.049
MW-114B	<0.053	<0.053	<0.053	<0.053	<0.053	<0.053	<0.053	<0.053
MW-114C	<0.057	<0.057	<0.057	<0.057	<0.057	<0.057	<0.057	<0.057
MW-354A	<0.054	<0.2	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
MW-354B	<0.056	<0.056	<0.056	<0.056	<0.056	<0.056	<0.056	<0.056
MW-358A	<0.051	<0.051	<0.051	<0.051	<0.051	<0.051	<0.051	<0.051
MW-358B	<0.54	<0.54	<0.54	<0.54	<0.54	<0.54	<0.54	<0.54

Concentrations expressed in µg/L (micrograms per liter)
< denotes non-detect result

Table A5
Results of 2012 Transect Monitoring Program - General Geochemical Indicator Parameters (Laboratory Measurements)
LCP Chemical, Brunswick, GA

Location	Chloride	pH	Silica, as SiO2	Sulfate	Sulfide	Total Dissolved Solids (TDS)	Total Organic Carbon (TOC)
DP-1A	8300	6.49	11.9	1780	2.80	16,100	96.2
DP-1B	20.7	9.35	22.3	13	1.40	821	39.9
DP-2A	2800	9.14	65.6	229	9.40	6,610	390.0
DP-2B	331	8.54	9.7	2.9	0.85	2,110	249.0
DP-3A	1880	6.27	17.1	551	<0.03	4,690	26.1
DP-3B	6890	7.53	19.0	3.1	50.20	13,700	635.0
DP-4A	1950	6.34	8.3	248	2.26	4,050	60.6
DP-5A	13500	7.18	14.8	1720	1.79	24,500	9.1
DP-5B	21	6.37	18.4	37.8	1.95	276	13.8
DP-6A	57.5	6.16	37.7	4.45	7.82	458	46.0
DP-6B	37	6.64	96.2	2.39	4.10	925	18.2
MW-104B	-	6.19	-	-	-	423	-
MW-104C	-	6.50	-	-	-	2,170	-
MW-110A	-	6.40	-	-	-	610	-
MW-110B	-	5.09	-	-	-	303	-
MW-110C	-	6.08	-	-	-	15,400	-
MW-111A	-	6.63	-	-	-	10,100	-
MW-111B	-	9.74	-	-	-	5,000	-
MW-111C	-	6.85	-	-	-	3,900	-
MW-112A	-	7.52	-	-	-	6,180	-
MW-112B	-	8.80	-	-	-	18,900	-
MW-112C	-	10.20	-	-	-	30,900	-
MW-113A	-	8.14	-	-	-	8,350	-
MW-113B	-	9.69	-	-	-	1,000	-
MW-113C	-	11.90	-	-	-	25,200	-
MW-114A	-	6.83	-	-	-	278	-
MW-114B	-	7.10	-	-	-	868	-
MW-114C	-	8.56	-	-	-	45,800	-
MW-354A	-	6.77	-	-	-	918	-
MW-354B	-	7.52	-	-	-	28,000	-
MW-358A	-	6.86	-	-	-	2,520	-
MW-358B	-	10.70	-	-	-	25,000	-

Concentrations expressed in mg/L (milligrams per liter)
< denotes non-detect result
- denotes parameter not sampled

Table A6
Results of 2012 Transect Monitoring Program-General Geochemical Indicator Parameters (Field Measurements)
LCP Chemical, Brunswick, GA

Location	Conductivity (mS/cm)	Dissolved Oxygen (µg/L)	Eh, field (mv)	pH, field	Salinity %	Temperature, field (C°)	Turbidity, field (NTU)
DP-1A	26.2	1.31	-110	6.41	---	20.91	72.2
DP-1B	0.559	0.2	-313	9.27	0.01	21.4	774
DP-2A	11	1.56	-331	9.21		22.57	181
DP-2B	1.94	0.21	-356	8.49	0.07	21.93	71000
DP-3A	5.27	4.09	-94	5.72	0.28	22.19	377
DP-3B	22.5	0.05	-384	7.24	---	20.81	35.5
DP-4A	6.45	0.03	-221	6.17	---	21.41	80
DP-5A	36.9	0.21	-304	7.24	2.25	24.76	0
DP-5B	0.437	2.73	-184	6.29	---	22.24	0
DP-6A	0.506	1	-244	5.49	0.02	21.74	0
DP-6B	0.477	0.04	-255	6.44	---	21.26	776
MW-104B	0.491	1.42	-176	5.86	0.01	21.83	1.52
MW-104C	3.39	0.5	-184	6.24	0.16	21.83	1.4
MW-110A	1.08	0.13	-305	6.17	---	20.99	8.89
MW-110B	0.573	1.41	75	4.81	---	20.73	0
MW-110C	22.6	0.61	-5	5.82	---	20.78	19
MW-111A	6.07	4.52	-328	6.49	0.27	21.19	48
MW-111B	5.24	0.87	-420	9.64	---	20.71	50.2
MW-111C	6.36	0.52	-56	6.7	---	21	2.64
MW-112A	10.4	0	-309	6.89	---	21.14	69.4
MW-112B	24.9	0.24	-420	8.94	1.46	22.91	10.1
MW-112C	38.7	0.75	-589	9.29	2.39	23.35	16.4
MW-113A	12.2	0.44	-391	7.88	---	23.87	119
MW-113B	1.04	0.39	-310	8.74	0.05	24.23	132
MW-113C	31	0.94	-97	11.94	---	25.42	4.75
MW-114A	0.253	0.93	-150	6.38	0.01	21.03	3.1
MW-114B	0.764	0	-50	6.17	---	20.7	9.1
MW-114C	66.9	0.88	-299	7.9	4.54	21.9	0.43
MW-354A	1.77	0.53	-265	5.71	0.09	22.02	0.01
MW-354B	5	0.03	-386	7.27	---	21.51	9.74
MW-358A	4.45	1.59	-289	6.14	0.24	22.44	0
MW-358B	32	0.14	-573	10.9	2.03	22.04	3.98

mS/cm: millisieman(s) per centimeter
µg/L: micrograms per liter
mv: millivolts
C°: degrees Celsius
NTU: Nephelometric Turbidity Units

Table A7
Measured Groundwater Elevation and Density Correction
LCP Chemical, Brunswick, GA

Location	Top of Casing Elevation (ft MSL)	Depth to Water from TOC (ft)	Total Dissolved Solids (mg/L)	Groundwater Density (g/cm^3)	Corrected Groundwater Elevation (ft MSL)
DP-1A	8.42	3.99	16,100	1.010	4.51
DP-1B	8.87	4.82	821	0.999	4.03
DP-2A	8.11	4.08	6,610	1.003	4.05
DP-2B	8.53	4.61	2,110	1.000	3.92
DP-3A	8.84	5.62	4,690	1.002	3.23
DP-3B	9.30	5.77	13,700	1.008	3.70
DP-4A	9.11	4.75	4,050	1.001	4.37
DP-5A	9.49	5.66	24,500	1.015	3.92
DP-5B	9.40	5.13	276	0.999	4.24
DP-6A	10.28	5.08	458	0.999	5.19
DP-6B	9.71	5.03	925	0.999	4.66
MW-101A	11.59	12.49	6,380	1.003	-0.86
MW-101B	10.92	12.14	11,000	1.006	-1.08
MW-101C	11.39	12.16	2,660	1.000	-0.76
MW-101D	11.61	12.59	106,000	1.071	5.68
MW-102A	7.59	5.67	6,540	1.003	1.96
MW-102B	8.16	7.22	3,290	1.001	0.96
MW-102C	7.69	6.84	4,490	1.002	0.90
MW-103A	7.55	4.99	7,320	1.003	2.61
MW-103B	7.56	4.89	1,840	1.000	2.66
MW-103C	7.67	5.10	3,810	1.001	2.60
MW-104B	9.28	5.78	423	0.999	3.47
MW-104C	9.17	5.75	2,170	1.000	3.42
MW-105A	12.47	7.46	214	0.999	5.00
MW-105B	12.27	7.27	657	0.999	4.98
MW-105C	12.47	7.49	2,920	1.000	5.00
MW-106A	14.65	9.21	681	0.999	5.43
MW-106B	14.69	9.27	84	0.999	5.39
MW-106C	14.39	9.68	13,700	1.008	5.05
MW-107A	16.93	10.71	108	0.999	6.21
MW-107B	16.99	10.83	66	0.999	6.13
MW-107C	17.52	12.45	214	0.999	5.01
MW-108A	17.34	11.36	239	0.999	5.97
MW-108B	17.43	11.41	83	0.999	5.97
MW-108C	17.33	12.31	262	0.999	4.96
MW-108D	17.80	12.38	232	0.999	5.33
MW-109A	15.95	10.66	296	0.999	5.28
MW-109B	15.79	10.54	2,930	1.000	5.26
MW-109C	15.46	10.51	8,760	1.004	5.10
MW-110A	11.86	7.11	610	0.999	4.74
MW-110B	12.36	7.22	303	0.999	5.11
MW-110C	11.90	7.95	15,400	1.009	4.31
MW-111A	9.79	5.02	10,100	1.005	4.85
MW-111B	9.77	4.95	5,000	1.002	4.87

Table A7
Measured Groundwater Elevation and Density Correction
LCP Chemical, Brunswick, GA

Location	Top of Casing Elevation (ft MSL)	Depth to Water from TOC (ft)	Total Dissolved Solids (mg/L)	Groundwater Density (g/cm^3)	Corrected Groundwater Elevation (ft MSL)
MW-111C	9.66	5.55	3,900	1.001	4.15
MW-112A	9.29	5.75	6,180	1.003	3.57
MW-112B	9.16	5.74	18,900	1.011	3.77
MW-112C	9.08	6.08	30,900	1.020	3.77
MW-113A	10.27	6.30	8,350	1.004	4.01
MW-113B	10.02	6.04	1,000	0.999	3.96
MW-113C	9.94	7.06	25,200	1.016	3.49
MW-114A	12.05	7.99	278	0.999	4.04
MW-114B	12.00	7.95	868	0.999	4.03
MW-114C	12.16	9.55	45,800	1.030	3.63
MW-115A	12.26	7.98	3,680	1.001	4.29
MW-115B	12.63	7.69	3,510	1.001	4.96
MW-115C	12.75	8.75	35,100	1.023	4.74
MW-115D	12.62	9.23	24,000	1.015	4.46
MW-116A	12.87	8.25	60	0.998	4.61
MW-116B	13.63	8.98	387	0.999	4.63
MW-116C	13.67	8.78	8,300	1.004	5.02
MW-117A	16.30	11.38	55	0.998	4.91
MW-117B	16.11	11.10	212	0.999	4.98
MW-117C	16.23	11.20	157	0.999	4.98
MW-117D	16.38	11.68	360	0.999	4.59
MW-131	8.05	4.11	3,080	1.001	3.95
MW-132	8.13	4.02	4,210	1.001	4.13
MW-135	7.75	3.91	2,390	1.000	3.84
MW-301A	6.86	2.45	18,200	1.011	4.51
MW-301B	6.44	2.46	6,210	1.003	4.07
MW-302	6.25	2.27	3,050	1.001	3.99
MW-303	6.56	2.99	524	0.999	3.55
MW-304	7.17	3.66	21,900	1.014	4.01
MW-306B	7.30	3.96	7,940	1.004	3.49
MW-307A	7.07	2.82	2,550	1.000	4.25
MW-307B	6.90	3.33	35,300	1.023	4.40
MW-308	7.54	5.52	19,200	1.012	2.32
MW-309	6.76	2.09	3,700	1.001	4.70
MW-310A	6.76	3.88	6,060	1.003	2.93
MW-310B	6.83	3.78	8,780	1.004	3.19
MW-311A	7.38	4.46	4,960	1.002	2.95
MW-311B	7.49	4.50	14,100	1.008	3.29
MW-314A	18.50	13.42	78	0.999	5.07
MW-314B	18.29	13.08	173	0.999	5.18
MW-351A	15.55	10.16	113	0.999	5.36
MW-351B	15.54	10.14	11,500	1.006	5.62
MW-352A	13.34	9.25	6,270	1.003	4.14
MW-352B	13.90	8.02	67,700	1.045	7.50

Table A7
Measured Groundwater Elevation and Density Correction
LCP Chemical, Brunswick, GA

Location	Top of Casing Elevation (ft MSL)	Depth to Water from TOC (ft)	Total Dissolved Solids (mg/L)	Groundwater Density (g/cm^3)	Corrected Groundwater Elevation (ft MSL)
MW-352D	13.80	8.71	3,380	1.001	5.15
MW-353A	12.71	8.13	5,940	1.003	4.63
MW-353B	12.57	7.90	38,800	1.025	5.49
MW-354A	10.65	7.09	918	0.999	3.54
MW-354B	10.53	7.22	28,000	1.018	3.85
MW-355A	14.55	9.35	66	0.999	5.17
MW-355B	14.60	9.39	534	0.999	5.17
MW-356A	12.85	7.53	1,650	1.000	5.31
MW-356B	12.58	7.33	4,950	1.002	5.30
MW-357A	12.02	7.60	16,600	1.010	4.73
MW-357B	11.67	7.92	20,700	1.013	4.22
MW-358A	9.99	6.54	2,520	1.000	3.45
MW-358B	10.08	7.18	25,000	1.016	3.37
MW-358D	10.64	8.38	43,000	1.028	4.69
MW-359A	13.17	8.37	462	0.999	4.78
MW-359B	13.21	8.43	7,520	1.004	4.89
MW-360D	14.12	11.15	35,100	1.023	4.42
MW-501A	11.47	6.38	788	0.999	5.06
MW-501B	11.54	6.54	8,820	1.005	5.16
MW-502A	10.65	6.76	3,070	1.001	3.90
MW-502B	10.61	5.69	5,220	1.002	4.99
MW-503A	10.99	6.46	1,620	1.000	4.52
MW-503B	10.91	6.45	4,560	1.002	4.52
MW-504A	11.46	7.46	7,510	1.004	4.09
MW-504B	11.51	6.60	14,700	1.009	5.21
MW-505A	10.91	5.90	7,430	1.004	5.10
MW-505B	11.34	6.56	26,900	1.017	5.38
MW-506A	10.67	5.13	10,300	1.006	5.71
MW-506B	10.49	6.42	27,600	1.017	4.81
MW-507A	11.41	7.70	16,400	1.010	3.97
MW-507B	11.25	7.97	33,300	1.021	4.17
MW-508A	10.23	5.91	8,240	1.004	4.44
MW-508B	10.16	6.81	46,500	1.030	4.66
MW-509A	10.24	5.81	2,920	1.000	4.44
MW-509B	10.40	6.16	20,800	1.013	4.67
MW-510A	11.41	6.61	10,400	1.006	4.94
MW-510B	11.06	6.48	27,000	1.017	5.21
MW-511A	11.51	6.58	4,080	1.001	4.97
MW-511B	11.41	6.80	20,400	1.012	5.11
MW-512A	11.66	6.65	2,100	1.000	5.01
MW-512B	11.64	6.85	13,600	1.008	5.13
MW-513A	12.88	7.71	4,000	1.001	5.20
MW-513B	12.83	7.85	18,800	1.011	5.40
MW-514A	12.51	7.37	2,960	1.000	5.15

Table A7
Measured Groundwater Elevation and Density Correction
LCP Chemical, Brunswick, GA

Location	Top of Casing Elevation (ft MSL)	Depth to Water from TOC (ft)	Total Dissolved Solids (mg/L)	Groundwater Density (g/cm^3)	Corrected Groundwater Elevation (ft MSL)
MW-514B	12.52	7.39	9,660	1.005	5.32
MW-515A	12.73	7.77	5,020	1.002	5.01
MW-515B	12.64	8.14	14,300	1.008	4.85
MW-516A	10.96	6.50	7,210	1.003	4.56
MW-516B	10.85	6.98	29,800	1.019	4.71
MW-517A	12.79	7.90	4,850	1.002	4.94
MW-517B	12.89	8.53	17,600	1.011	4.80
MW-518A	11.54	7.14	8,160	1.004	4.52
MW-518B	11.63	7.82	14,700	1.009	4.16
MW-519A	12.87	7.99	4,920	1.002	4.93
MW-519B	12.90	8.27	42,900	1.028	5.81

ft MSL: feet relative to Mean Sea Level
mg/L: milligrams per liter
g/cm^3: grams per cubic centimeter

Table A8
Definition of the Individual Transects
LCP Chemical, Brunswick, GA

Transect	Wells, Well Clusters, and Temporary Points
1	MW-114, DP-1, MW-113, DP-2, MW-112
2	MW-112, DP-3, MW-358
3	MW-358, MW-354, MW-104, DP-4
4	DP-4, DP-5, MW-110
5	MW-110, DP-6, MW-111

Table A9
Hydraulic Conductivity from Slug Tests at Transect Wells (Geosyntec, 1997)
LCP Chemical, Brunswick, GA

Well	Hydraulic Conductivity (cm/s)
MW-104A	1.18E-02
MW-104B	2.90E-02
MW-104C	1.60E-02
MW-112A	1.90E-02
MW-112B	1.19E-02
MW-112C	2.05E-03
MW-113A	1.30E-02
MW-113B	7.37E-03
MW-113C	9.85E-04
MW-114A	4.30E-03
MW-114B	1.52E-02
MW-114C	1.00E-03
MW-354A	1.42E-02
MW-354B	2.97E-03
MW-358A	1.05E-02
MW-358B	2.19E-02

cm/s: centimeters per second

Table A10
Concentration of Mercury, Lead, and Total PAH in each well used in the Transect Calculation
LCP Chemical, Brunswick, GA

Well	Mercury (µg/L)	Lead (µg/L)	Total PAH (µg/L)
DP-1A	8.800E-01	4.800E+00	2.100E-01
DP-1B	2.020E+01	1.060E+01	5.041E+00
DP-2A	8.560E+00	1.170E+01	6.389E-01
DP-2B	7.080E+00	5.170E+01	2.921E+00
DP-3A	1.080E-02	5.910E+00	5.220E-02
DP-3B	7.600E-01	3.580E+00	4.500E-01
DP-4A	6.470E-02	5.640E-01	2.771E-01
DP-4C	2.540E+00	6.780E+00	9.448E-01
DP-5A	6.900E-04	0.000E+00	1.192E+00
DP-5B	1.130E-04	1.310E-01	1.523E+00
DP-6A	1.740E-03	4.530E-01	7.512E+01
DP-6B	2.400E-02	5.100E+01	1.854E+00
MW-104B	3.730E-02	1.000E-01	5.176E-01
MW-104C	2.540E+00	6.780E+00	9.448E-01
MW-110A	8.190E-03	2.750E-01	9.749E+00
MW-110B	2.600E-04	0.000E+00	3.859E+00
MW-110C	3.890E-02	0.000E+00	2.197E-01
MW-111A	6.360E+00	1.650E+02	2.063E+02
MW-111B	3.720E+00	2.600E+01	6.631E+01
MW-111C	1.800E-03	0.000E+00	6.680E-02
MW-112A	8.000E-02	2.060E+01	2.854E+01
MW-112B	7.720E+00	9.050E+00	9.690E-01
MW-112C	1.500E+01	7.630E+00	3.924E+00
MW-113A	2.760E+01	6.680E+01	6.437E+00
MW-113B	3.440E+00	3.470E+00	1.831E+00
MW-113C	6.910E+01	3.180E-01	5.047E-01
MW-114A	1.030E-01	1.420E+00	2.086E+00
MW-114B	2.780E-01	5.580E+00	4.020E-01
MW-114C	4.800E-01	0.000E+00	7.445E-02
MW-354A	2.500E-02	1.540E-01	5.145E-01
MW-354B	5.300E-01	5.330E+00	1.124E+00
MW-358A	3.430E-03	1.360E-01	6.930E-02
MW-358B	1.250E+01	3.220E+00	2.570E+00

µg/L: micrograms per liter

Table A11
Depth to Water Table Used for Calculating Mass Discharge
LCP Chemical, Brunswick, GA

Well	Depth to Water Table (ft)
DP-1	2.76
DP-2	3.39
DP-3	4.63
DP-4	3.39
DP-5	4.26
DP-6	3.10
MW-104	3.48
MW-110	4.32
MW-111	2.35
MW-112	3.14
MW-113	3.24
MW-114	5.49
MW-354	3.59
MW-358	3.24

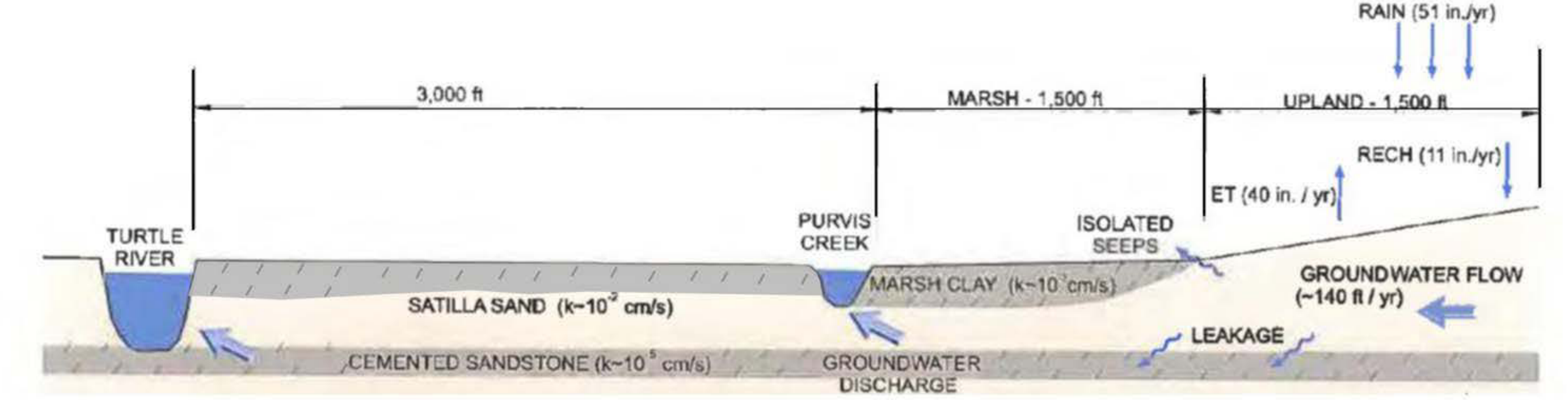
ft: feet

Table A12
Computed Mass Discharge Towards the Marsh
LCP Chemical, Brunswick, GA

Transect	Mercury (kg/yr)	Lead (kg/yr)	Total PAH (kg/yr)
1	0.35	0.73	0.15
2	0.051	0.13	0.11
3	0.022	0.018	0.012
4	0.002	0.007	0.030
5	0.022	0.62	0.72

kg/yr: kilograms per year

Figures

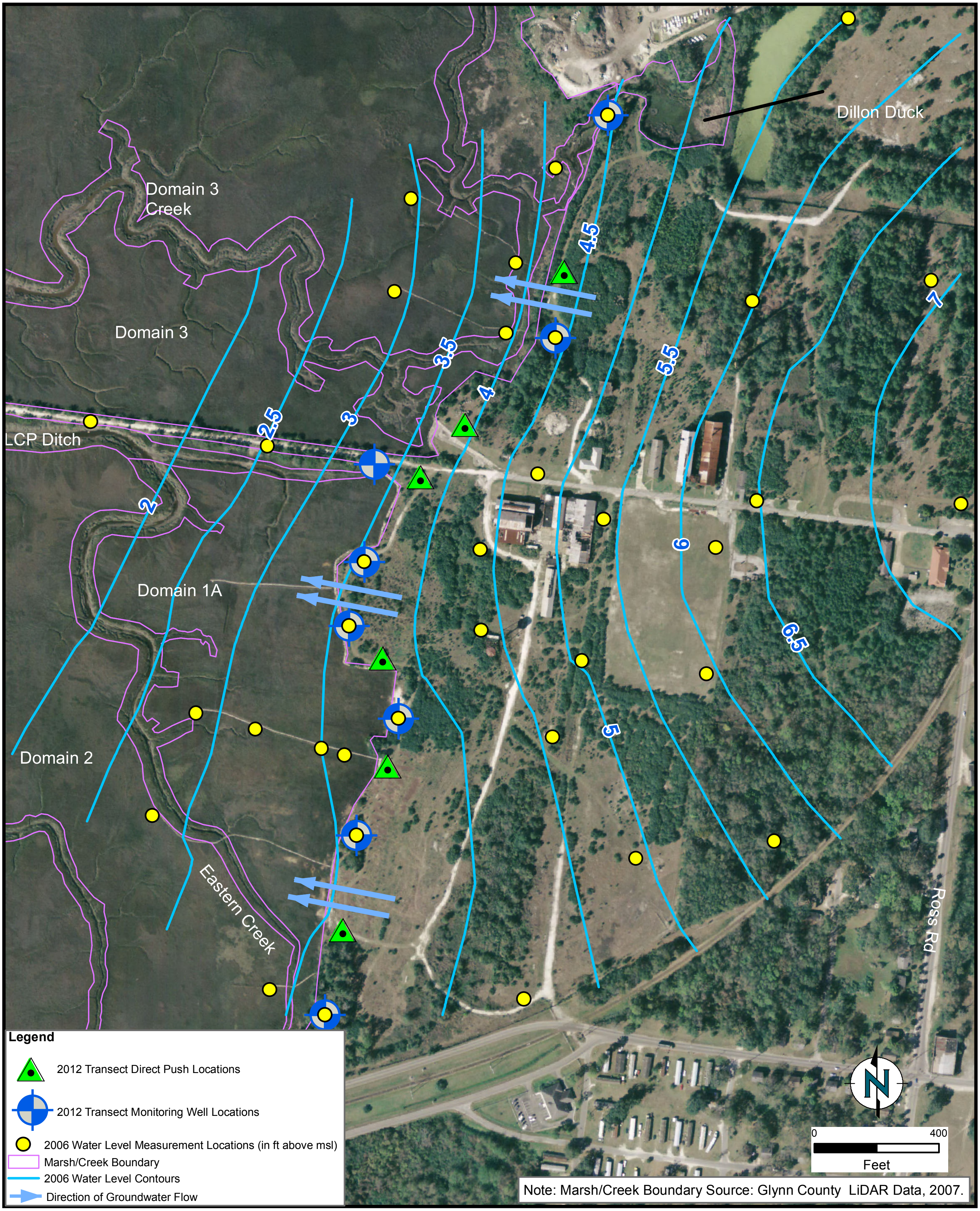


Source: Adapted from Figure 2.1-1 1997 RI Report (GeoSyntec Consultants, 1997)

Shallow Groundwater Flow System

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
A1



Note: Marsh/Creek Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

Groundwater Flow Direction and Gradients

LCP CHEMICAL SITE
BRUNSWICK, GA

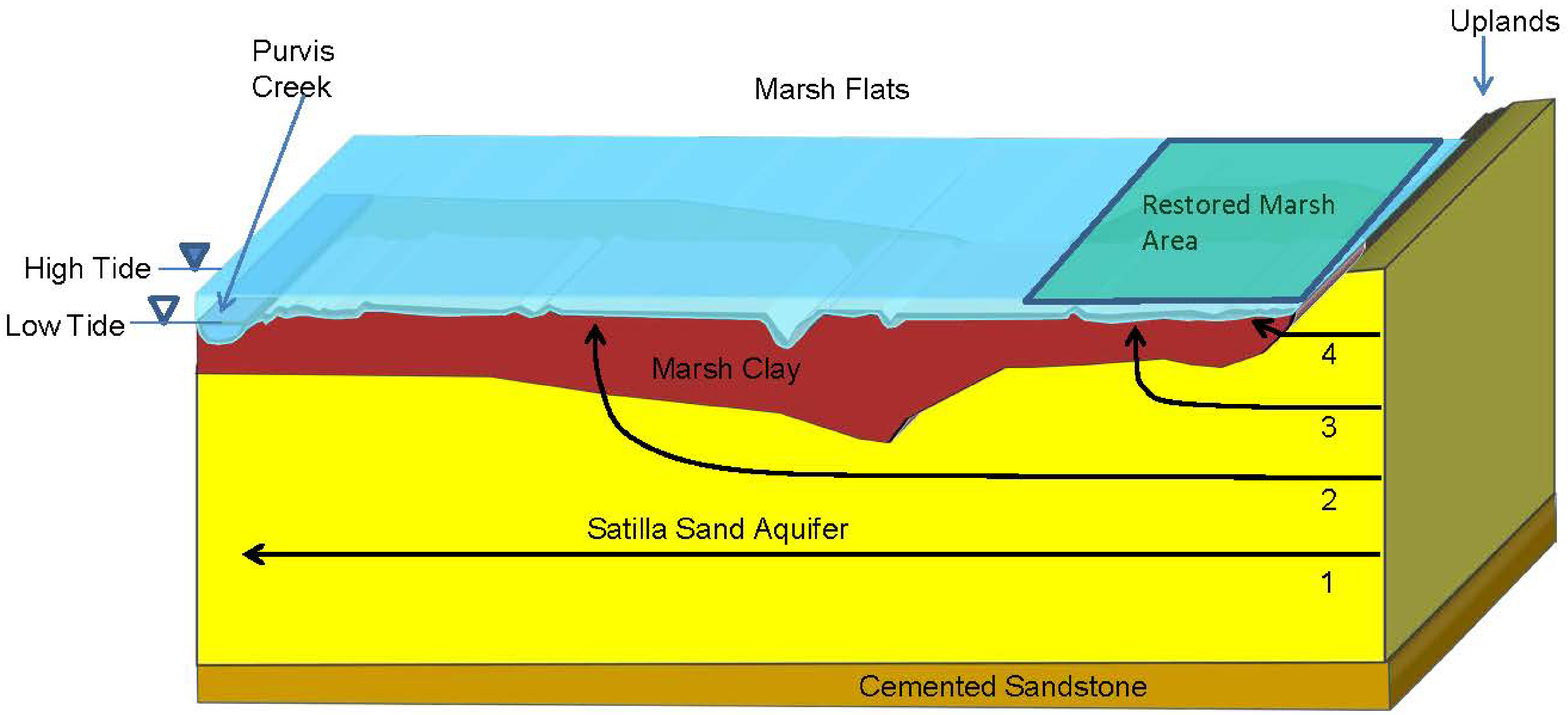
DRAFT

Figure
A2

DRAFTED BY: MRJ

DATE: 03/28/2013

PROJECT: 02-27105C



1 Flow Path to Purvis Creek and Beyond
2 Flow Path to Marsh Flats and Intertidal Channels
3 Flow Path to Restored Marsh Area
4 Flow Path to Nearshore Seeps

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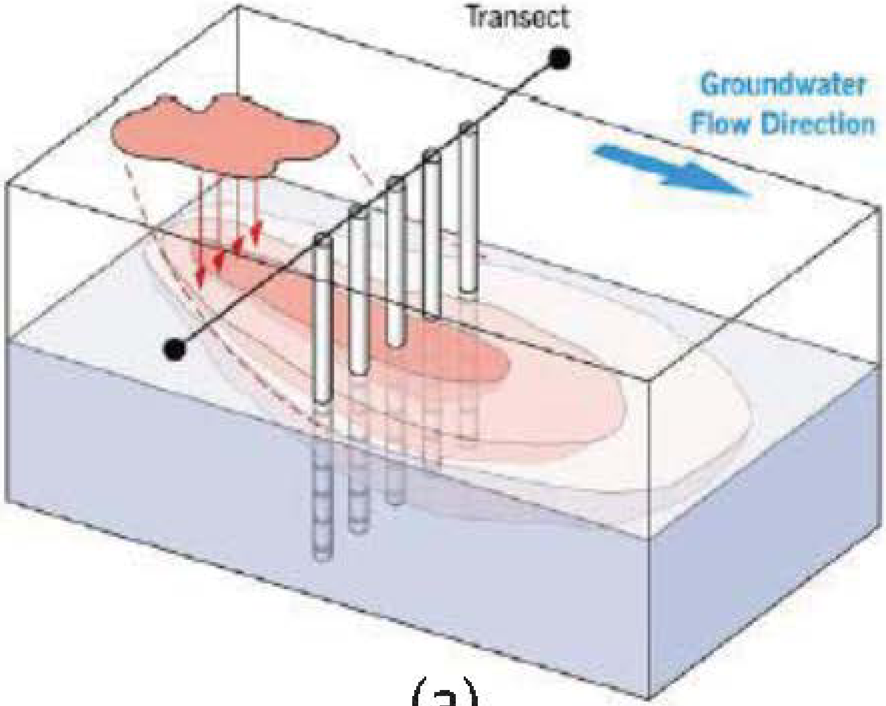
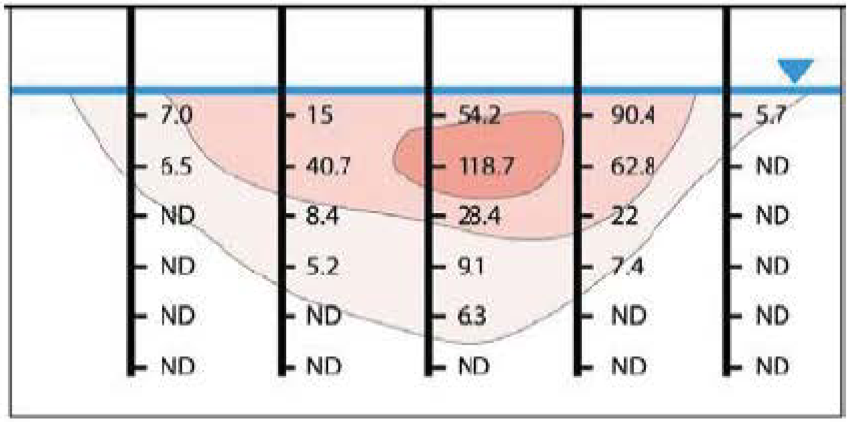
Groundwater Conceptual Site Model

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

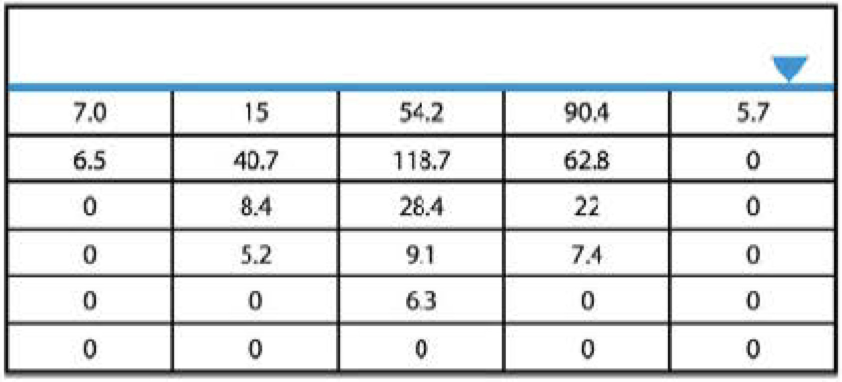
Figure
A3



(a)



(b)



7.0	15	54.2	90.4	5.7
6.5	40.7	118.7	62.8	0
0	8.4	28.4	22	0
0	5.2	9.1	7.4	0
0	0	6.3	0	0
0	0	0	0	0

(c)

Source: Adapted from ITRC 2010 Figure 4-1

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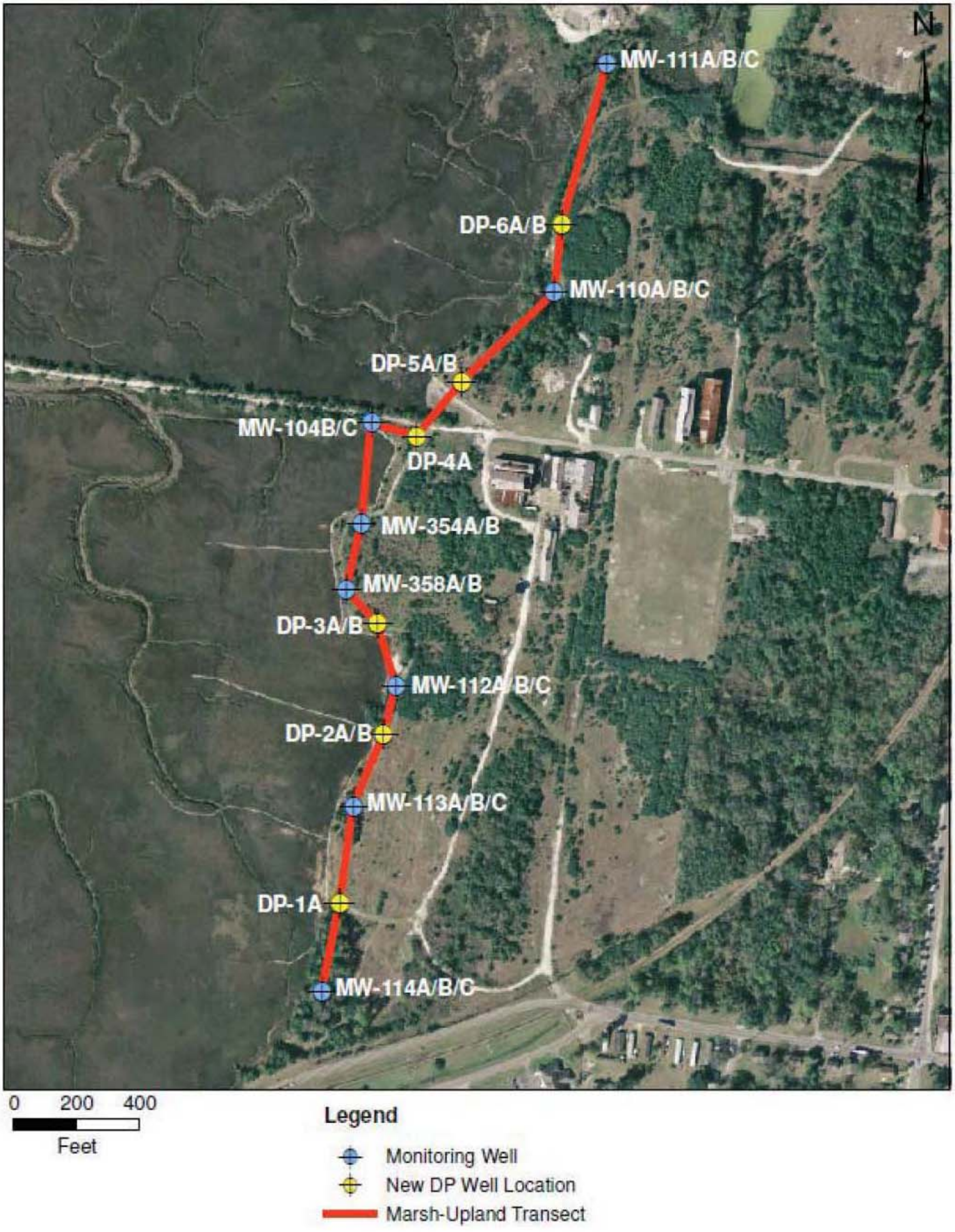
The Transect Method

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure
A4



Note: Figure content prepared by Environmental Planning Specialists, Inc.

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Marsh-Upland Transect Monitoring Wells

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
A5

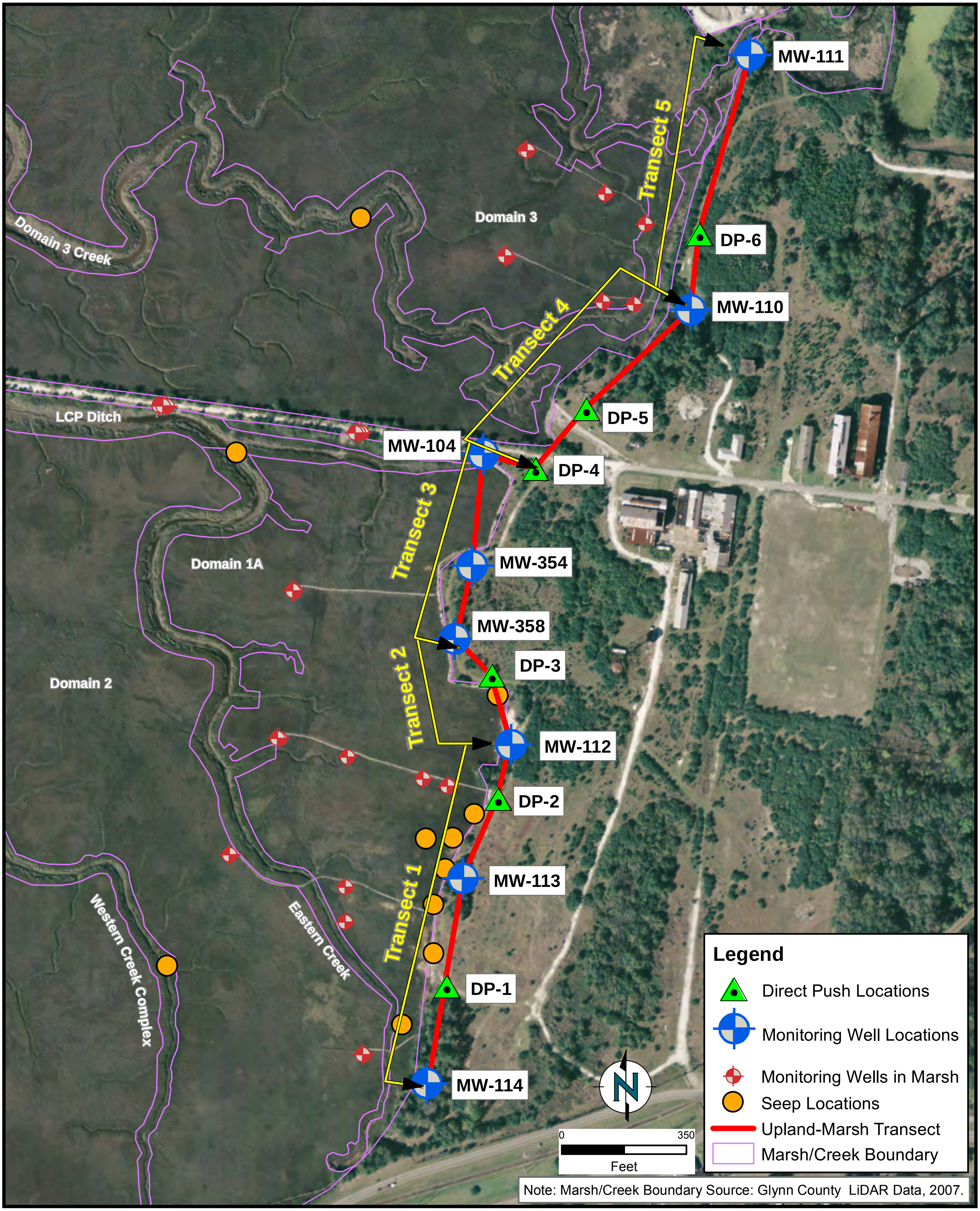
DRAFTED BY:

DATE: 3/29/2013

PROJECT_NO

Note: Figure content prepared by Environmental Planning Specialists, Inc.

ENVIRON ANCHOR QEA		**Potentiometric Surface Map April 2012** **Upper Satilla Aquifer** LCP CHEMICAL SITE BRUNSWICK, GA	Figure A6
DRAFTED BY:	DATE: 3/29/2013		PROJECT_NO



Note: Marsh/Creek Boundary Source: Glynn County LiDAR Data, 2007.

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Well Locations Included in the Site Transect Calculation

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
A7

DRAFTED BY: MRJ
DATE: 3/28/2012
PROJECT: 0227105C

DRAFT

Appendix B
Hydrodynamic Modeling
LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
Anchor QEA, LLC

ENVIRON International Corporation

Date:
March 29, 2013

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List of Acronyms and Abbreviations

ADCP	acoustic Doppler current profiler
cfs	cubic foot per second
cfs/mi^2	cubic foot per second per square mile
ft/s	foot per second
LiDAR	Light Detection and Ranging
mi^2	square mile
NAVD88	North American Vertical Datum 1988
NOAA	National Oceanic and Atmospheric Administration
OU1	Operable Unit 1
RMSE	root mean square error
Study Area	Brunswick LCP OU1 Site
USGS	United States Geological Survey
WSE	water surface elevation

1 Introduction

This hydrodynamic modeling study was performed to evaluate the characteristics and system responses to the various remedial alternatives in support of the Feasibility Study for Operable Unit 1 (OU1) at the LCP site in Brunswick, Georgia. The Brunswick LCP OU1 site (Study Area) is located in the upper portions of an estuarine system that is composed of the South Brunswick and Turtle rivers (**Figure B1-1**). The Study Area, which is approximately 700 acres in size, is composed of a complex system of tidal creeks that are connected to and interact with relatively large areas of inter-tidal vegetated marshes (**Figure B1-2**).

The primary objectives of the modeling study were to develop a conceptual site model and to evaluate the potential effects of various remedial alternatives on hydrodynamics and circulation within the Study Area.

The technical approach focused on the development, calibration, and application of a hydrodynamic model of the Study Area. Site-specific data were collected during field studies conducted during January and February 2012. The calibrated model was used to evaluate hydrodynamics and circulation within the Study Area for the following conditions: 1) typical tidal conditions over a spring-neap tidal cycle, 2) 100-year flood, and 3) hurricane storm surge. The potential effects of two remedial alternatives on current velocities and circulation patterns (i.e., extent and frequency of marsh inundation) were compared to current conditions.

2 Hydrodynamic Model Development and Calibration

2.1 Description of Hydrodynamic Model Structure

The RMA-2 hydrodynamic model was used for this study. This model is a component of the Surface Modeling System, developed by the U.S. Army Corps of Engineers (2011), and it has been used to simulate hydrodynamics at numerous estuarine sites. RMA-2 is a two-dimensional, depth-averaged model that uses an unstructured numerical grid, which makes it possible to accurately represent complex system geometry and bathymetry over a wide range of spatial scales. This capability is useful for incorporating the secondary and tertiary creek channels within the Study Area into the model. In addition, RMA-2 is able to simulate flooding and drying of inter-tidal channels and marsh areas. A two-dimensional, depth-averaged model provides realistic simulation of hydrodynamics in the Study Area because significant density-driven circulation due to vertical stratification of salinity does not occur within the site.

Development and calibration of the hydrodynamic model required these types of data:

- Bathymetry and geometry
- Freshwater inflows
- Water surface (tidal) elevation
- Current velocity

The model predicts temporal and spatial variations in: 1) water surface elevation; 2) water depth; 3) current velocity; and 4) bed shear stress.

2.2 Numerical Grid and Bathymetry

Realistic simulation of tidal hydrodynamics within the Study Area necessitated using a numerical grid that extended outside the Study Area (**Figure 2-1**). In addition to the Study Area, the numerical grid incorporates channel and inter-tidal areas of the Turtle and South Brunswick rivers so that the tidal prism of the estuarine system is accurately simulated by the model. The boundary-fitted numerical grid contains approximately 5,000 grid cells with a wide range of spatial resolution. Grid cells in the Turtle and South Brunswick rivers have a relatively coarse resolution (over 700 feet in the across- and along-channel directions). The numerical grid within the Study Area has a relatively fine resolution, with spatially variable grid cells that realistically represent differences in geometry between primary, secondary, and tertiary creek channels (**Figure B2-2**). Grid cells within Purvis Creek, which is a primary channel, range in size from 100 to 250 feet and 30 to 50 feet along and across the channel directions, respectively. Grid cells used to resolve secondary and tertiary channels (e.g., Eastern Creek) are typically 25 to 50 feet and 5 to 15 feet along and across the channel directions, respectively.

The bathymetry and topography inputs for the hydrodynamic model were specified using data and information from four sources. The Glynn County (Georgia) Light Detection and Ranging (LiDAR) survey conducted in 2008 provided topography data for the inter-tidal marsh areas throughout the model domain. Within the Study Area, creek channel inputs were specified using data collected during a single-beam bathymetry conducted in January 2012. For the region outside of the Study Area, in-channel bathymetry inputs were specified using data from the National Oceanic and Atmospheric Administration's (NOAA's) National Geophysical Data Center Coastal Relief Model (2012). The topography for areas outside the coverage of the Glynn County LiDAR dataset was specified by the U.S. Geological Survey (USGS) National Elevation Dataset (2009).

As described above, data from these four sources were combined to generate the spatial distribution of bed elevation (i.e., bathymetry and topography) throughout the model domain (**Figures 2-3 and 2-4**). Bed elevation inputs to RMA-2 model are specified at grid nodes, which are located at the corners of a grid cell. To ensure realistic representation of bathymetry and topography within the model, spatial averages of bed elevation data within the vicinity of each node were calculated and used as input to the model.

2.3 Boundary Conditions

The model required specification of water surface elevation (WSE) at the downstream boundary of the model, which is located near the USGS Brunswick River gauging station (ID No. 022261794) at the Sidney Lanier Bridge (**Figure B2-5 and B2-6**). Tidal elevation data collected at the USGS gauging station at Saint Simons Island (**Figure B2-6**) were used to specify WSE at the downstream boundary of the model. Two tidal gauging stations are also located near the downstream boundary: 1) USGS Brunswick River station; and 2) NOAA Saint Simons Island station (**Figure B2-6**). Water surface elevations measured at these three gauging stations are very similar, with minimal differences in amplitude and phase. Thus, data collected at any of these three stations could have been used to specify WSE input at the downstream boundary. Data collected at the USGS Saint Simons Island station were used to specify model inputs because this station has the longest historical data record. **Figure B2-7** shows WSE specified at the downstream boundary during the model calibration period (January 18 to February 7, 2012), which is discussed in Sections 2.4 and 2.5. During this 21-day period, the WSE ranged between minus 6 and plus 4 feet North American Vertical Datum 1988 (NAVD88) and included a spring-neap tidal cycle.

No USGS flow gauging stations are located on tributaries to the Turtle and South Brunswick rivers (see **Figure B2-5** for tributary locations). Thus, flow rates for those tributaries were estimated using data collected at USGS gauging stations on a stream within a watershed that is located in the vicinity of the Turtle and South Brunswick rivers. Specifically, flow rate data collected at the USGS gauging station on the Little Satilla River near Offerman Dam were used to estimate tributary inflows to the model. The average flow rate of the Little Satilla River is 500 cubic feet per second (cfs), with a drainage area of 645 square miles (mi^2) at the USGS gauging station. The average flow rate was normalized by the drainage area to compute a runoff rate of approximately 0.8 cubic feet per second per square mile (cfs/mi^2) for the Little Satilla River. The combined drainage area of the Turtle and South Brunswick rivers is 232 mi^2. Multiplying the average runoff rate for the Little Satilla River by this drainage area produced an estimated average flow rate for the Turtle and South Brunswick rivers of 190 cfs.

Historical flow rate data from the Little Satilla River for the 60-year period from 1951 to 2010 were used to determine a flow rate of 20,700 cfs for the 100-year flood, which corresponds to a runoff rate of 32 cfs/mi^2. This runoff rate was used to estimate the 100-year flood discharge for the Turtle and South Brunswick rivers, which was 7,400 cfs.

The combined inflow rate for the Turtle and South Brunswick rivers was divided between three inflow locations, based on the approximate sub-watershed drainage area (**Figure B2-5**). Average inflow conditions were assumed during the calibration simulation discussed below. The 100-year flood was simulated during the evaluation of remedial alternatives, which is discussed in more detail in Section 3.

2.4 Model Calibration

The hydrodynamic model was calibrated using water level sensor data and acoustic Doppler current profiler (ADCP) data collected between January 18 and February 7, 2012. WSE data were obtained from the two water level sensors deployed in Turtle River and Purvis Creek (i.e., Stations WL1 and WL2 in **Figure B2-8**). Four ADCPs were deployed during this field study: one in Turtle River, two at locations in Purvis Creek, and one within Eastern Creek (i.e., Stations T1, P1, P2, and E1 in **Figure B2-8**, respectively). These ADCPs provided WSE and along-channel current velocity data, which were used to evaluate model performance during the calibration process.

The ADCP data indicated that qualitative differences exist between tidal currents in the Turtle River and Purvis Creek. At Station T1 in the Turtle River, current velocities during ebb and flood tides are approximately symmetrical for both spring and neap conditions (see **Figures B2-9 and B2-10**). Within Purvis Creek, at Station P1, asymmetric patterns are observed in tidal currents during ebb and flood tides, with a higher degree of asymmetry occurring during spring tide (**Figure B2-11**) than during neap tide conditions (**Figure B2-12**). These observations were used to evaluate the ability of the model to simulate differences in tidal hydrodynamics between Turtle River and Purvis Creek.

Two model inputs were refined during the calibration process: 1) Manning's *n* coefficient, which is a parameter that describes the surface roughness of the river bottom; and 2) the effective bed elevation of inter-tidal marsh areas within the Study Area. The Manning's *n* coefficient was set to a relatively high value of 0.3 in the inter-tidal marsh areas in order to incorporate the effects of dense vegetation on hydrodynamic drag forces (Chow 1959). A Manning's *n* value of 0.02 was specified in the creek channels, with a value of 0.01 in Eastern Creek. The difference in Manning's n values between Eastern Creek and other creek channels reflects localized variations in channel geometry and resolution of the numerical grid which are incorporated into the model via this lumped input parameter.

Bed elevation values within inter-tidal, vegetated marshes of the Study Area were originally approximated using LiDAR data collected by Glynn County. During the calibration process, it was determined that decreasing the marsh bed elevation by an average of 1 foot resulted in considerable improvements in the model's simulation of existing conditions. This refinement in model marsh bed elevation was considered valid due to the inherent inaccuracies with LiDAR measurements that are typically observed over marsh vegetation. To this effect, a NOAA (2010) study on LiDAR data collected within a South Carolina marsh notes:

> When testing the marsh category separately, it becomes clear the marsh land cover is a unique category that may have significantly higher errors and biases than the 'upland' (i.e., traditional) land covers. This suggests that LiDAR data are highly positively biased in marsh land cover.

The root mean square error (RMSE) for LiDAR data collected from the South Carolina marsh in the NOAA study was 0.76 feet, which is very close to the marsh bed elevation refinement of 1 foot used for this study.

As discussed in Section 2.2, the LiDAR data used to specify bed elevation in the inter-tidal marsh areas were collected during 2008 as part of a larger survey that encompassed all of Glynn County, Georgia. Optimal Geomatics (2008) performed a quality control analysis of the LiDAR data, which were collected from a wide range of land use categories (including marshes), and concluded:

> Glynn County, GA contains areas of thick marsh grass vegetation, which is very difficult to fully penetrate with LiDAR. Additional ground validation was taken in order to establish the accuracy associated with the [digital elevation model] for this particular vegetation class. …The testing of these points revealed an RMSE of 0.86 feet.

Optimal Geomatics (2008) collected validation data from three general types of land surfaces during the quality control study: 1) hard surfaces (e.g., bare earth, road); 2) upland vegetation (e.g., grass, brush, trees); and 3) high marsh grass areas (i.e., vegetated marshes). The validation data were collected at locations throughout Glynn County (**Figure B2-13**), with a cluster of validation measurements obtained at each sampling location (**Figure B2-14**). Reported errors in the LiDAR data (i.e., difference between LiDAR and validation measurement) (Optimal Geomatics, 2008) were used to generate cumulative frequency distributions of the LiDAR errors for hard surfaces, upland vegetation, and high marsh grass areas (refer to **Figures B2-15, B2-16, and B2-17**, respectively). These results produced these conclusions about the Glynn County LiDAR data:

- Errors for all surfaces may be represented by a normal (Gaussian) distribution, which means that relative comparisons of errors for different surfaces are reliable.
- The median error (i.e., 50^{th} percentile) for hard surfaces (**Figure B2-15**) and upland vegetation (**Figure B2-16**) ranged between approximately plus or minus 0.25 feet, with no significant bias for nearly all of the surfaces shown on these two figures.
- The distribution of errors for high marsh grass, or vegetated marshes (**Figure B2-17**), is positively biased, with a median value of approximately plus 0.8 feet. This type of land surface is most predominant in the Study Area.

One measurement of bed elevation was available to validate the LiDAR data collected from marsh areas within the Study Area. The LiDAR error for this measurement is consistent with the Glynn County error distribution (**Figure B2-17**). The results of the quality control analysis provide significant support for lowering the LiDAR-derived average elevation of vegetated marshes within the Study Area by 1 foot during model calibration.

2.5 Calibration Results

Comparisons of predicted and measured WSE at the water level sensor locations (WL1 and WL2) during the 21-day calibration period are presented in **Figure B2-18**. During the calibration period, WSE at both locations ranged between approximately minus 6 and plus 4 feet NAVD88. These results indicate that: 1) high tide is predicted accurately; 2) the model tended to slightly under-predict WSE during low tide; 3) predicted WSE was in phase with measure values; and 4) changes in tidal range throughout the spring-neap cycle were reproduced by the model. Overall, predicted WSE at both locations was in satisfactory agreement with measured values.

Model predictions of WSE and along-channel velocity at Stations T1, P1, P2, and E1 during the calibration period in 2012 are compared to measured values in **Figures B2-19 to B2-22**. The along-channel velocity at Station T1 fluctuated between approximately plus 2 feet per second (ft/s; flood tide) and minus 2.5 ft/s (ebb tide). The predicted along-channel velocity at Station T1 was slightly under-predicted during ebb tide. Overall, the comparisons of velocity and WSE are acceptable for the objectives of this study (**Figure B2-19**).

Peak current velocities during ebb and flood tides within Purvis Creek tended to be slightly lower than peak velocities in Turtle River. Generally, the predicted current velocities at Stations P1 and P2 reproduced the shape, magnitude, and phase of the measured velocities with good accuracy (**Figures B2-20 and B2-21**). WSEs at Stations P1 and P2 were slightly under-predicted during low tide, but this result is consistent with model performance at Station WL1.

In the Eastern Creek, the predicted WSE reproduced the magnitude and phase of measured values at Station E1 (**Figure B2-22**). The model also realistically simulated flooding and drying at this location. During flood tide, the maximum along-channel velocity within the Eastern Creek was under-predicted. However, the model adequately predicted maximum velocity during ebb tide, which is similar in magnitude to peak values during flood tide.

The calibration results for the hydrodynamic model show that the WSE and current velocity is predicted with adequate accuracy within the Study Area. In addition to satisfactorily predicting the magnitude of WSE and current velocity, the model was able to reproduce the shape of the tidal signal within the Study Area, including realistic simulation of asymmetrical characteristics of the tidal signal. Model results for the 21-day calibration period demonstrate that the model captured these key characteristics of hydrodynamics within the Study Area:

- Amplitude and phase of WSE
- Qualitative differences in the symmetry (asymmetry) of tidal currents during ebb and flood tide between Turtle River and Purvis Creek

- Changes in the magnitude of along-channel velocity during the neap-spring tidal cycle
- Flooding and drying of secondary channels and inter-tidal marsh areas

Successful calibration of the model indicated that it can be used as a management tool to reliably evaluate remedial alternatives for a range of flow and tidal conditions (i.e., typical tidal conditions over a spring-neap tidal cycle, 100-year flood, and hurricane storm surge).

3 Evaluation of Sediment Remedy Alternatives

Successful calibration of the model produced a quantitative tool that was used to evaluate the potential effects of two sediment remedy alternatives on hydrodynamics and circulation within the Study Area. This model was used to predict changes in inundated inter-tidal area and maximum current velocity due to remediated bed conditions in order to quantify the effects of the two remedial alternatives on hydrodynamics in the marsh.

The remedial alternatives consisted of two sediment-management-area footprints that cover 48 acres of the Study Area. Sediment Remedy Alternative 2 (**Figure B3-1**) consisted of dredging and backfill with a net removal of 0.5 feet in all remediation areas. Sediment Remedy Alternative 3 (**Figure B3-2**) specified a combination of remedial action with dredging and backfill (net removal of 0.5 feet), capping (net increase in bed elevation of 1 foot) and thin cover placement (net increase in bed elevation of 0.5 feet). Existing conditions and the two remedial alternatives were simulated for three hydrodynamic conditions: 1) typical tidal conditions over a spring-neap tidal cycle; 2) 100-year flood; and 3) hurricane storm surge.

3.1 Sediment Remedy Alternatives: Typical Tidal Conditions

The remedial alternatives were evaluated for typical tidal conditions over a spring-neap cycle (i.e., 21-day calibration period in 2012). The spatial distribution of maximum predicted current velocity for existing conditions and for Sediment Remedy Alternatives 2 and 3 are presented in **Figures B3-3, B3-4, and B3-5**, respectively. Spatial patterns of maximum velocity are similar for all three conditions. As expected, higher velocities occur within the main channel of Purvis Creek, with velocities greater than 2 ft/s near the mouth of Purvis Creek. The inter-tidal marsh areas experience lower current velocities, with peak values that were less than 0.25 ft/s. Maximum velocities in the secondary channels were typically between 0.25 and 1.5 ft/s, with higher velocities occurring in a few isolated areas.

To evaluate the effect of remediated bed elevations on the Study Area hydrodynamics, maximum increases in current velocity between the remedial scenarios and existing conditions were determined.

The spatial distribution of differences in maximum predicted velocity between Sediment Remedy Alternative 2 and existing conditions is shown in **Figure B3-6** and can be summarized as follows:

- The predicted maximum velocity in Purvis Creek did not experience a significant change (i.e., less than plus or minus 0.1 ft/s) following remediation.
- The predicted maximum velocity in Eastern Creek decreased by 0.1 to 0.5 ft/s, which is consistent with lowering the sediment bed following remediation.
- Overall, implementation of Sediment Remedy Alternative 2 has a minor effect on velocity, with the maximum increase in velocity being 0.21 ft/s within the Study Area.

The spatial distribution of differences in maximum predicted velocity between Sediment Remedy Alternative 3 and existing conditions is shown in **Figure B3-7**. As shown on this figure and presented in **Table B3-1**, the maximum increase in predicted velocity in the Study Area is 0.44 ft/s following remediation. Generally, increases in predicted velocity due to Sediment Remedy Alternative 3 occur within the remediation footprint, with typical increases being less than 0.5 ft/s.

To further investigate the effects of both remedial scenarios on circulation and marsh inundation (i.e., spatial extent and frequency) within the Study Area, the areal extent of inundation within inter-tidal marsh areas was compared between remediated conditions and existing conditions. The areal extent of inundation was compared at high and low water levels (i.e., maximum WSE during flood tide and minimum WSE during ebb tide) during neap and spring tidal conditions. For spring tide conditions, high and low water levels were plus 3.9 and minus 4.7 feet NAVD88, respectively, which corresponded to conditions on January 23, 2011. For neap tide conditions, high and low water levels were plus 1.4 and minus 4.1 feet NAVD88, respectively, which occurred on January 28, 2011. During spring tide, the entire Study Area was predicted to be inundated during high water, with less than 10% of the Study Area inundated during low water. During neap tide conditions, about 60% of the Study Area was inundated during high water.

Total inundated areas for Sediment Remedy Alternatives 2 and 3 are compared to existing conditions in **Figures B3-8 and B3-9**, respectively. The change in the areal extent of inundation due to either remedial scenario was less than 4%, which indicates that the remedial scenarios would not have a significant effect on circulation and marsh inundation (i.e., spatial extent and frequency) within the Study Area.

3.2 Sediment Remedy Alternatives: 100-year Flood Conditions

A 100-year flood on tributaries to the estuary was simulated assuming that typical tidal conditions (i.e., 21-day calibration period) existed at the downstream boundary. Maximum predicted current velocities for existing conditions and Sediment Remedy Alternatives 2 and 3 for the 100-year flood are presented in **Figures B3-10, B3-11, and B3-12**, respectively. The differences in predicted velocity relative to existing conditions for Sediment Remedy Alternatives 2 and 3 are shown in **Figures B3-13 and B3-14**, respectively.

Results of the 100-year flood simulation are similar to the results for typical tidal conditions with average tributary flow (see **Figures B3-3 through B3-7**), which is due to the relatively low freshwater inflow to the Turtle and South Brunswick rivers, even during a rare flood. As presented in **Table B3-1**, during the 100-year flood event, maximum increases in velocity are 0.20 and 0.43 ft/s for Sediment Remedy Alternatives 2 and 3, respectively. These results indicate that the remediated bed conditions do not have a significant impact on hydrodynamics within the Study Area, even during a 100-year flood event.

3.3 Sediment Remedy Alternatives: Hurricane Storm Surge

The hurricane storm surge simulation considered a 100-year storm surge occurring during a spring tidal cycle as the worst-case condition. A representative spring tidal cycle, which spanned 9 days, was selected from the historical record at the USGS Saint Simons Island gauging station. The increase in WSE corresponding to the 100-year storm surge event was estimated from the NOAA gauging station at Fort Pulaski, Georgia, which was the closest gauging station to the Study Area with storm exceedance data. At the Fort Pulaski station, a 100-year return period event corresponds to a WSE of plus 6.8 feet NAVD88.

To simulate conservative storm surge conditions (i.e., accounting for the combined effects of spring tides and the 100-year storm surge), WSE values during the spring tidal cycle were adjusted such that the maximum WSE reached the estimated 100-year storm surge elevation (**Figure B3-15**). Maximum increases in predicted current velocity for all remedial scenarios and hydrodynamic conditions are summarized in **Table B3-1**.

When compared to the typical tidal condition and 100-year flood simulations, larger areas within Purvis Creek and the secondary channels were predicted to have maximum velocities greater than 2 ft/s during the hurricane storm surge following remedy implementation (**Figures B3-16 through B3-18**). As presented in **Table B3-1**, maximum increases in velocity relative to existing conditions due to implementation of Sediment Remedy Alternatives 2 and 3 were 0.20 and 0.55 ft/s, respectively. In general, predicted increases in maximum velocity are larger for Sediment Remedy Alternative 3 than Sediment Remedy Alternative 2 (**Figures B3-19 and B3-20**). However, the increase in maximum velocity is typically less than 0.5 ft/s for both remedial scenarios, with only isolated areas experiencing larger changes (i.e., greater than 0.5 ft/s).

Although the velocity changes associated with the 100-year flood and hurricane storm surges were relatively minor, primarily impacting the remediation areas and not the remaining marsh, they may influence various remedy design parameters such as armoring requirements and construction/material placement methods.

4 Summary

The hydrodynamic model was developed and calibrated using site-specific data to the extent feasible. A boundary-fitted numerical grid, with relatively high resolution in the Study Area, was used to represent spatial variations in geometry and bathymetry throughout this estuarine system. The model was calibrated using WSE and current velocity data collected during a 21-day period (January 18 to February 7, 2012), which included a spring-neap tidal cycle. The model reproduced four key characteristics of hydrodynamics within the Study Area:

- Amplitude and phase of WSE
- Qualitative differences in the symmetry (asymmetry) of tidal currents during ebb and flood tide between Turtle River (Purvis Creek)
- Changes in the magnitude of along-channel velocity during the neap-spring tidal cycle
- Flooding and drying of secondary channels and inter-tidal marsh areas

Successful calibration of the model indicated that it can be used as a management tool to develop a conceptual site model and to reliably evaluate remedial alternatives for a range of flow and tidal conditions.

The hydrodynamic model was used as a tool to evaluate the potential effects of two remedial alternatives on hydrodynamics and circulation within the Study Area. To quantify the effects of the remedial alternatives on hydrodynamics, the model was used to predict changes in inundated inter-tidal area and maximum current velocity due to remediated bed conditions. The hydrodynamic model was used to simulate two remedial scenarios: 1) Sediment Remedy Alternative 2 consisted of dredging and backfill with a net change of minus 0.5 feet in all remediation areas; and 2) Sediment Remedy Alternative 3 specified a combination of remedial action with dredging and backfill (net change of minus 0.5 feet), capping (net increase in bed elevation of 1 foot) and thin cover (net increase in bed elevation of 0.5 feet). Existing conditions and the two remedial scenarios were simulated for three hydrodynamic conditions: 1) typical tidal conditions over a spring-neap tidal cycle; 2) 100-year flood; and 3) hurricane storm surge. In general, the change in the areal extent of inter-tidal inundation due to either remedial scenario was less than 4%, which indicated that the remedial scenarios would not have a significant effect on the circulation and marsh inundation within the Study Area. Overall, only relatively minor increases in maximum current velocities (relative to existing conditions) were predicted to occur for the two remedial scenarios.

5 References

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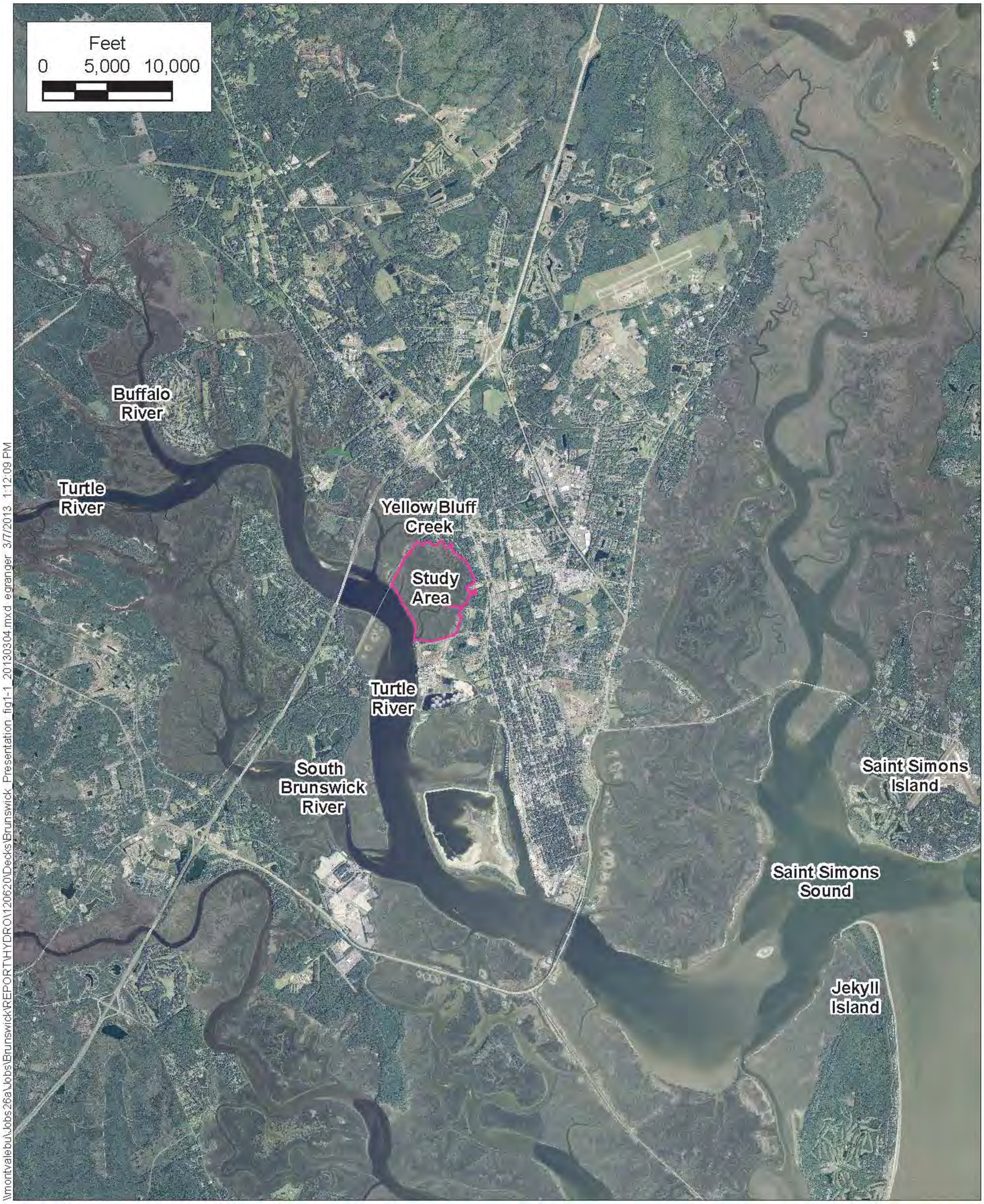
Table

Table B3-1: Maximum Increases in Predicted Current Velocity for Sediment Remedy Alternatives 2 and 3

Sediment Remedial Alternatives	Maximum Increase: Typical Tidal Conditions (ft/s)	Maximum Increase: 100-year Flood (ft/s)	Maximum Increase: Hurricane Storm Surge (ft/s)
2	0.21	0.20	0.20
3	0.44	0.43	0.55

Note:
ft/s – feet per second

Figures



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Overview of Brunswick River Estuary

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B1-1

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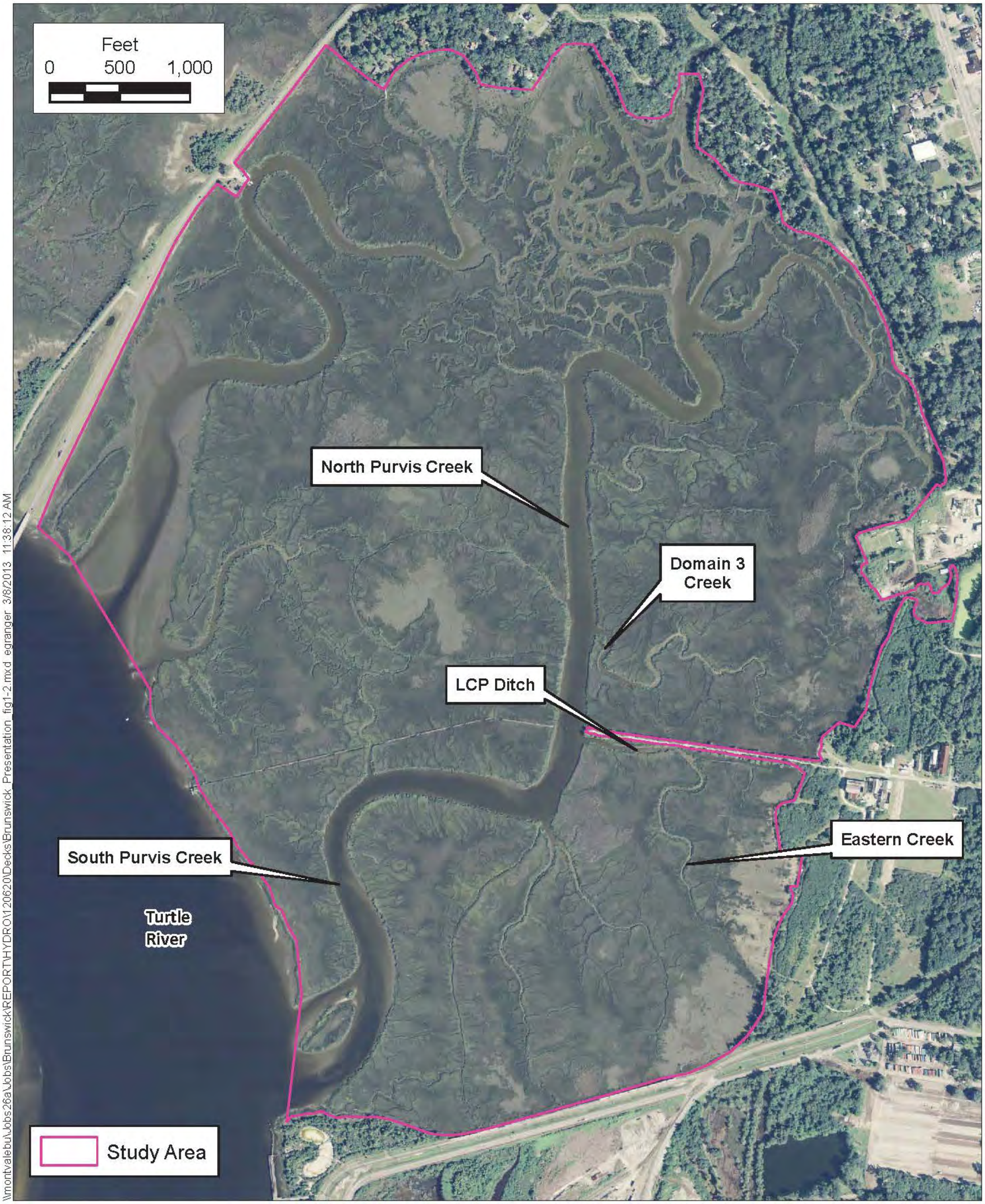

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Study Area Adjacent to Brunswick LCP Site

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B1-2

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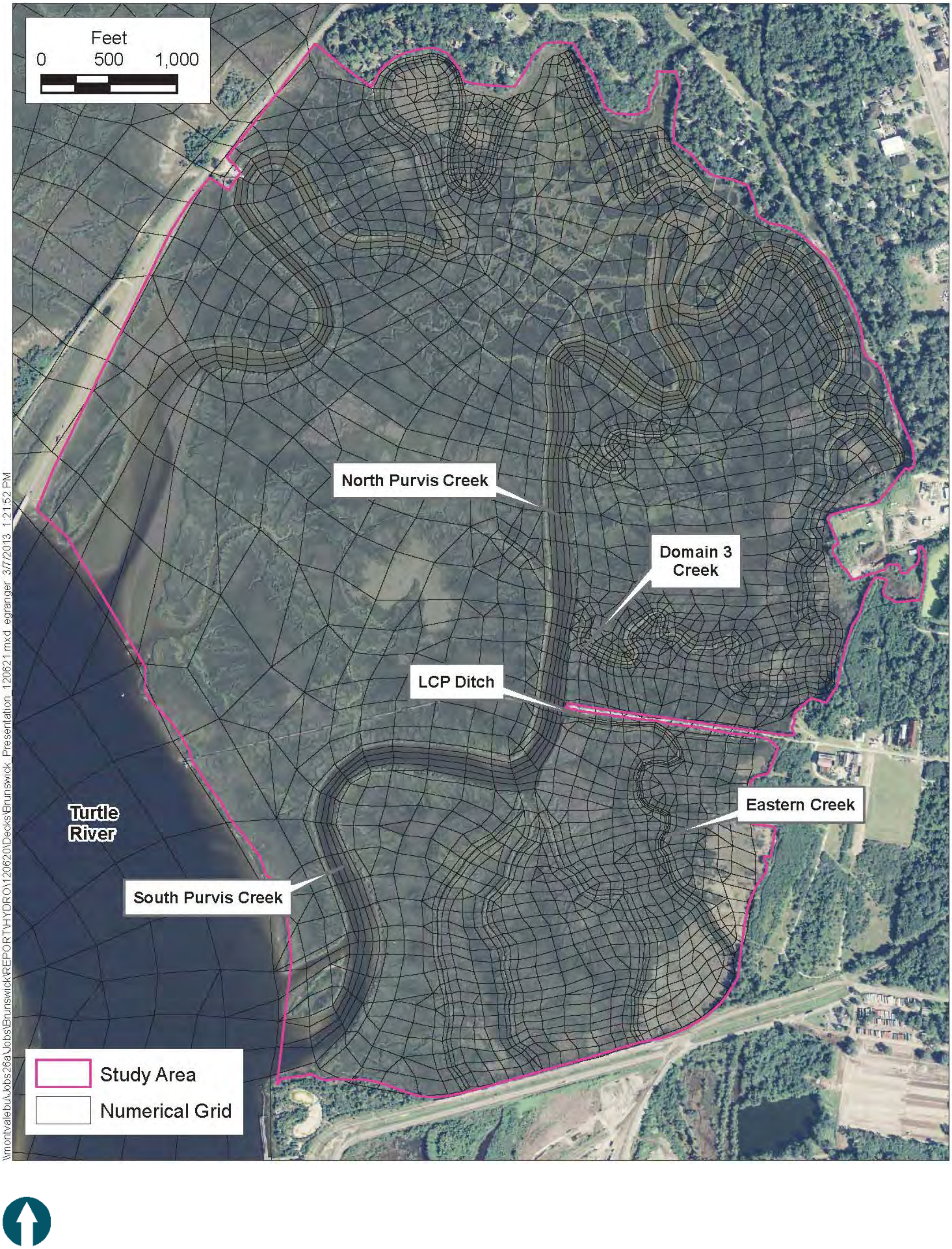
DATE: March 29, 2013

Numerical Grid for Model Domain

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-1

PROJECT 02-27105C



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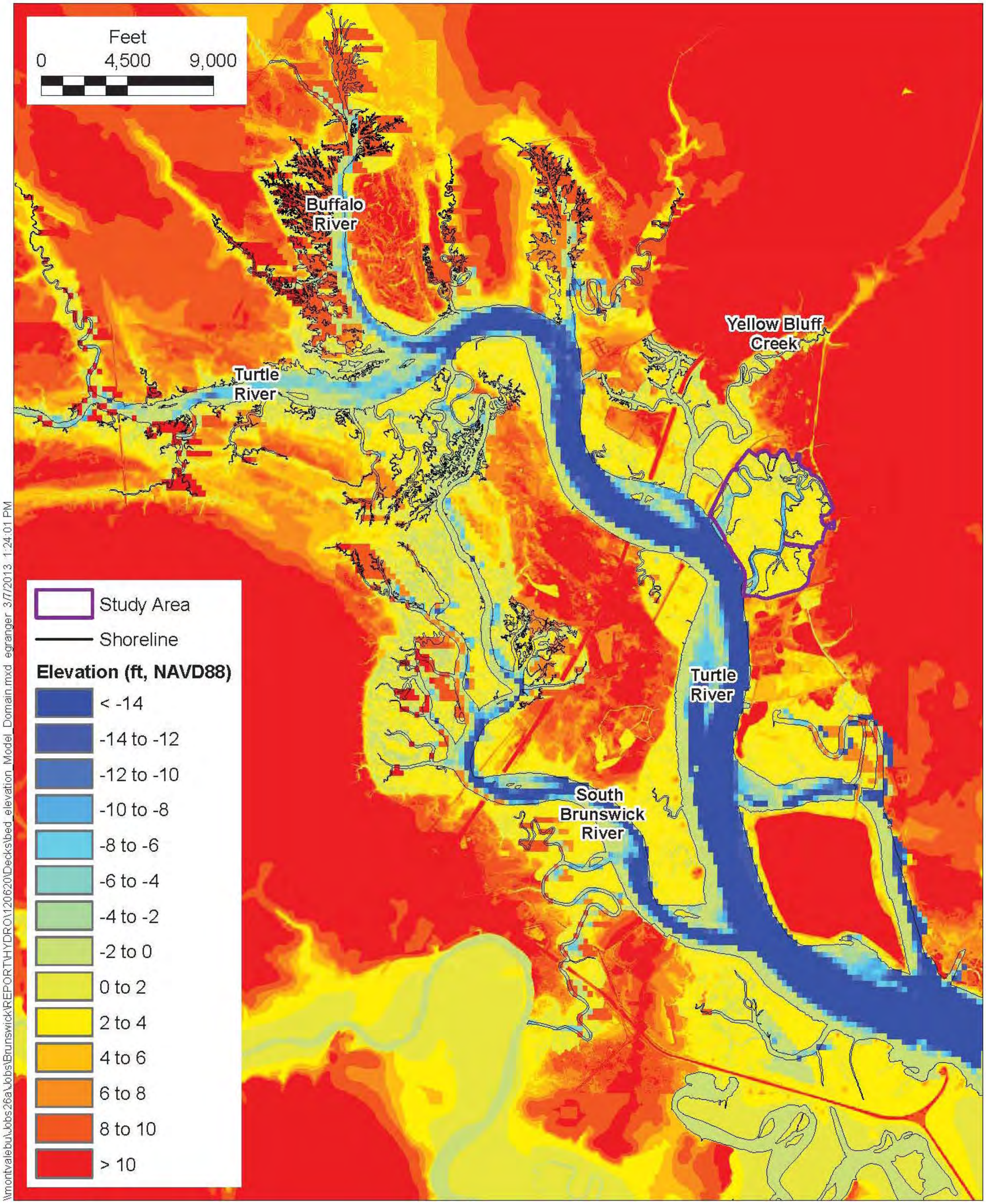
Numerical Grid within the Study Area

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-2

PROJECT 02-27105C



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Bed Elevation for Model Domain

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-3

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DATE: March 29, 2013

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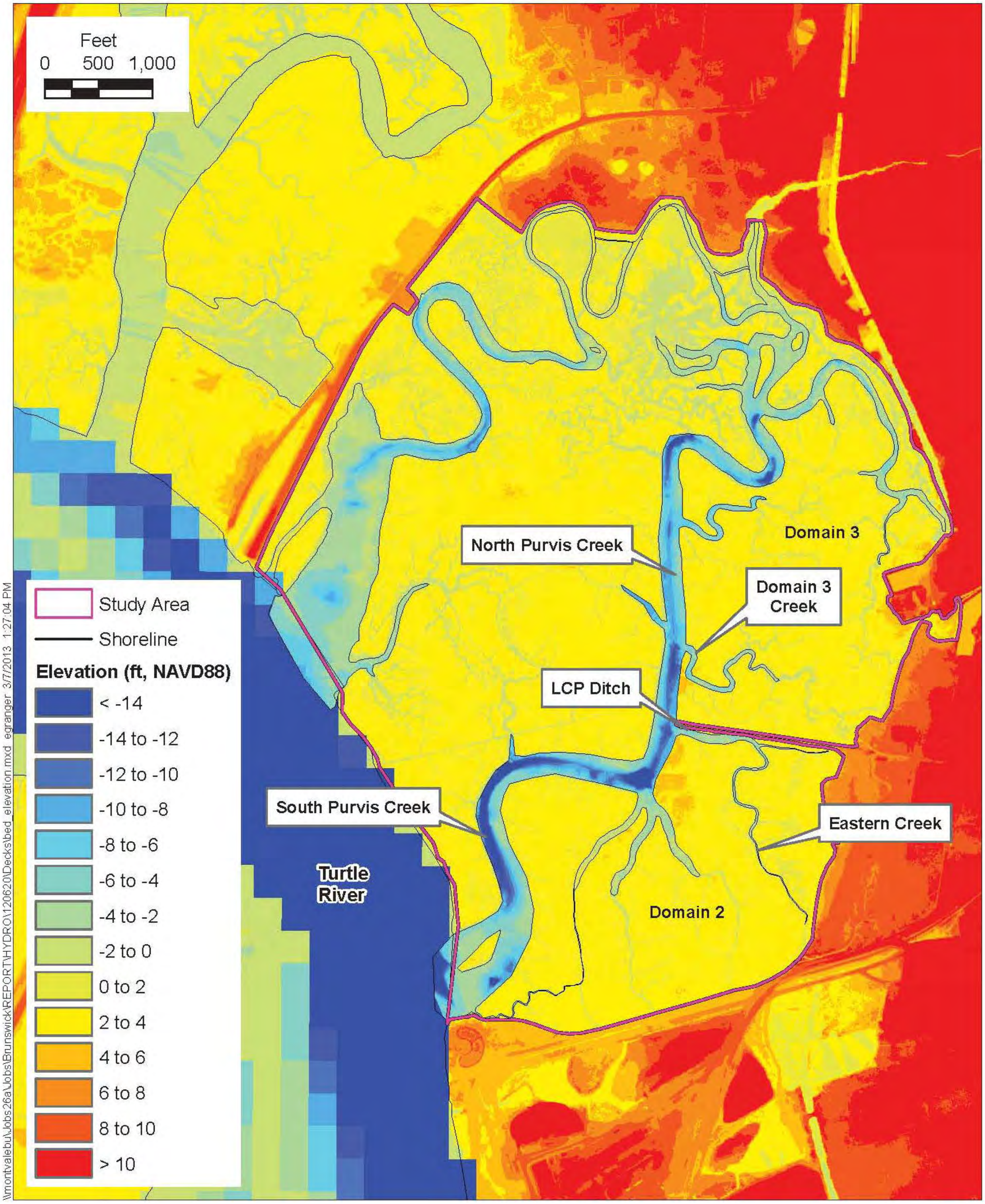

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Surface Elevation within the Study Area based on
LiDAR Data in Marshes and
Single-beam Bathymetry in Channels

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-4

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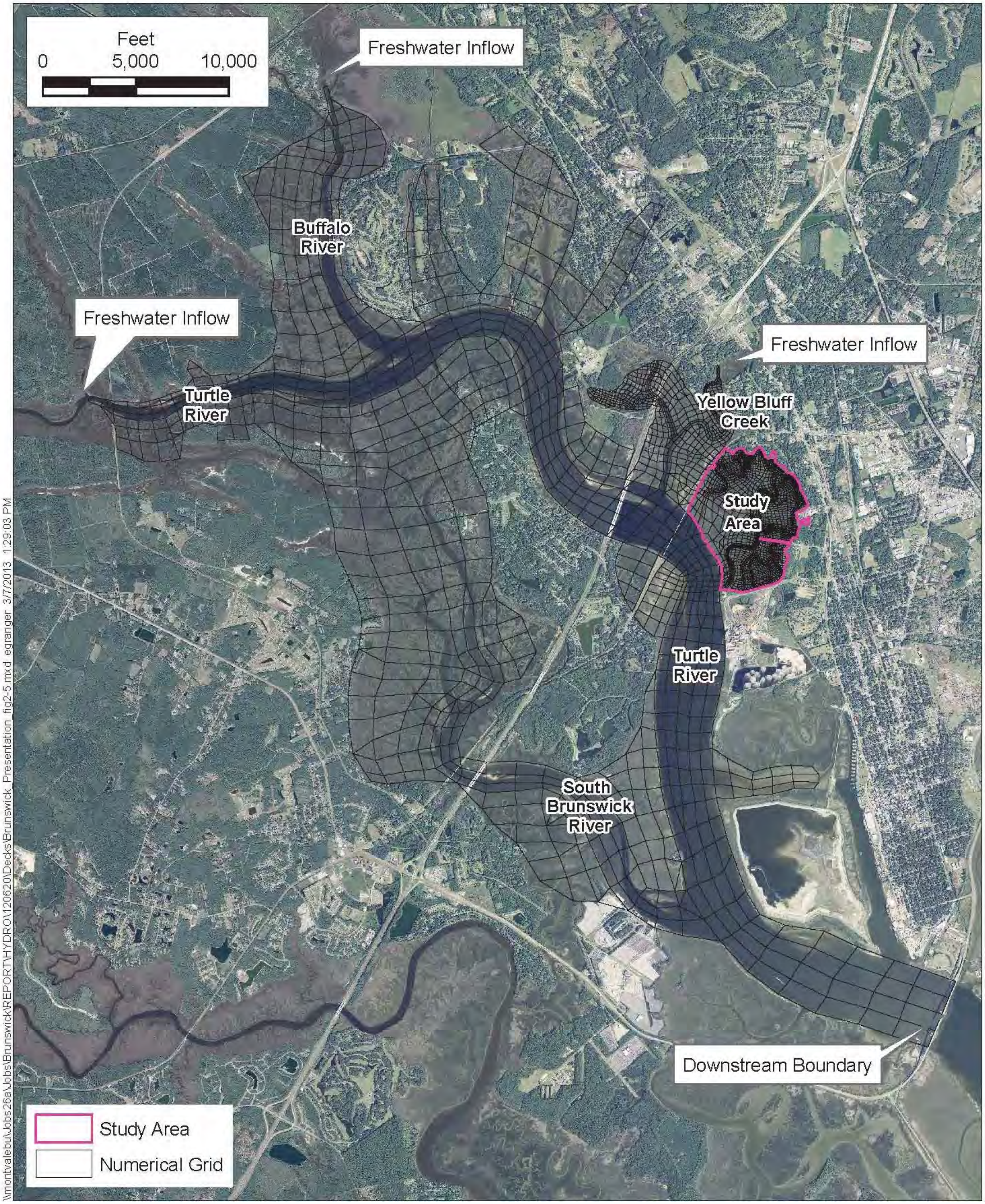

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Locations of Downstream Boundary
and Freshwater Inflows

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-5

PROJECT 02-27105C

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Locations of Tidal Gauging Stations

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-6

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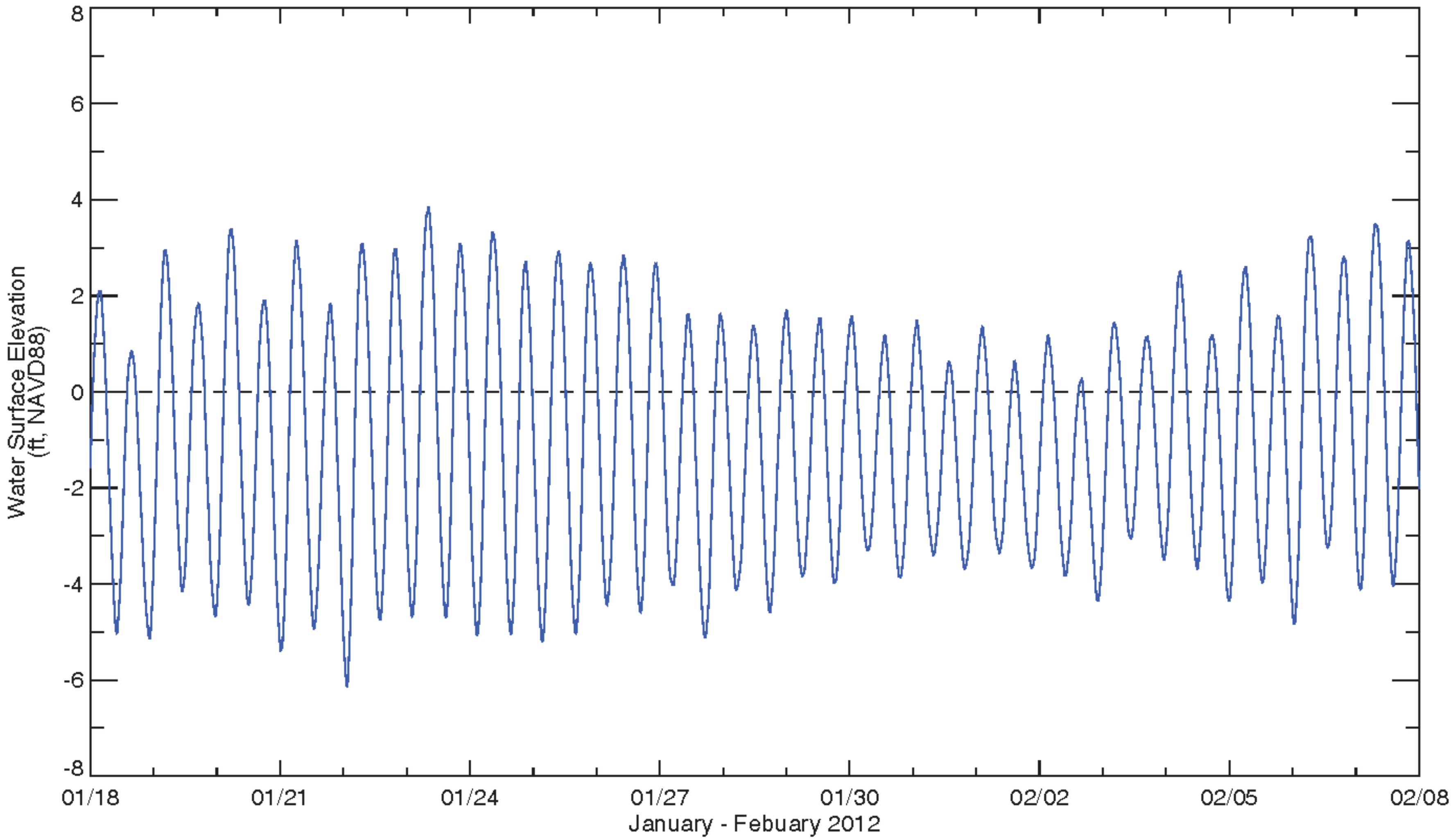

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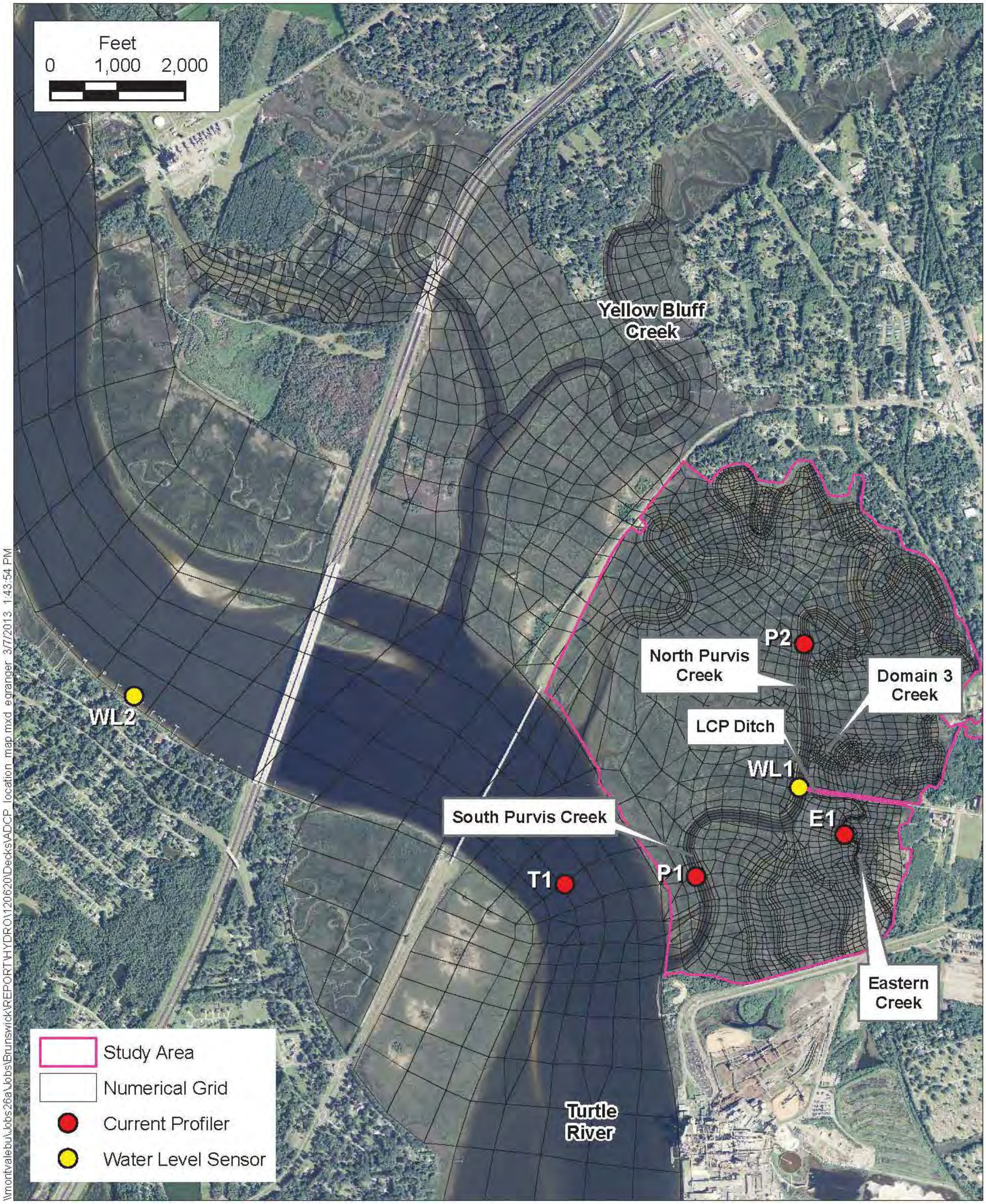
Water Surface Elevation at Downstream Boundary during Calibration Period

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-7

PROJECT 02-27105C



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Locations of Water Level Sensors and ADCPs near Study Area

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-8

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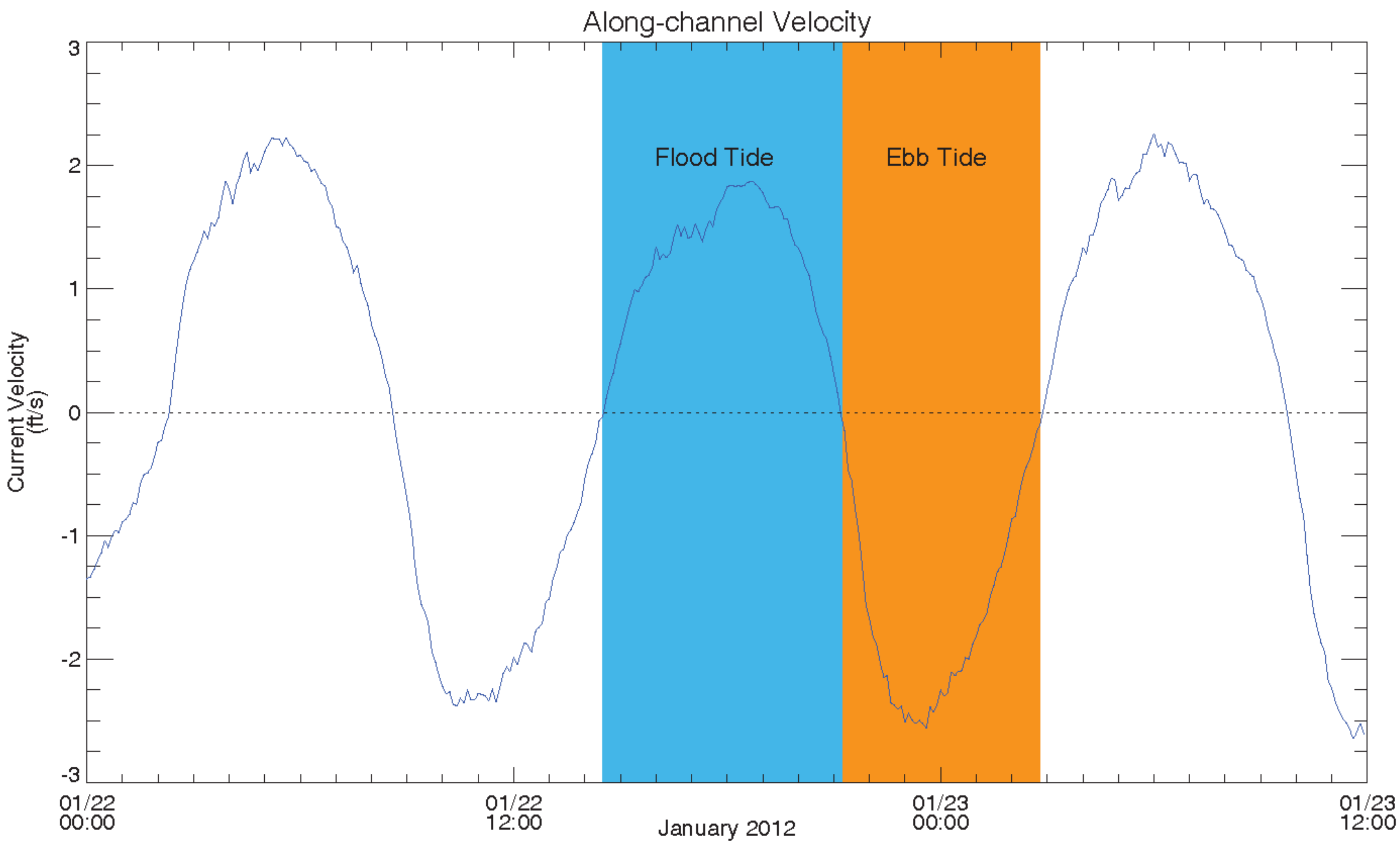

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Behavior of Tidal Currents in Turtle River (Station T1) during Spring Tide

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-9

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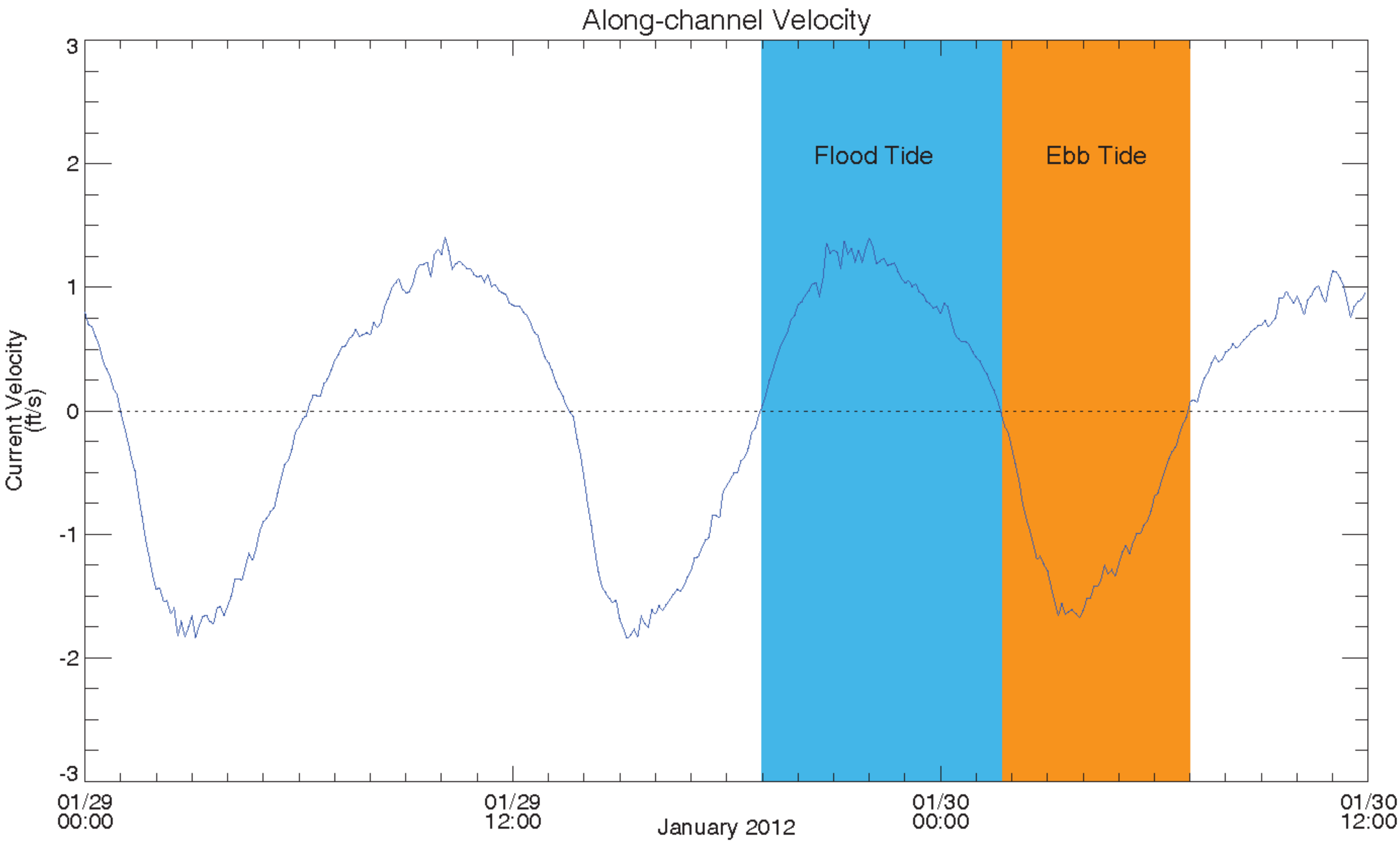

Behavior of Tidal Currents in Turtle River (Station T1) during Neap Tide

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-10

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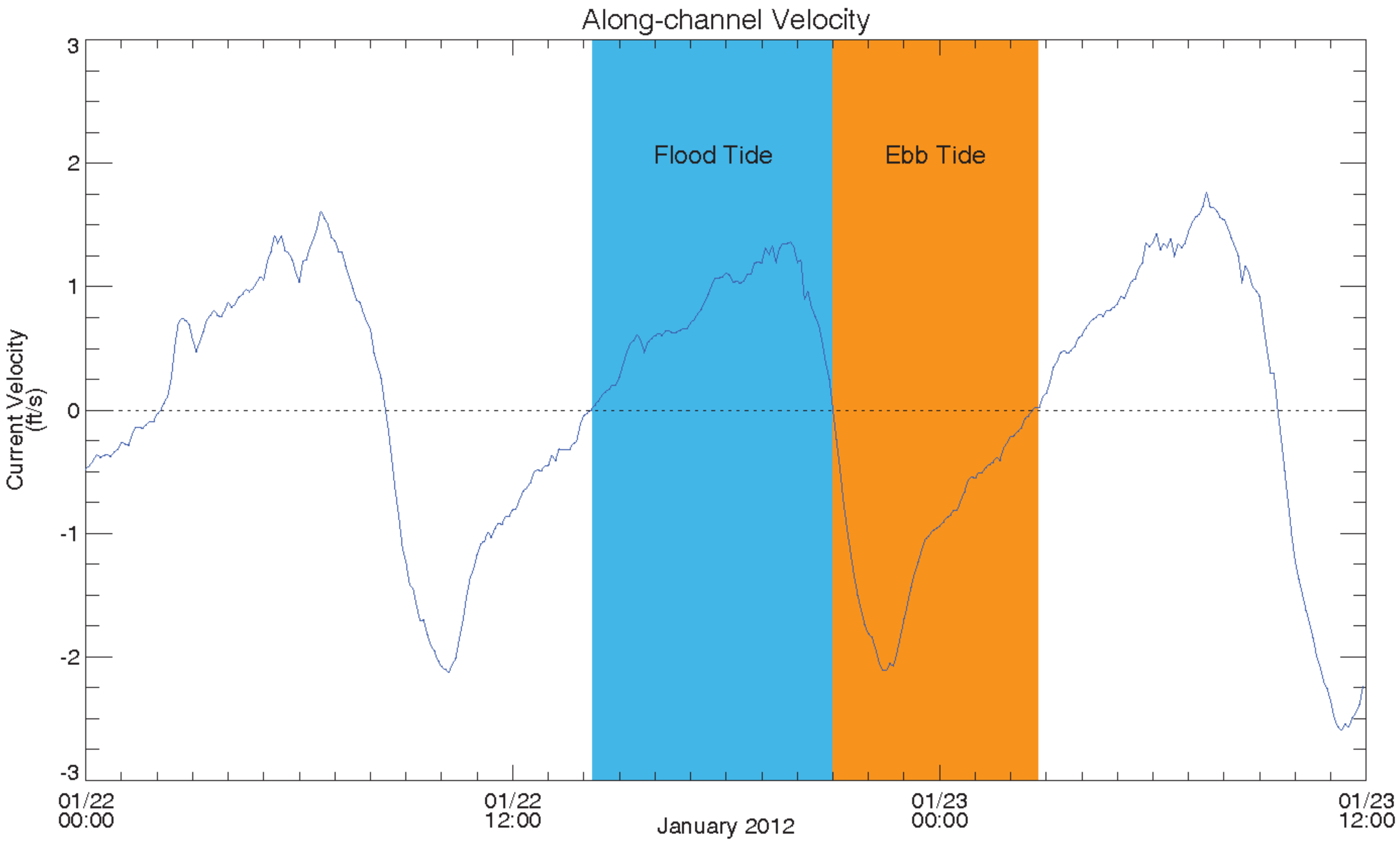

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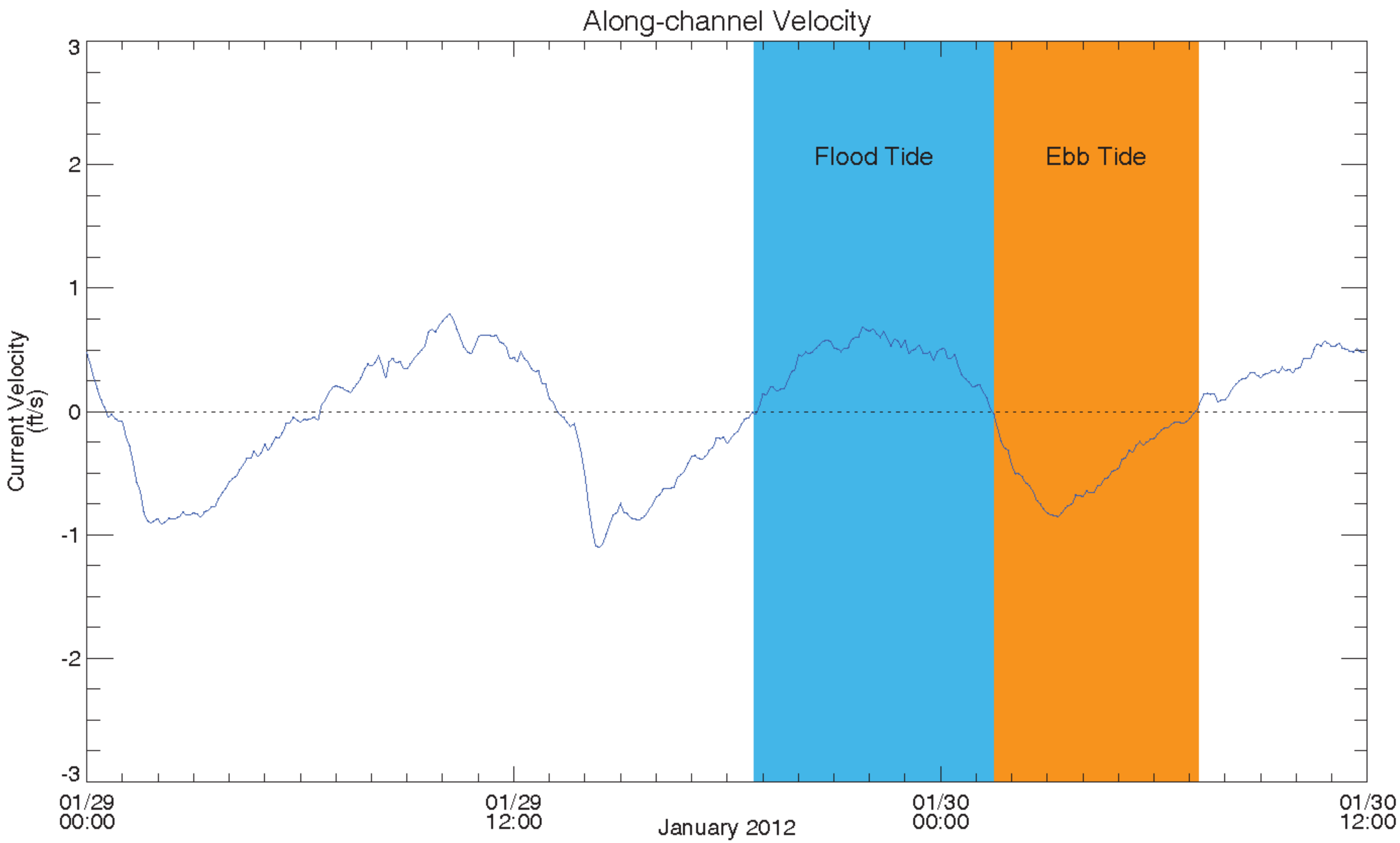
Behavior of Tidal Currents in Purvis Creek (Station P1) during Spring Tide

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-11

PROJECT 02-27105C



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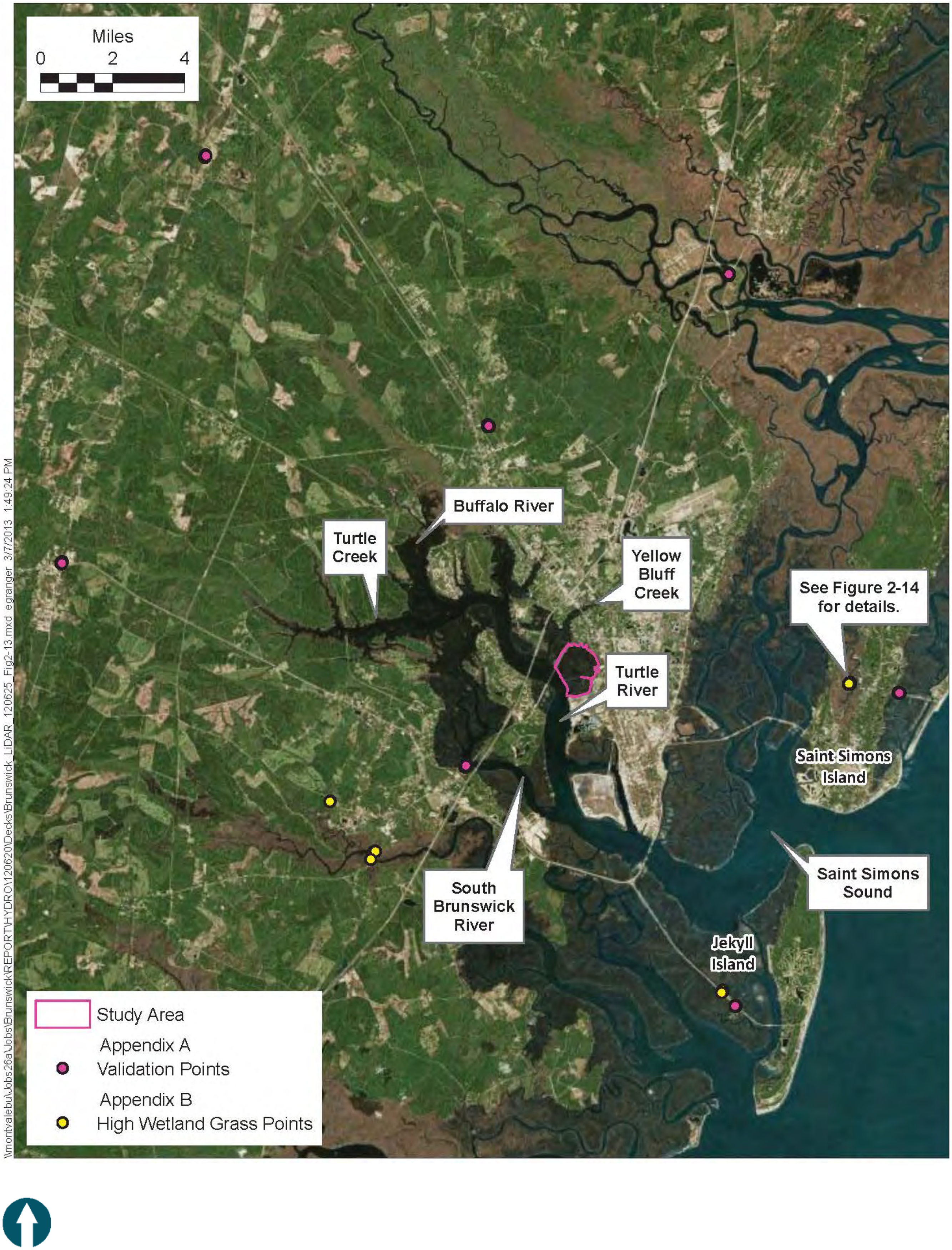
Behavior of Tidal Currents in Purvis Creek (Station P1) during Neap Tide

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-12

PROJECT 02-27105C



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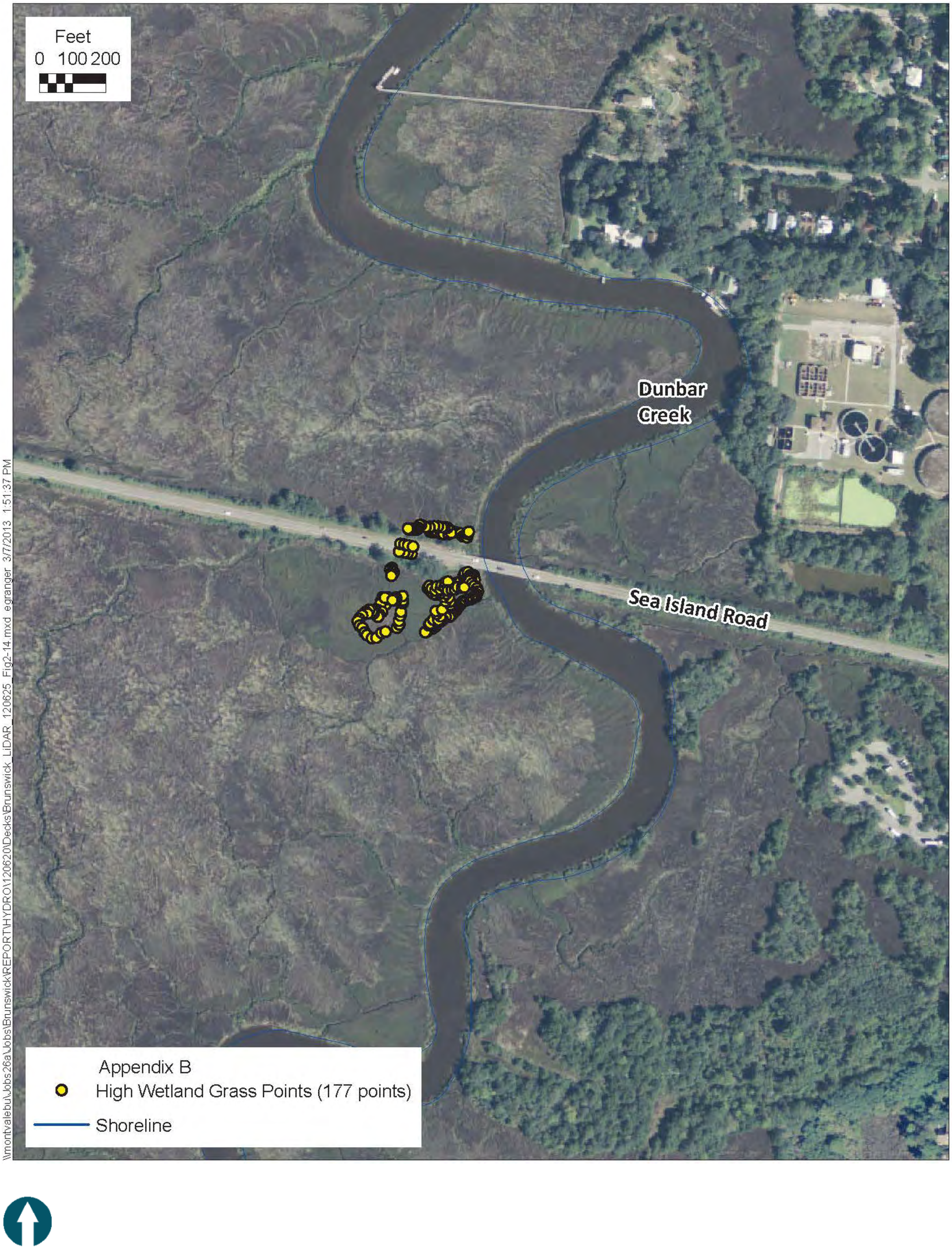
LiDAR DEM Quality Control Survey Locations in Glynn County, Georgia

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-13

PROJECT 02-27105C



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Cluster of LiDAR Validation Measurements at a Quality Control Survey Location

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-14

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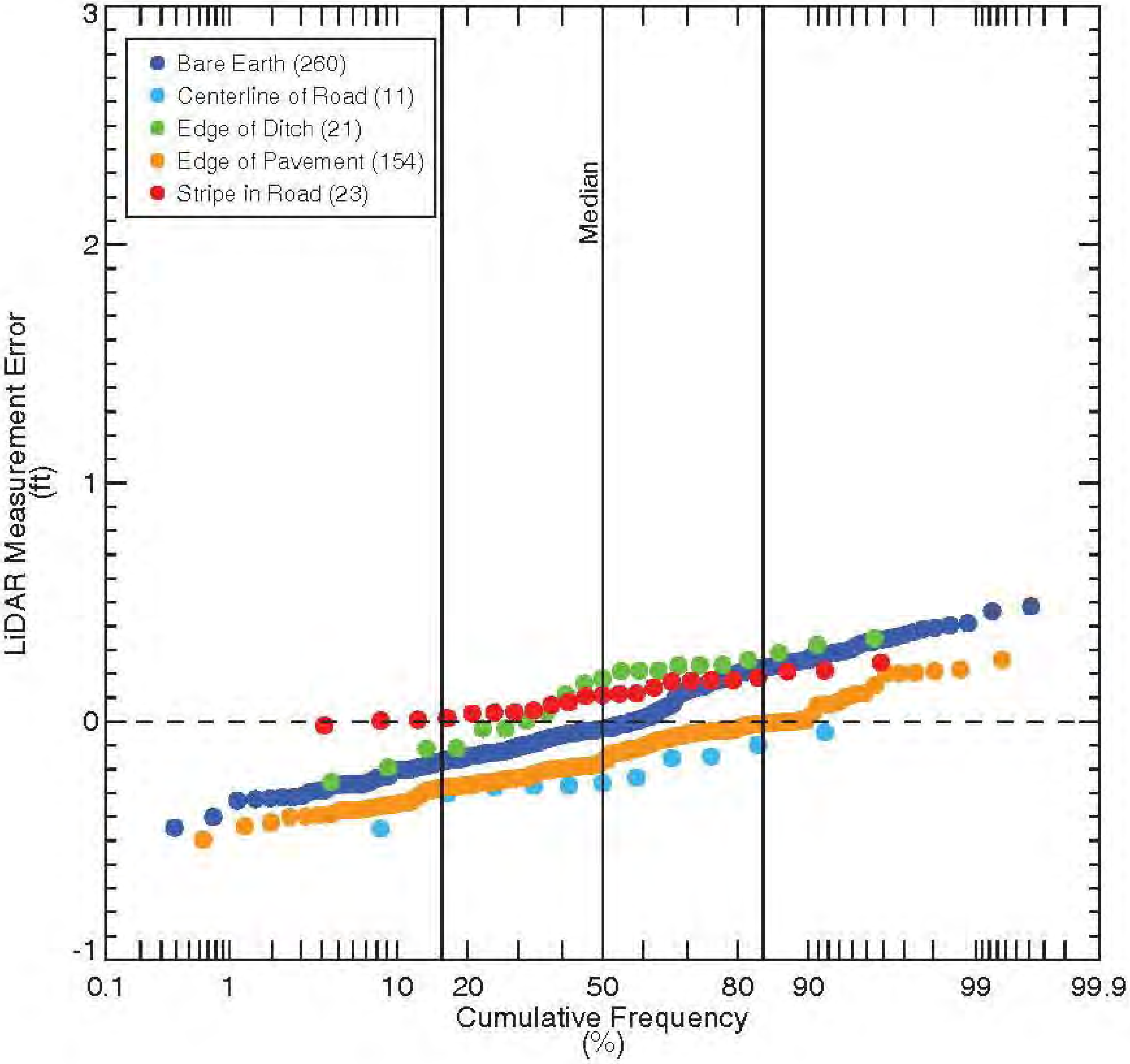
PROJECT 02-27105C



Note: Number of measurements for each surface noted in parentheses in legend.

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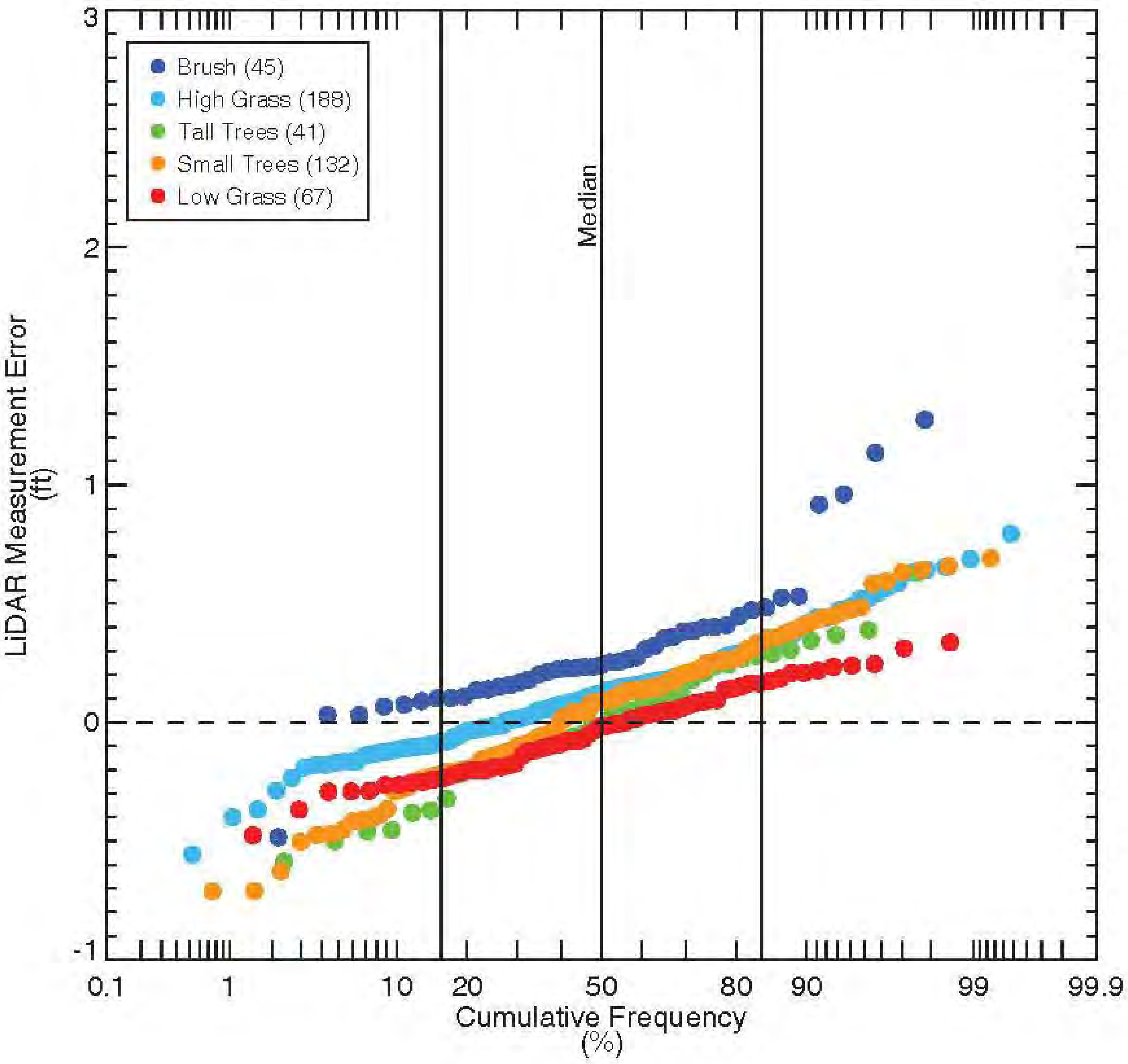
Cumulative Frequency Distributions of LiDAR Measurement Errors at Validation Points for Hard Surfaces

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-15

PROJECT 02-27105C



Note: Number of measurements for each surface noted in parentheses in legend.

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Cumulative Frequency Distributions of LiDAR Measurement Errors at Validation Points for Upland Vegetation

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B2-16

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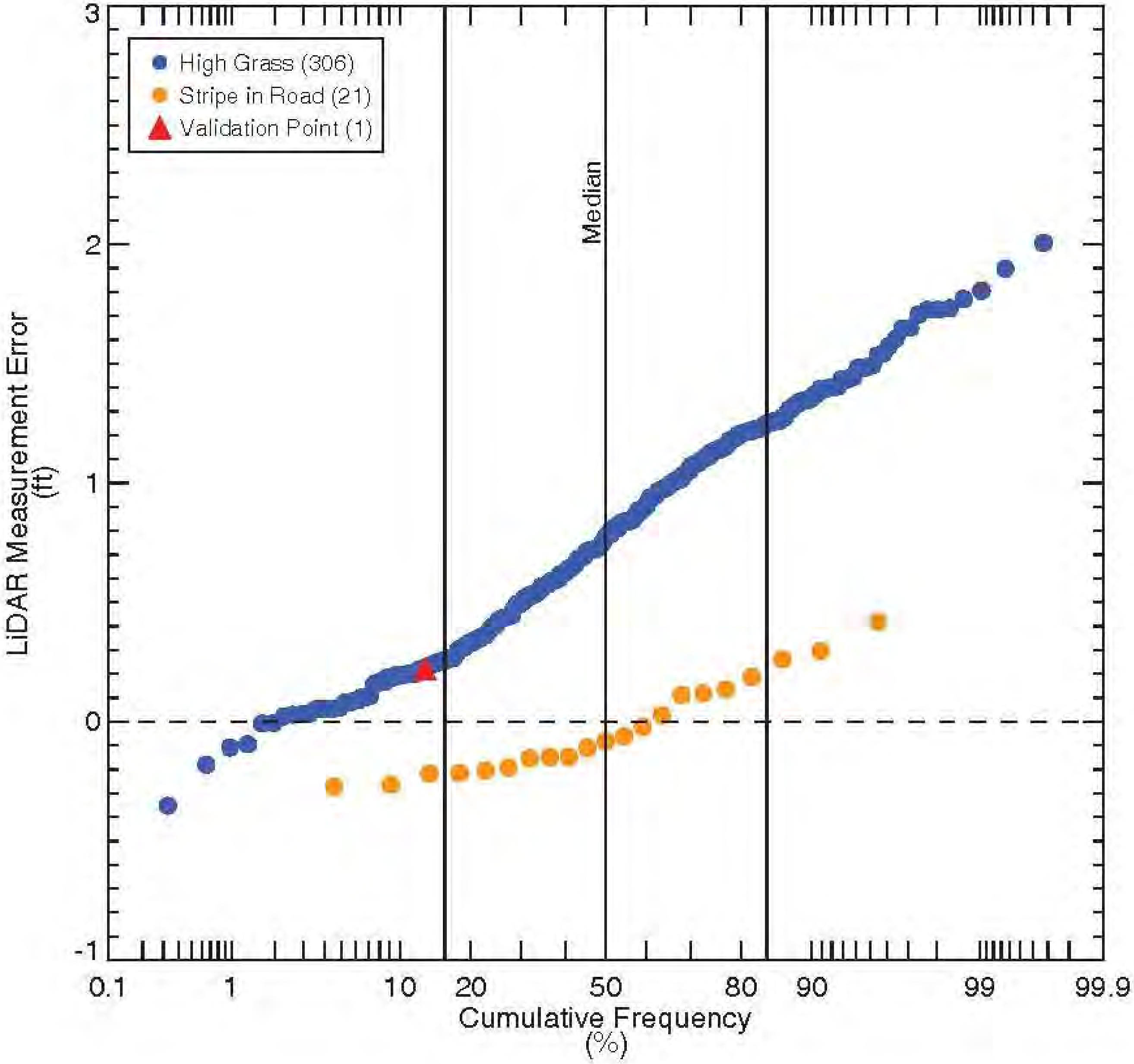

Note: Number of measurements for each surface noted in parentheses in legend.

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Cumulative Frequency Distributions of LiDAR Measurement Errors in Marsh High Grass Areas

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-17

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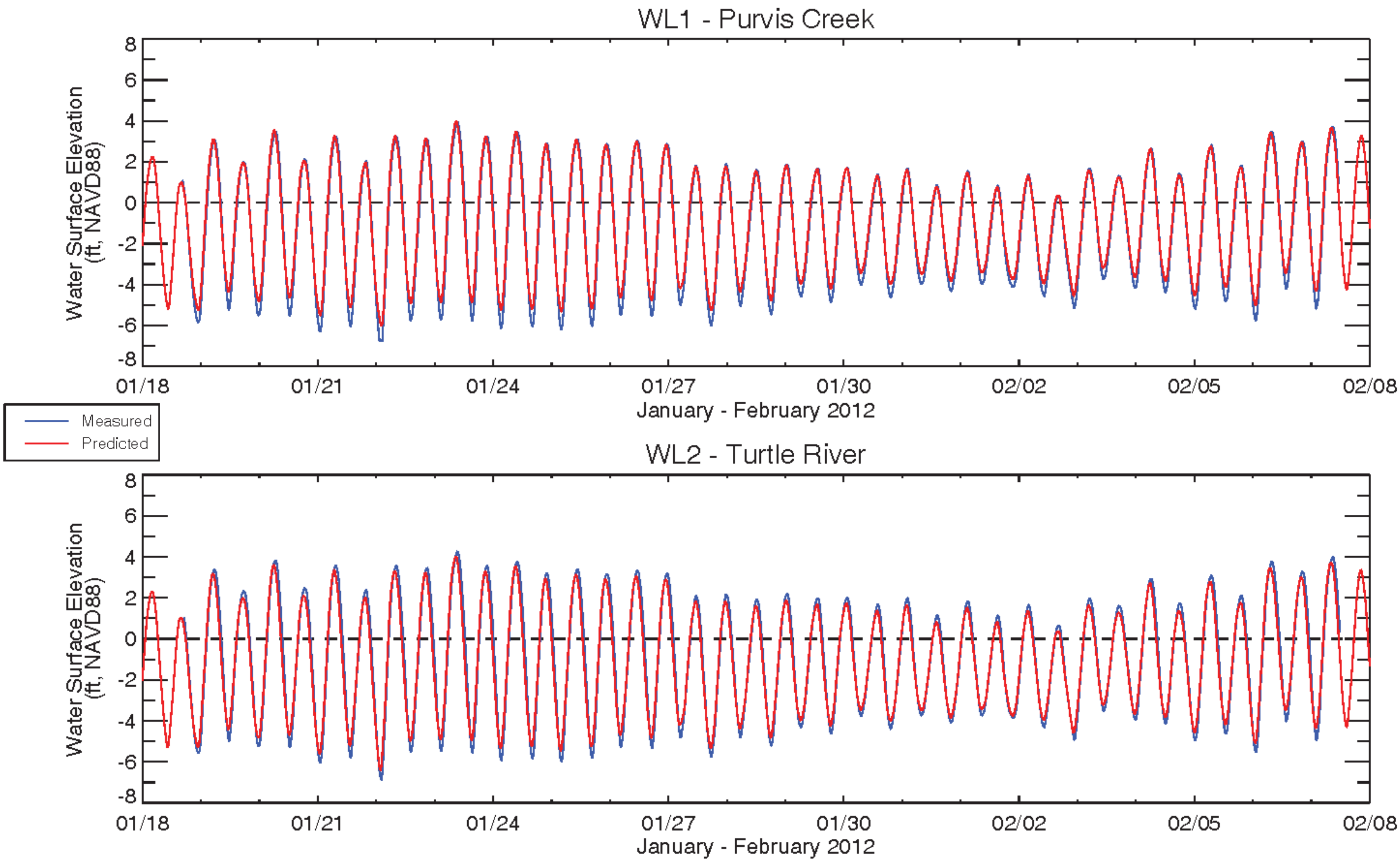

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Comparison of Predicted and Measured Water Surface Elevation
at Stations WL1 and WL2

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-18

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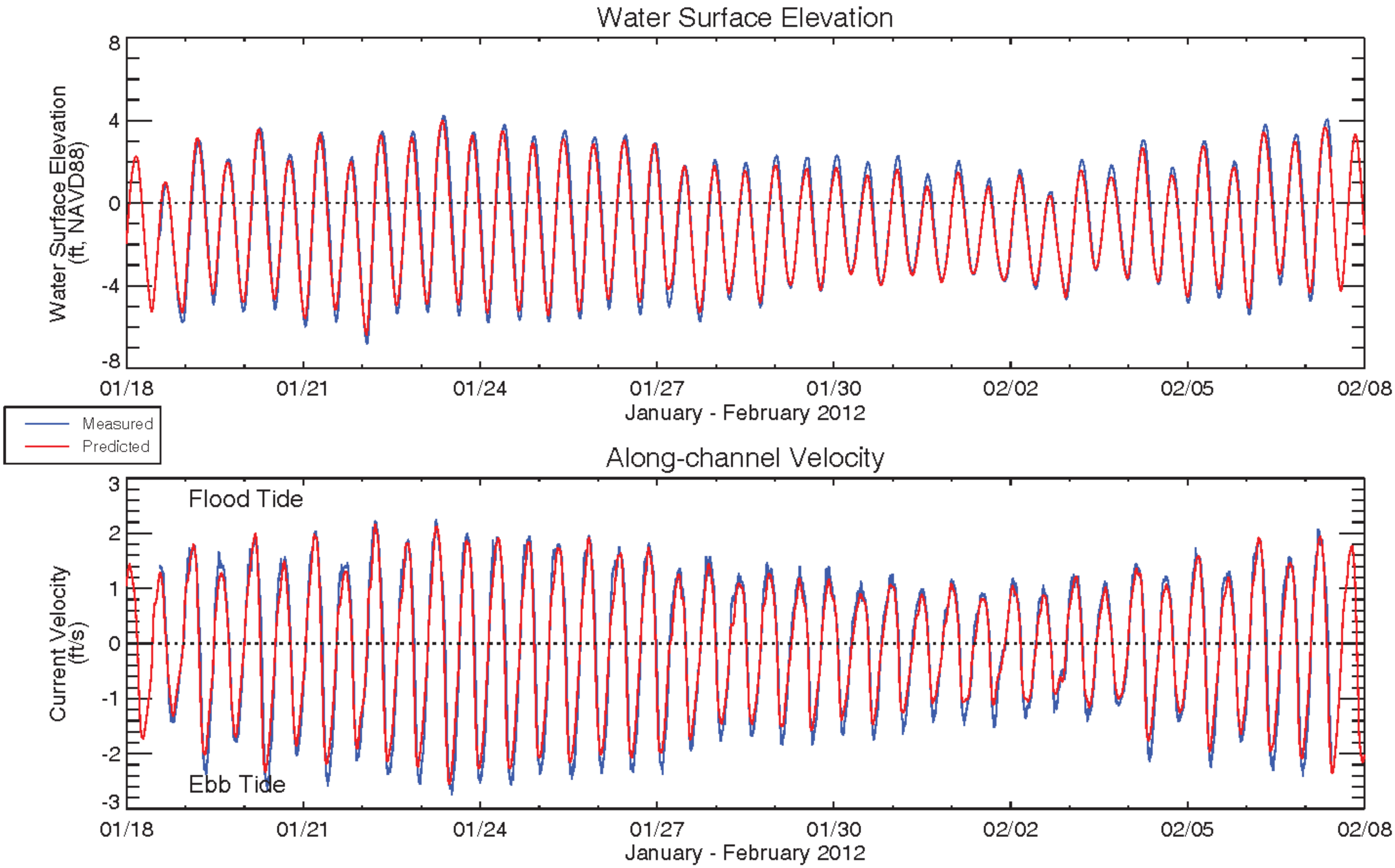

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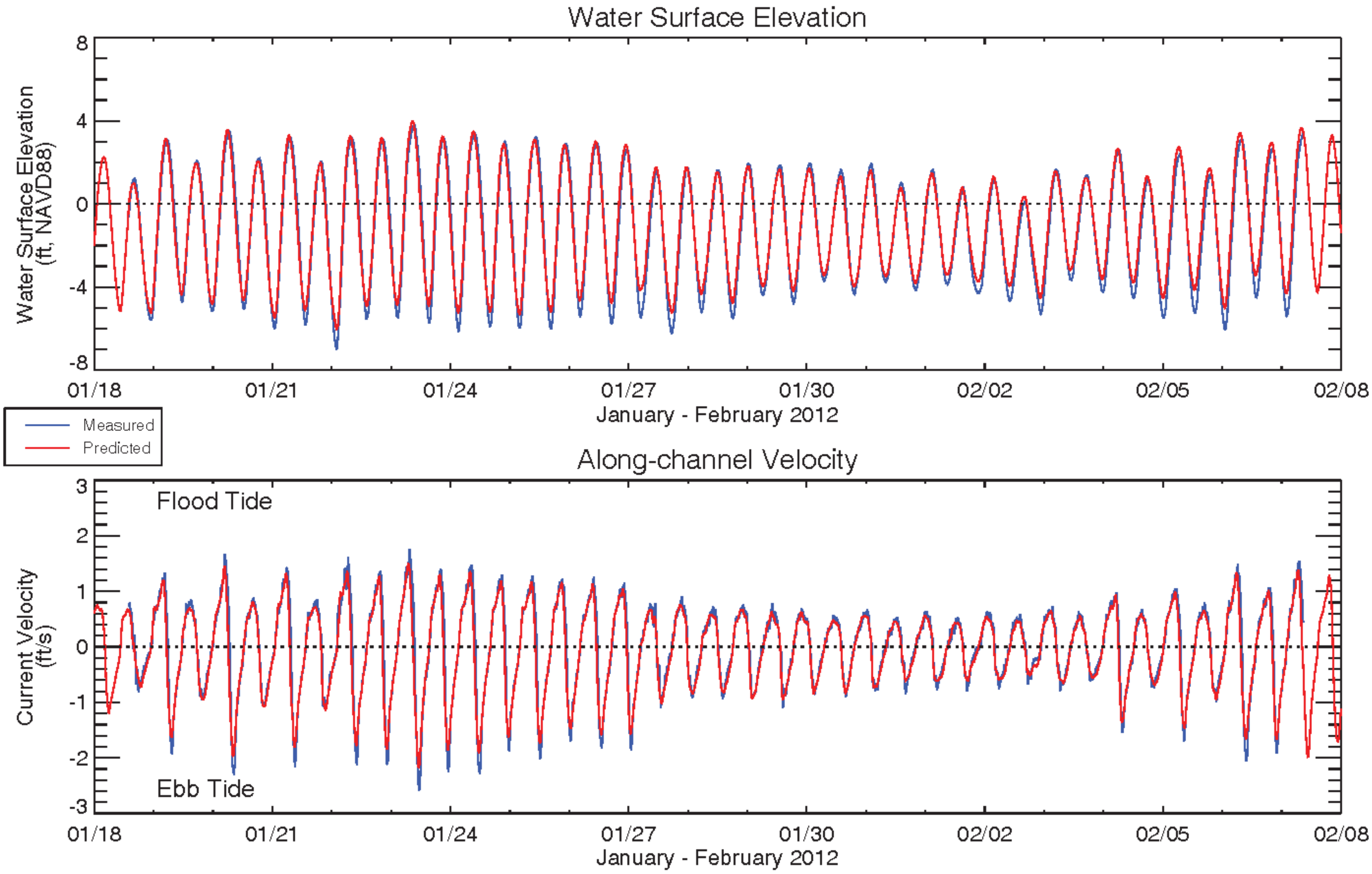
Comparison of Predicted and Measured Water Surface Elevation and Along-channel Current Velocity at Station T1 during Calibration Period

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-19

PROJECT 02-27105C



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ENVIRON

Comparison of Predicted and Measured Water Surface Elevation and
Along-channel Current Velocity at Station P1 during Calibration Period

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-20

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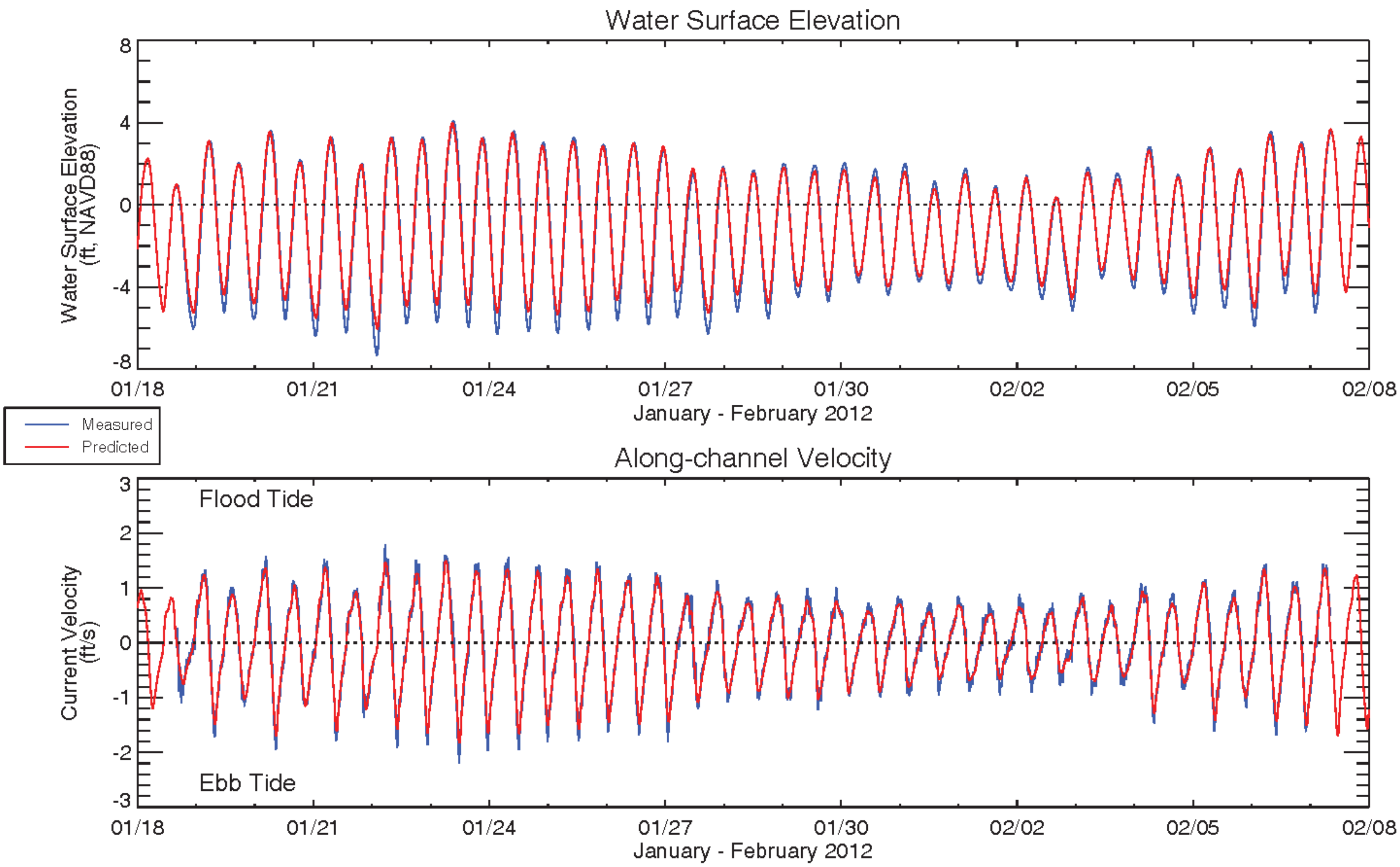

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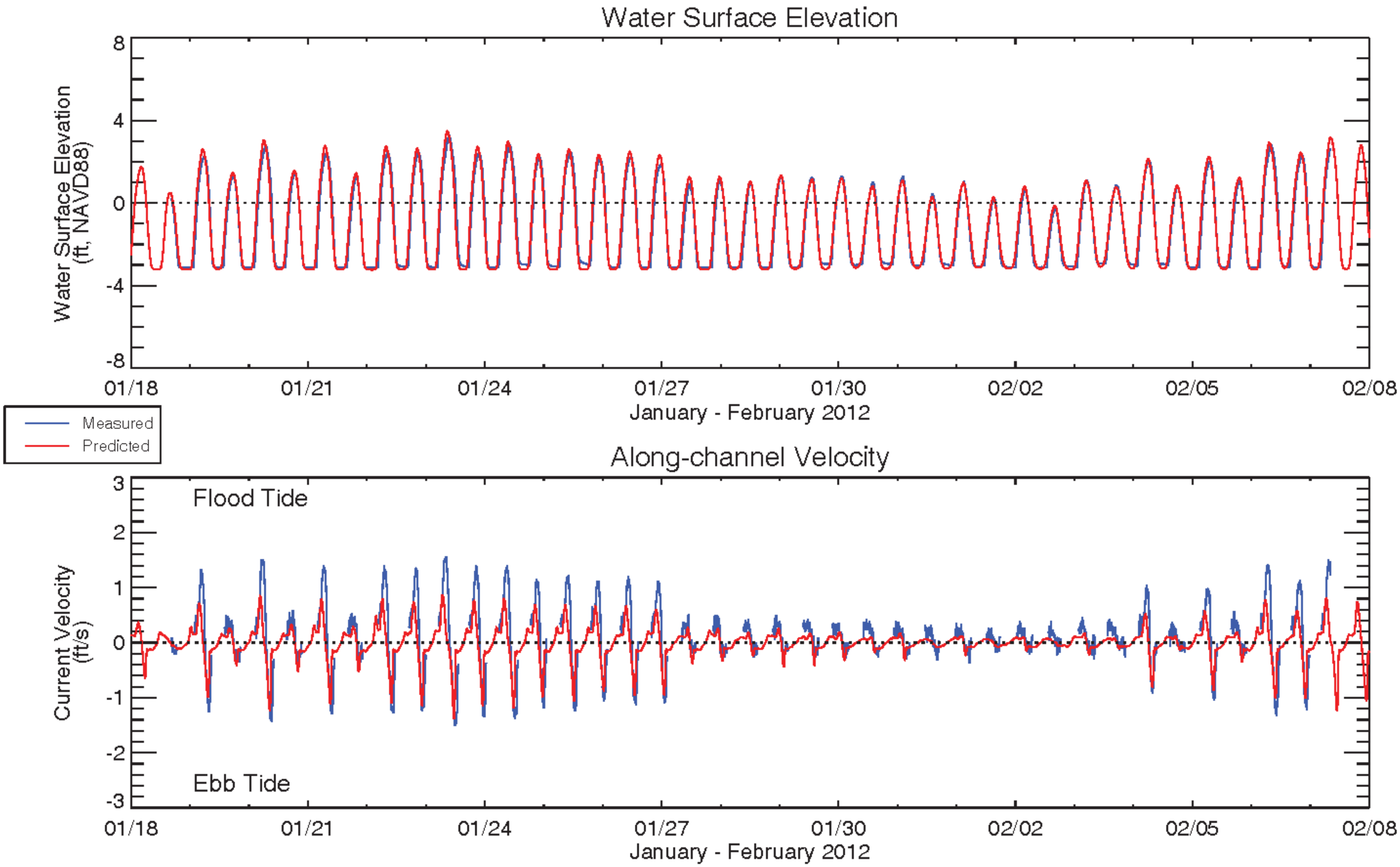
Comparison of Predicted and Measured Water Surface Elevation and Along-channel Current Velocity at Station P2 during Calibration Period

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-21

PROJECT 02-27105C



ANCHOR QEA ENVIRON

Comparison of Predicted and Measured Water Surface Elevation and Along-channel Current Velocity at Station E1 during Calibration Period

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B2-22

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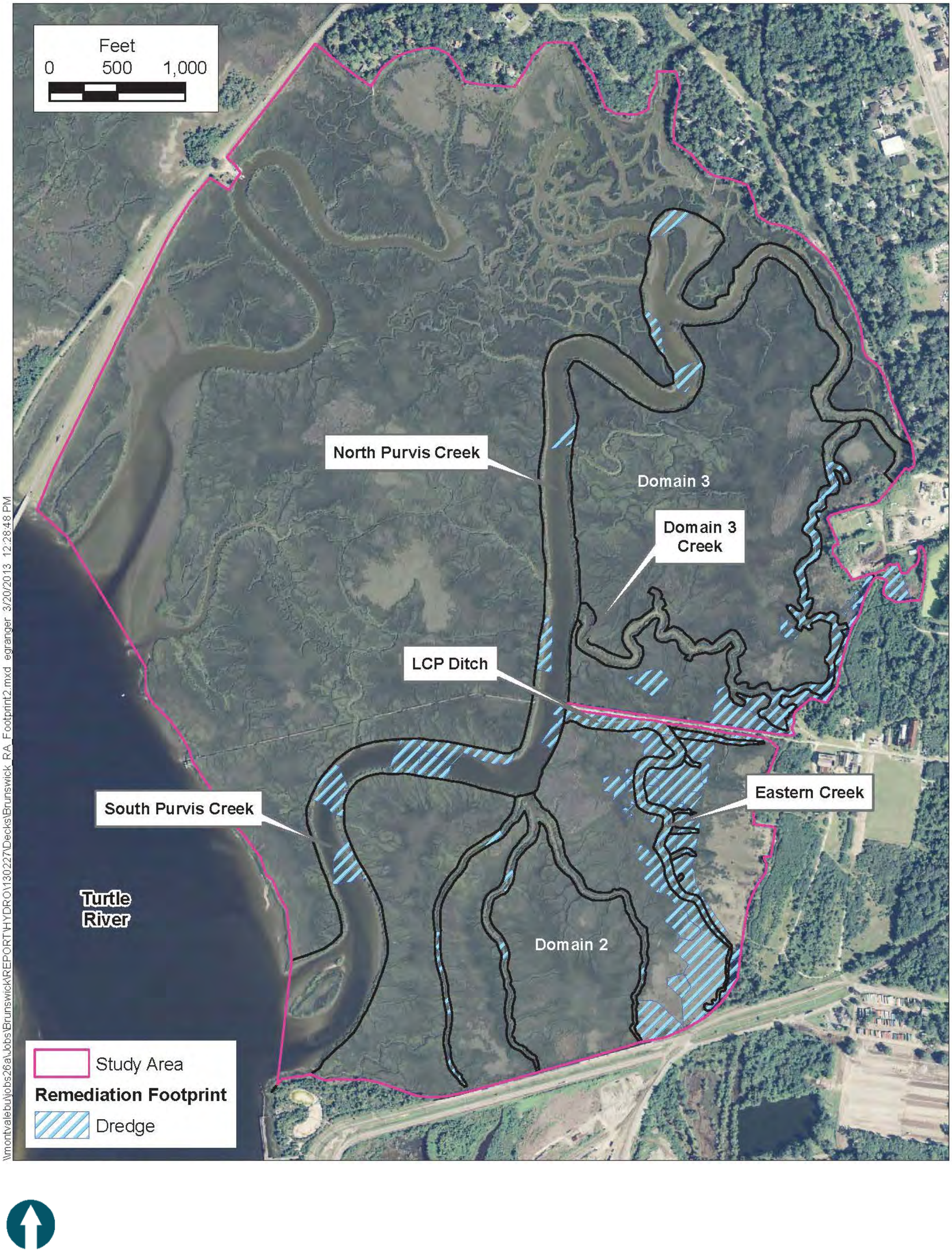

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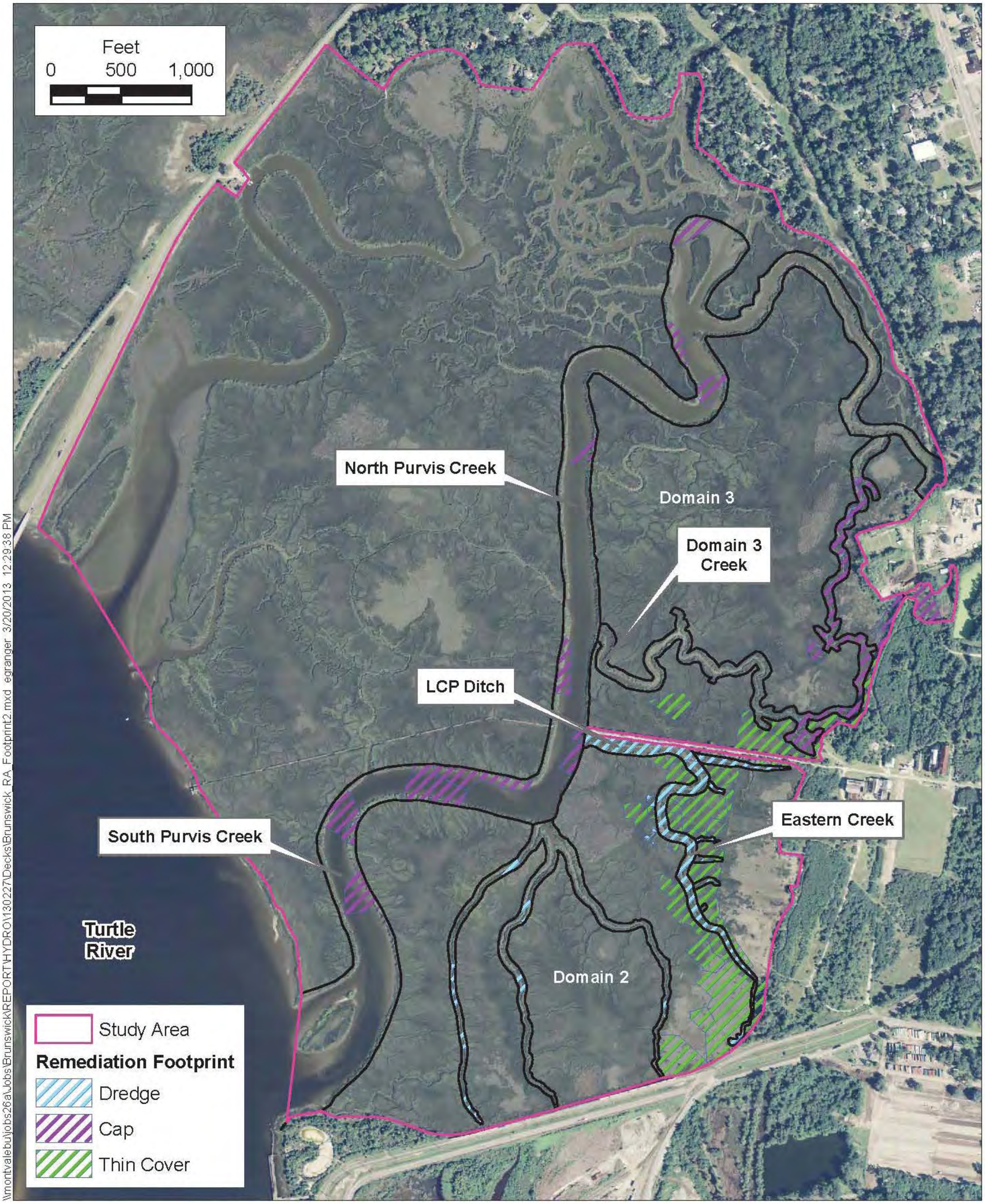
Remedial Alternative Footprint for Alternative 2

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-1

PROJECT 02-27105C



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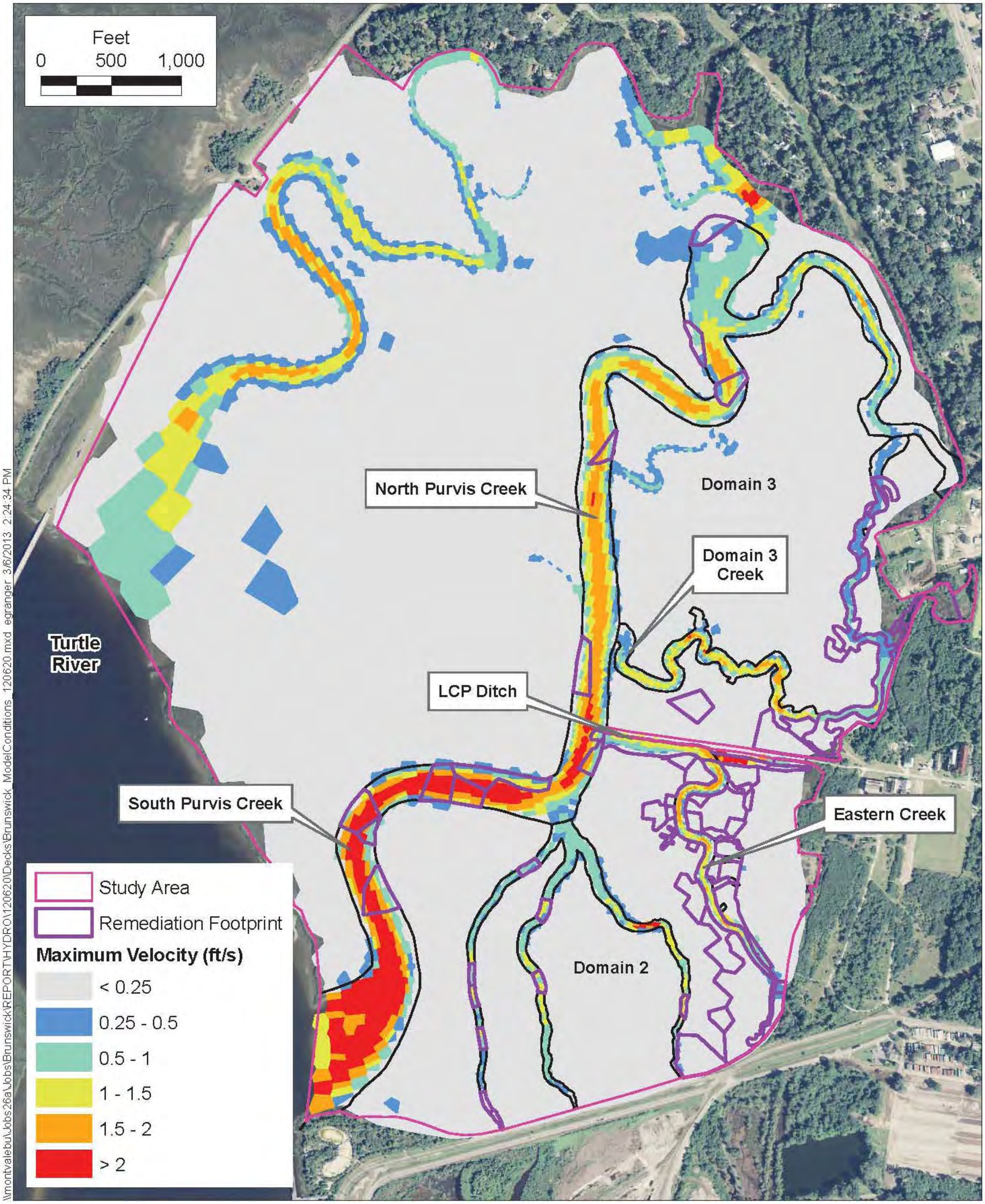
DATE: March 29, 2013

Remedial Alternative Footprint for Alternative 3

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-2

PROJECT 02-27105C



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ENVIRON

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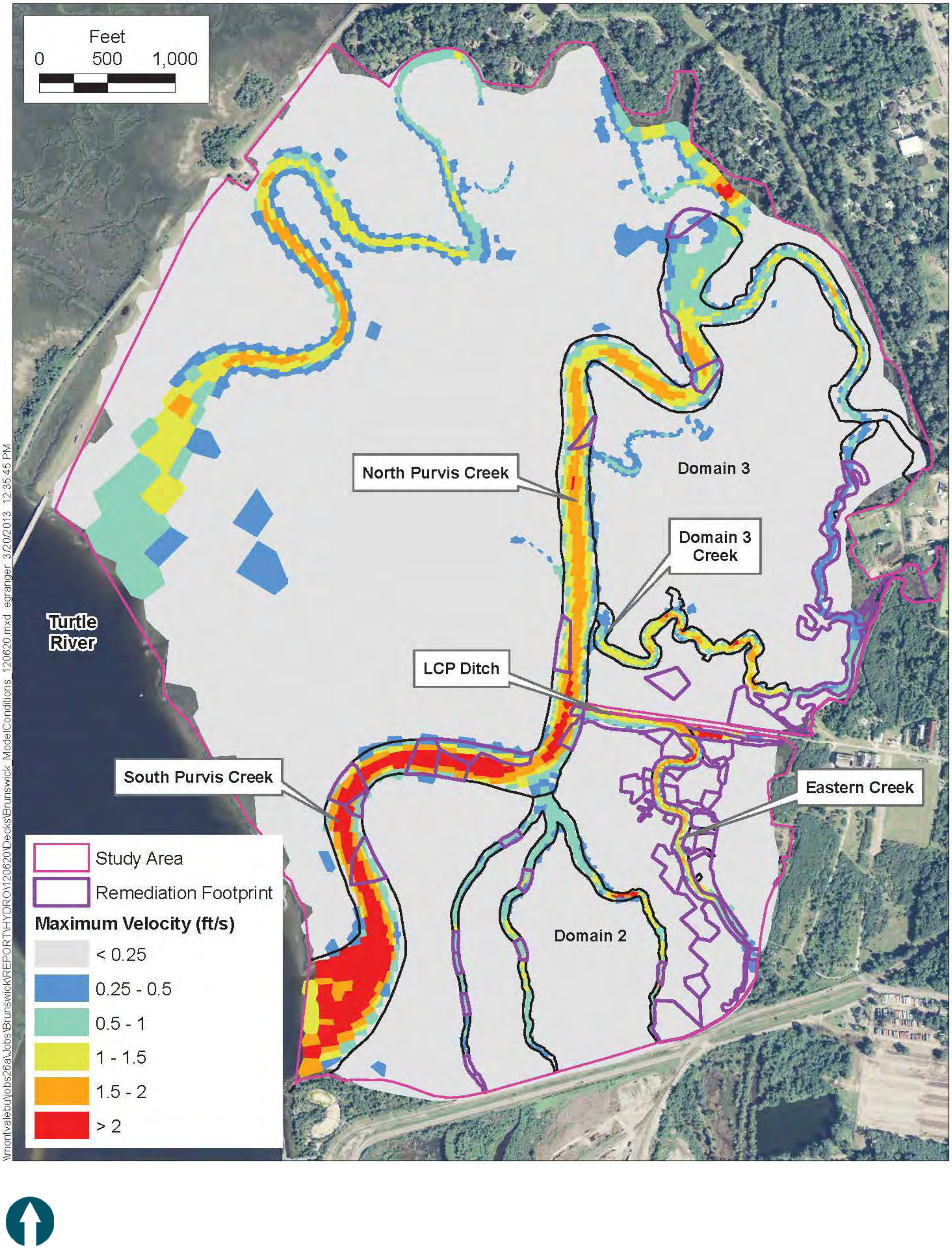
DATE: March 29, 2013

Maximum Predicted Current Velocity for Existing Conditions: Typical Tidal Conditions

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-3

PROJECT 02-27105C



Maximum Predicted Current Velocity for Alternative 2: Typical Tidal Conditions

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-4

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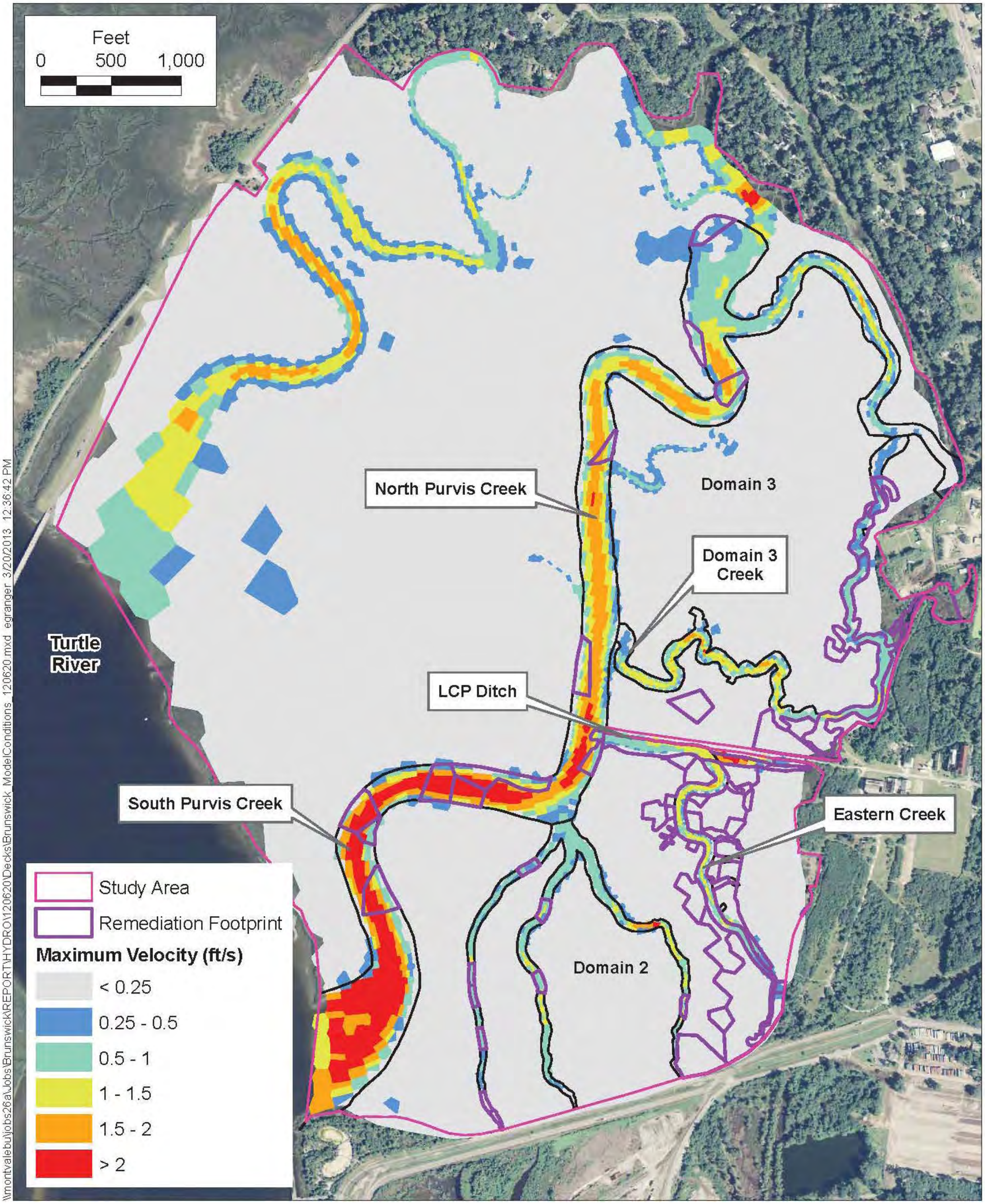

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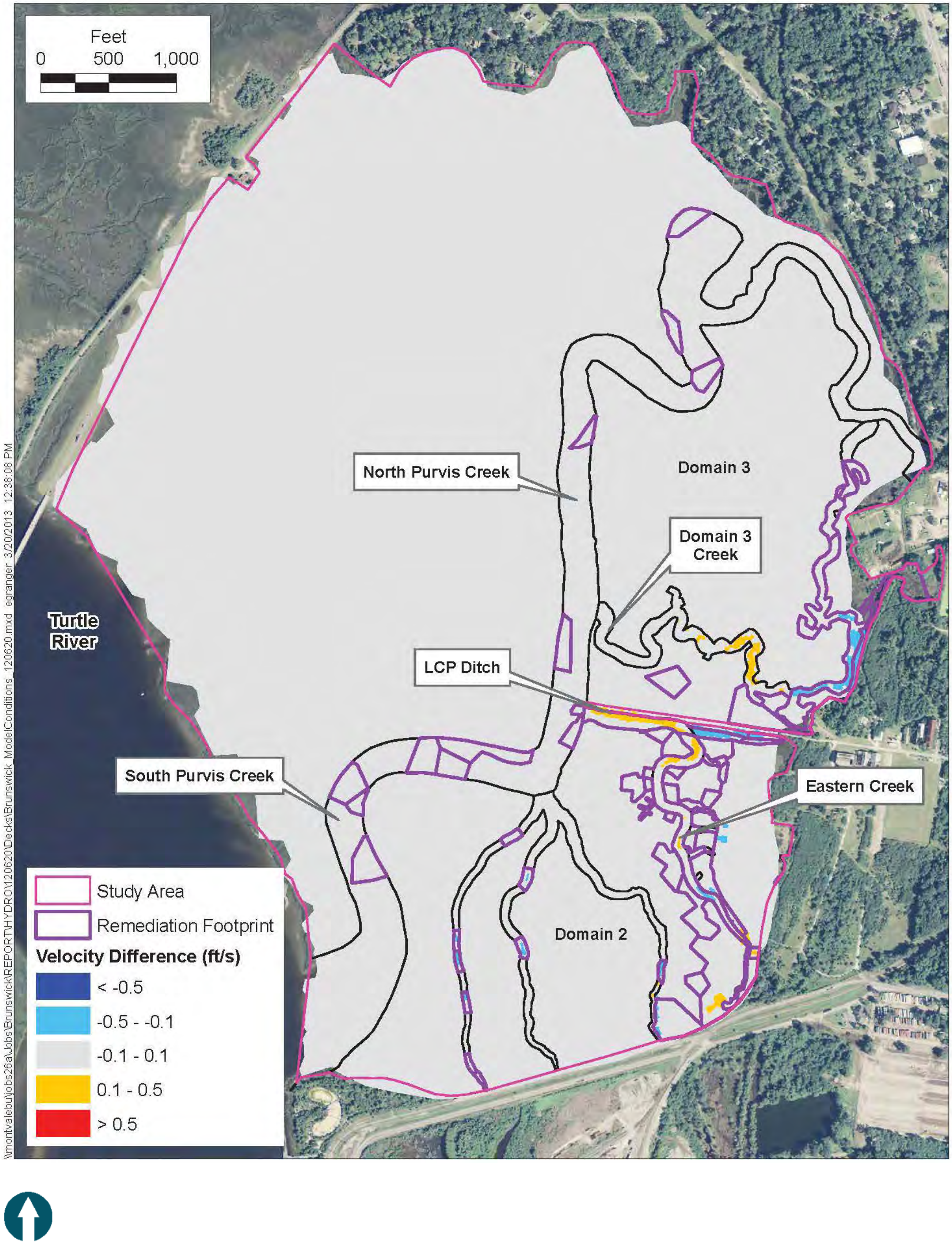
Maximum Predicted Current Velocity for
Alternative 3: Typical Tidal Conditions

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-5

PROJECT 02-27105C



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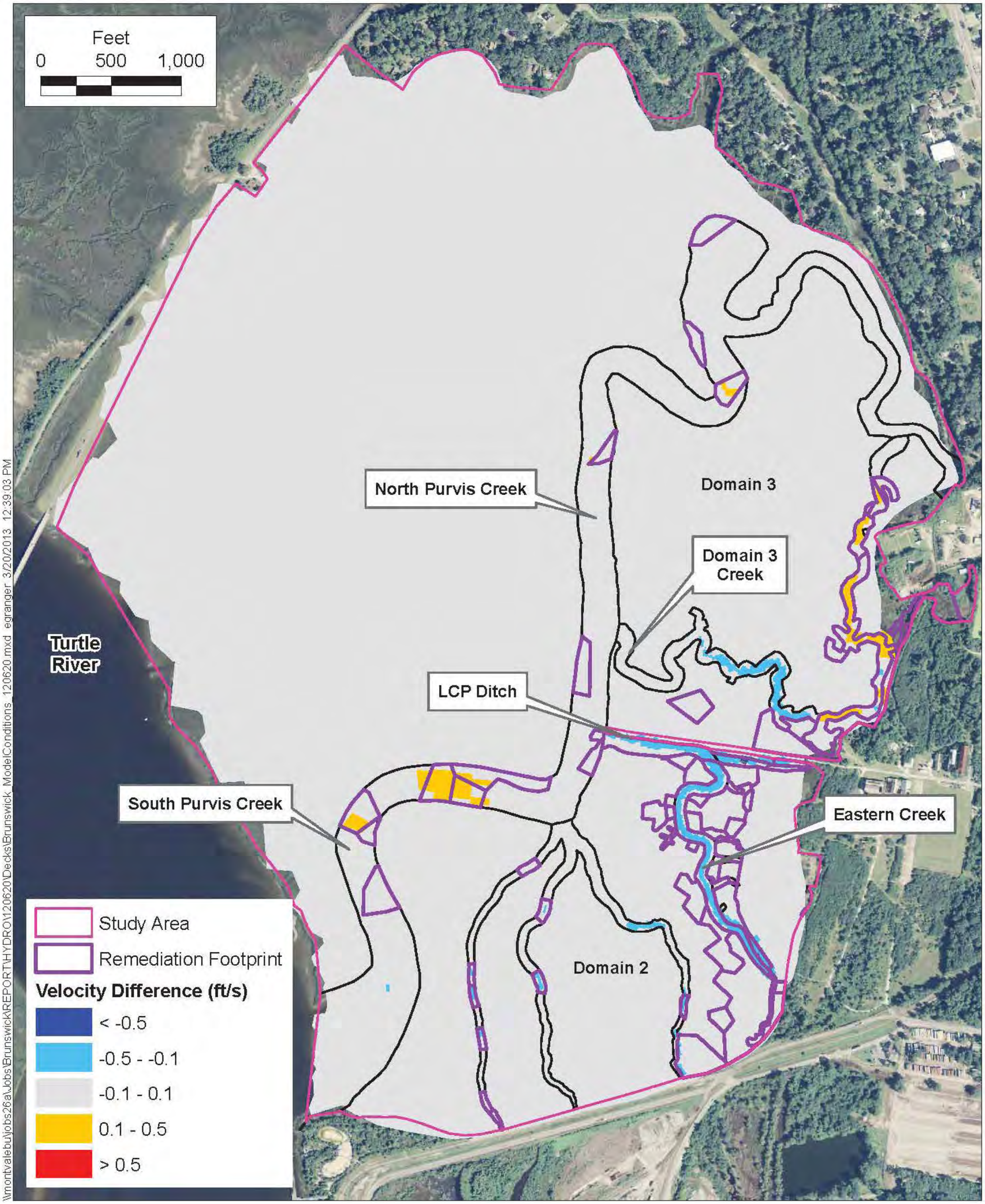
Difference in Maximum Predicted Current Velocity between Alternative 2 and Existing Conditions: Typical Tidal Conditions

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-6

PROJECT 02-27105C



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Difference in Maximum Predicted Current Velocity between Alternative 3 and Existing Conditions: Typical Tidal Conditions

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-7

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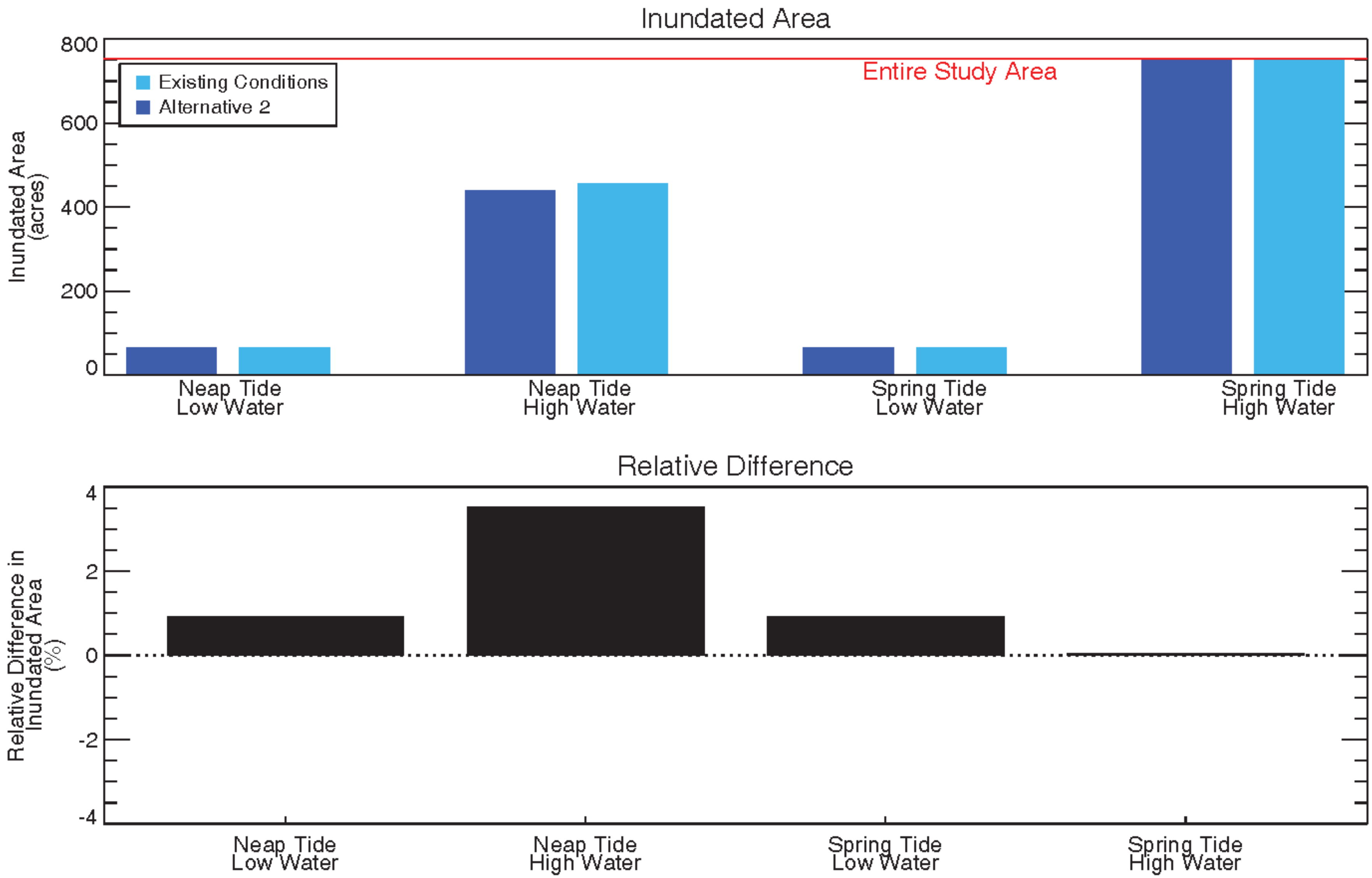
PROJECT 02-27105C



Note: Relative difference is computed as the Alternative 2 inundated area minus the existing conditions inundated area, divided by the total study area.

ANCHOR QEA

ENVIRON

Comparison of Inundated Area at Low and High Tide between
Alternative 2 and Existing Conditions: Typical Tidal Conditions

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-8

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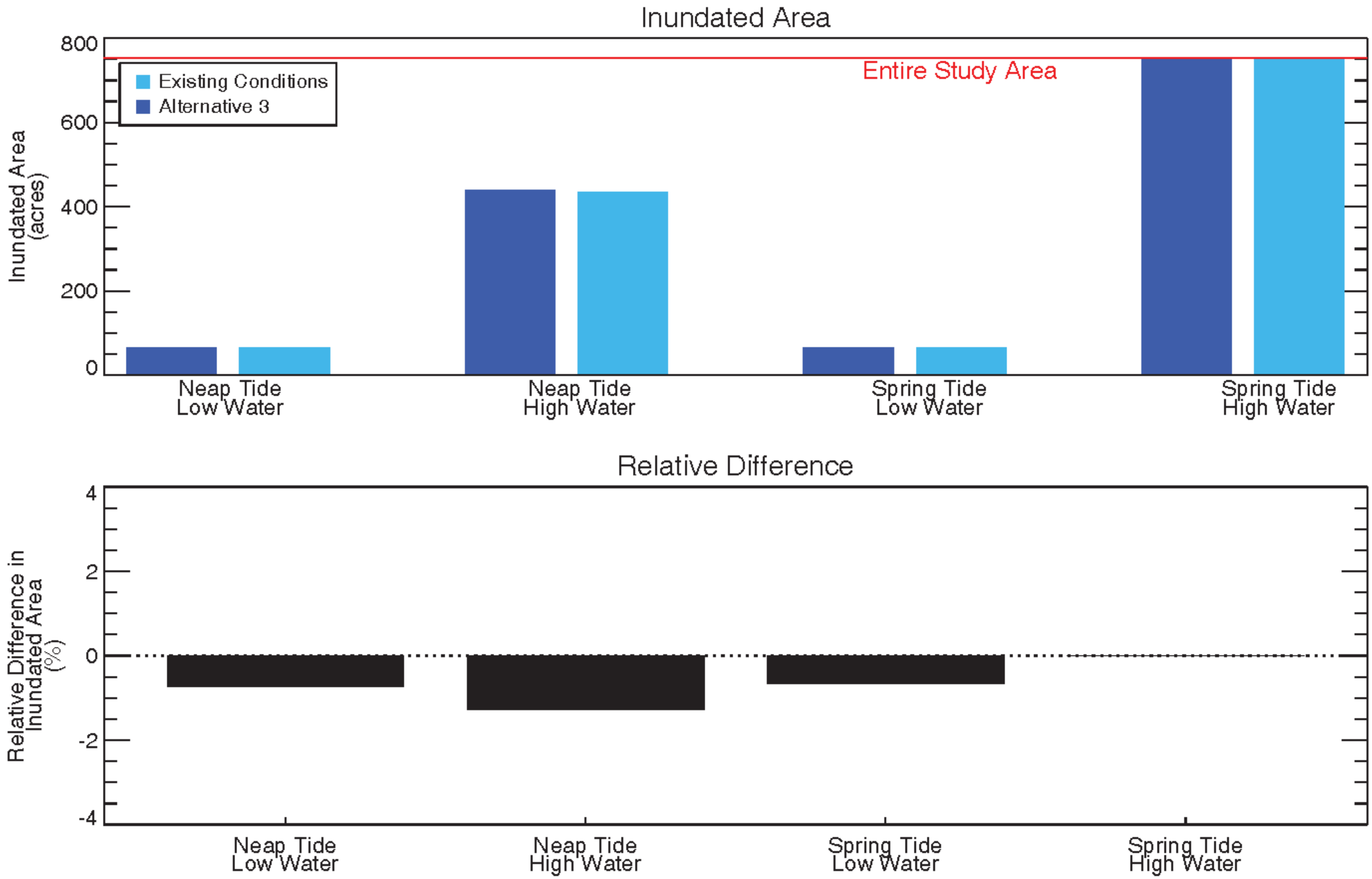

Note: Relative difference is computed as the Alternative 3 inundated area minus the existing conditions inundated area, divided by the total study area.

ANCHOR QEA ENVIRON

Comparison of Inundated Area at Low and High Tide between
Alternative 3 and Existing Conditions: Typical Tidal Conditions

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-9

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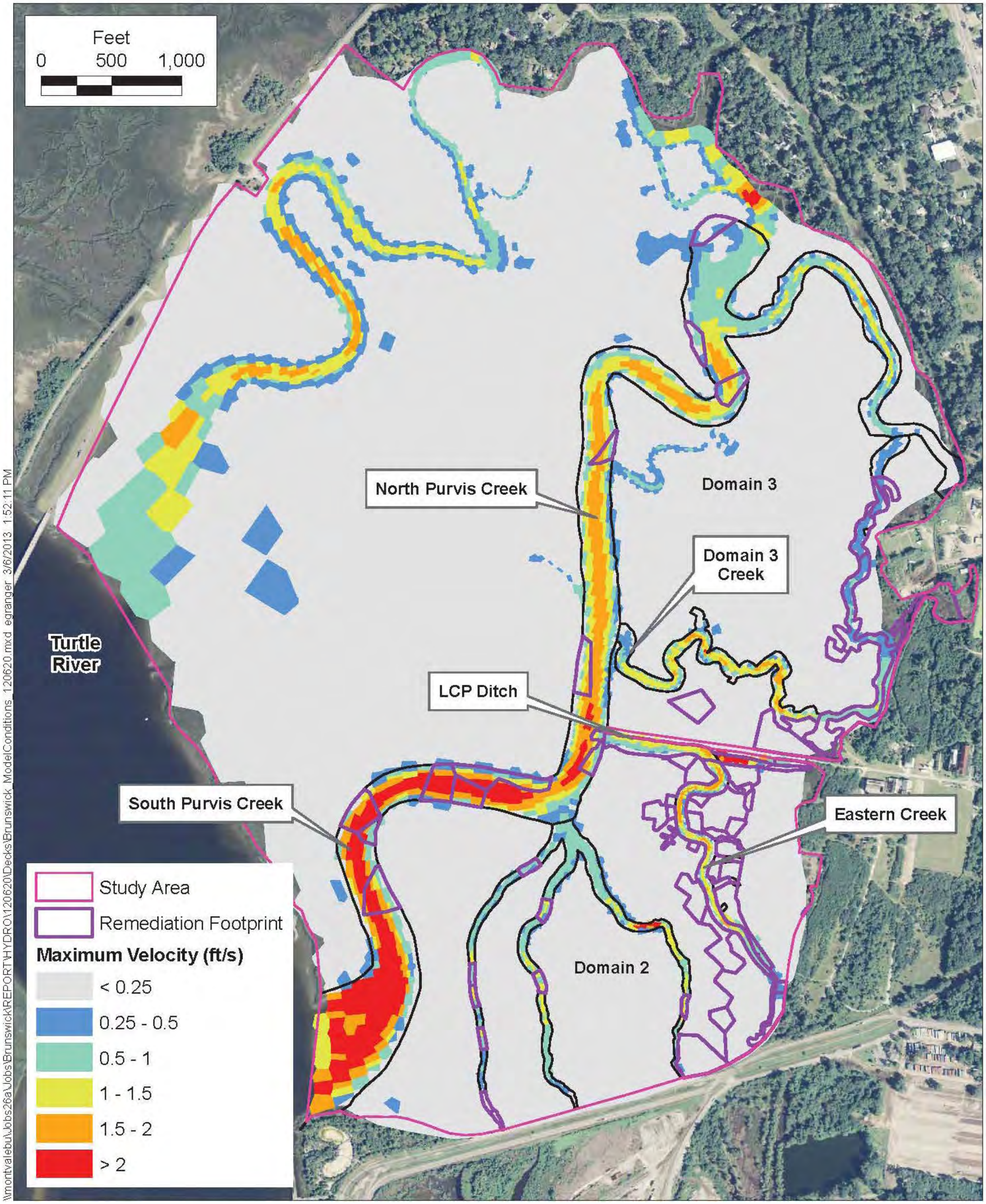

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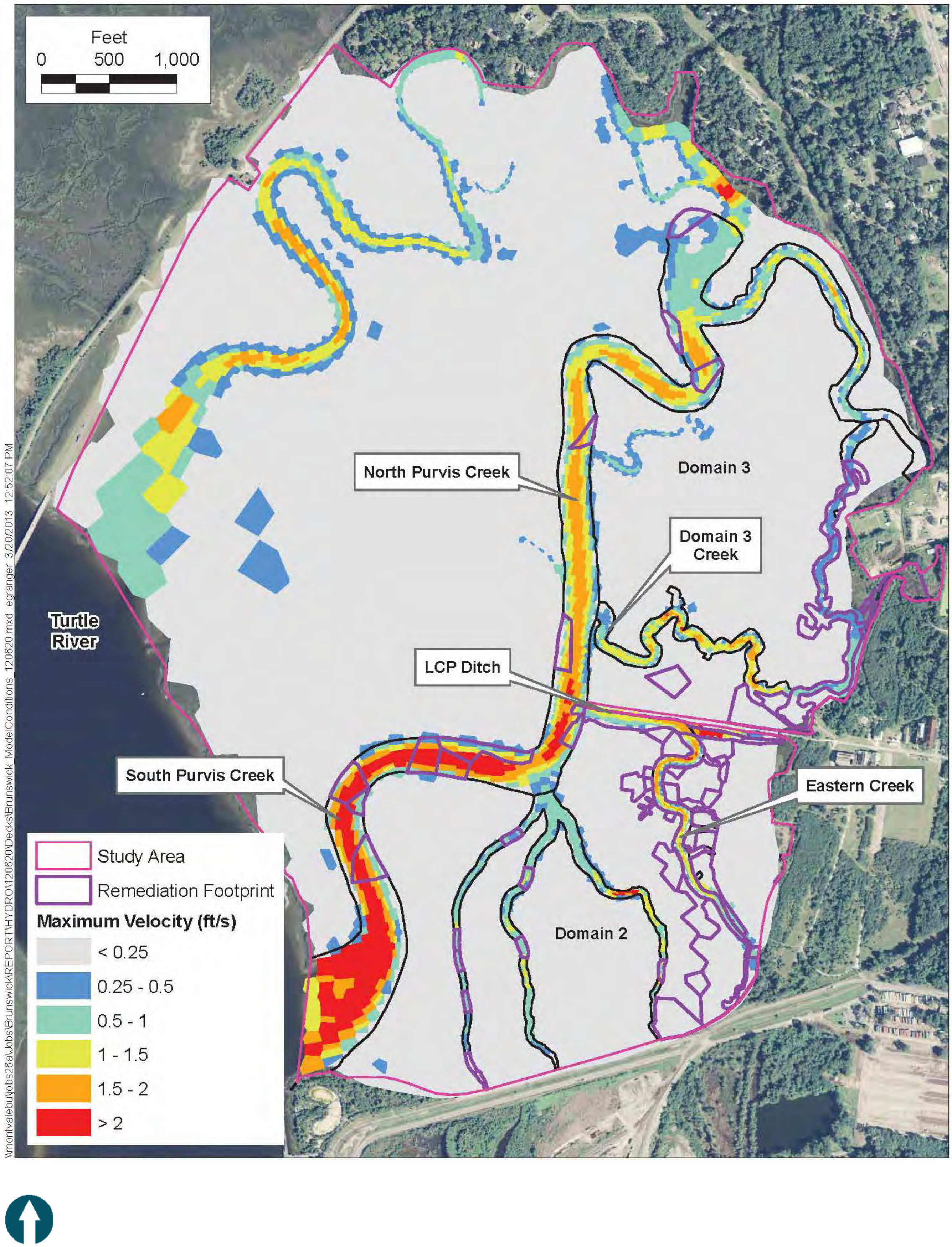
Maximum Predicted Current Velocity for Existing Conditions: 100-year Flood

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-10

PROJECT 02-27105C



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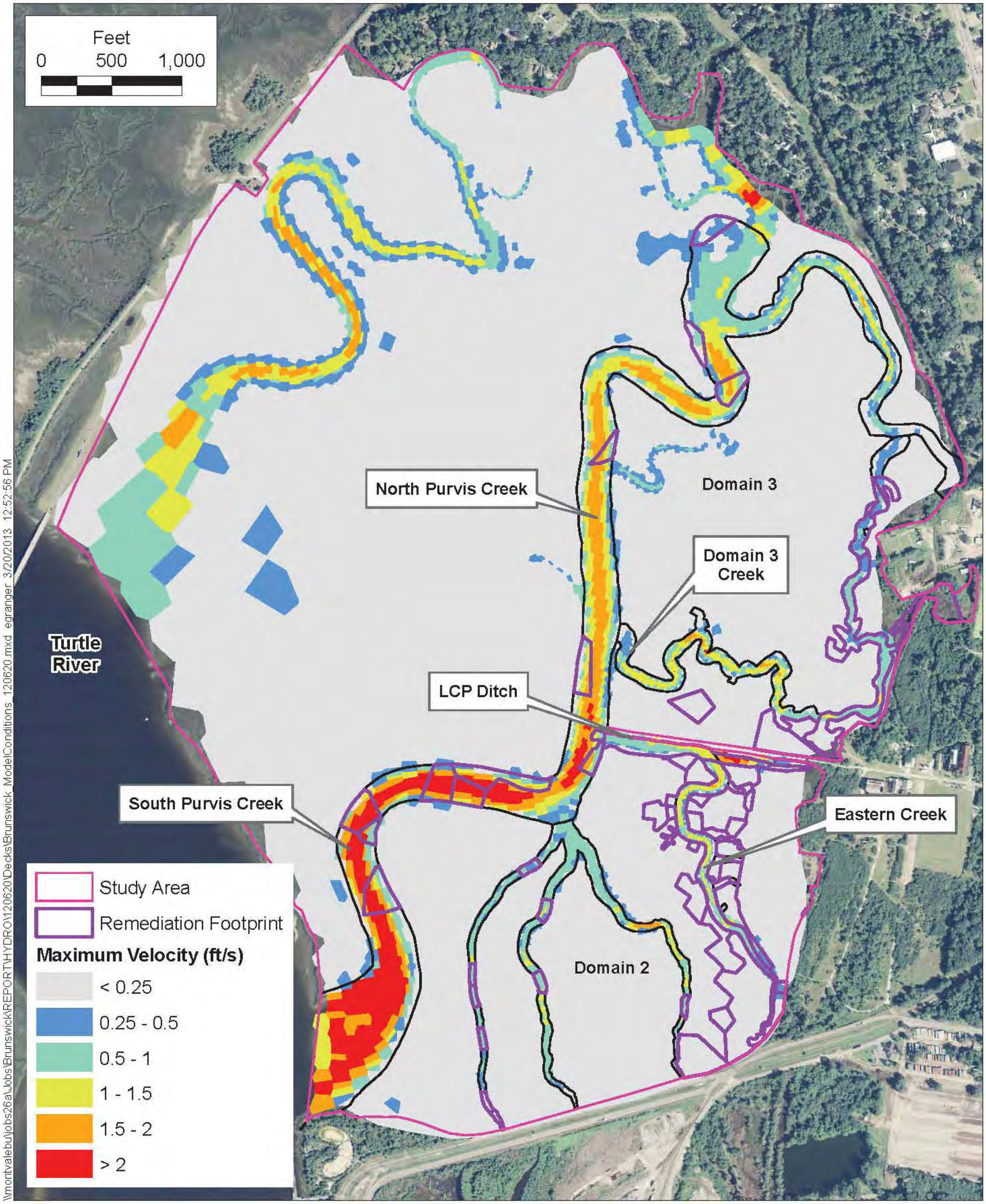
Maximum Predicted Current Velocity for Alternative 2: 100-year Flood

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-11

PROJECT 02-27105C



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ANCHOR QEA ENVIRON

DRAFTED BY: Anchor QEA

DATE: March 29, 2013

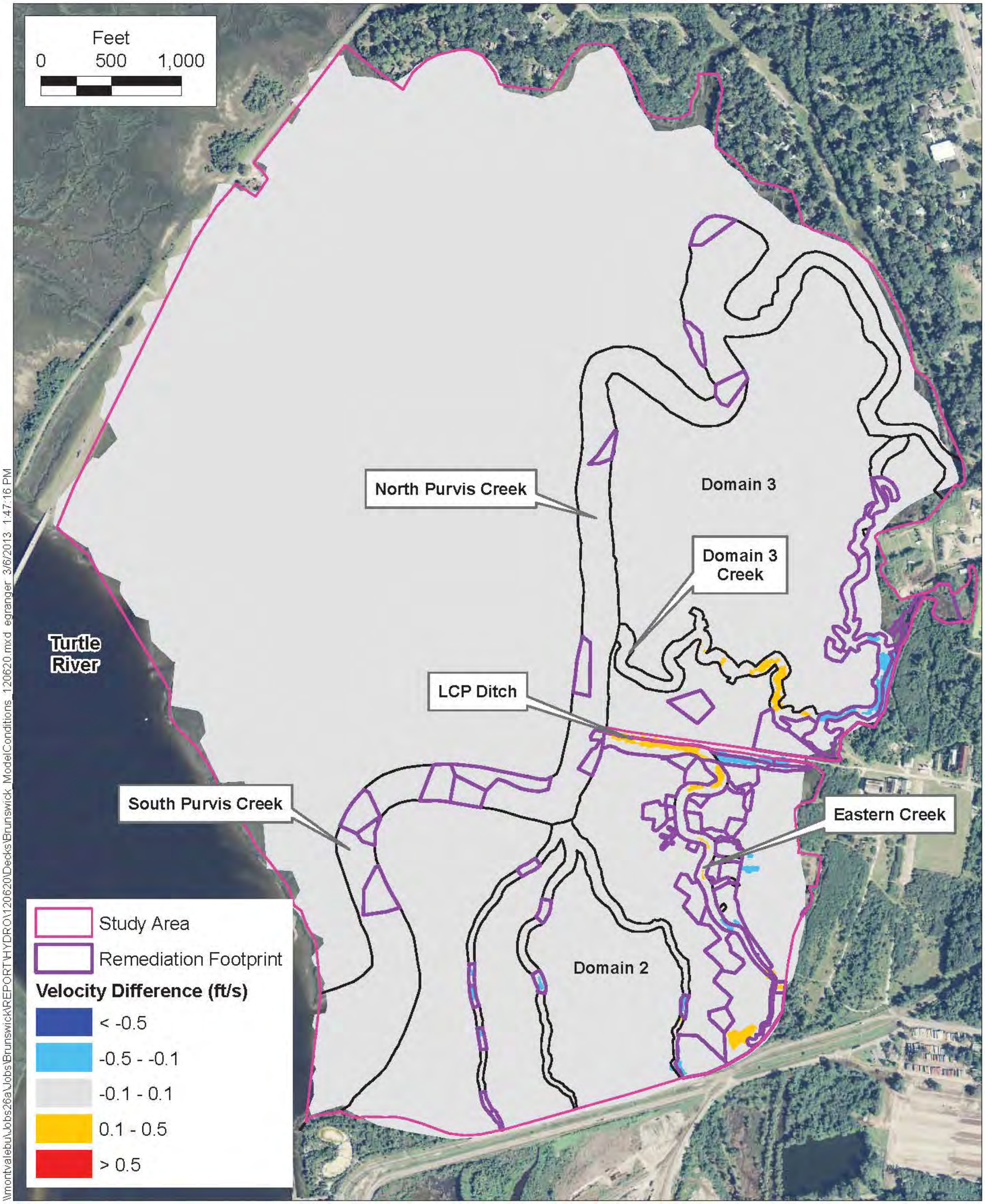
Maximum Predicted Current Velocity for
Alternative 3: 100-year Flood

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-12

PROJECT 02-27105C



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ANCHOR QEA ENVIRON

DRAFTED BY: Anchor QEA | DATE: March 29, 2013

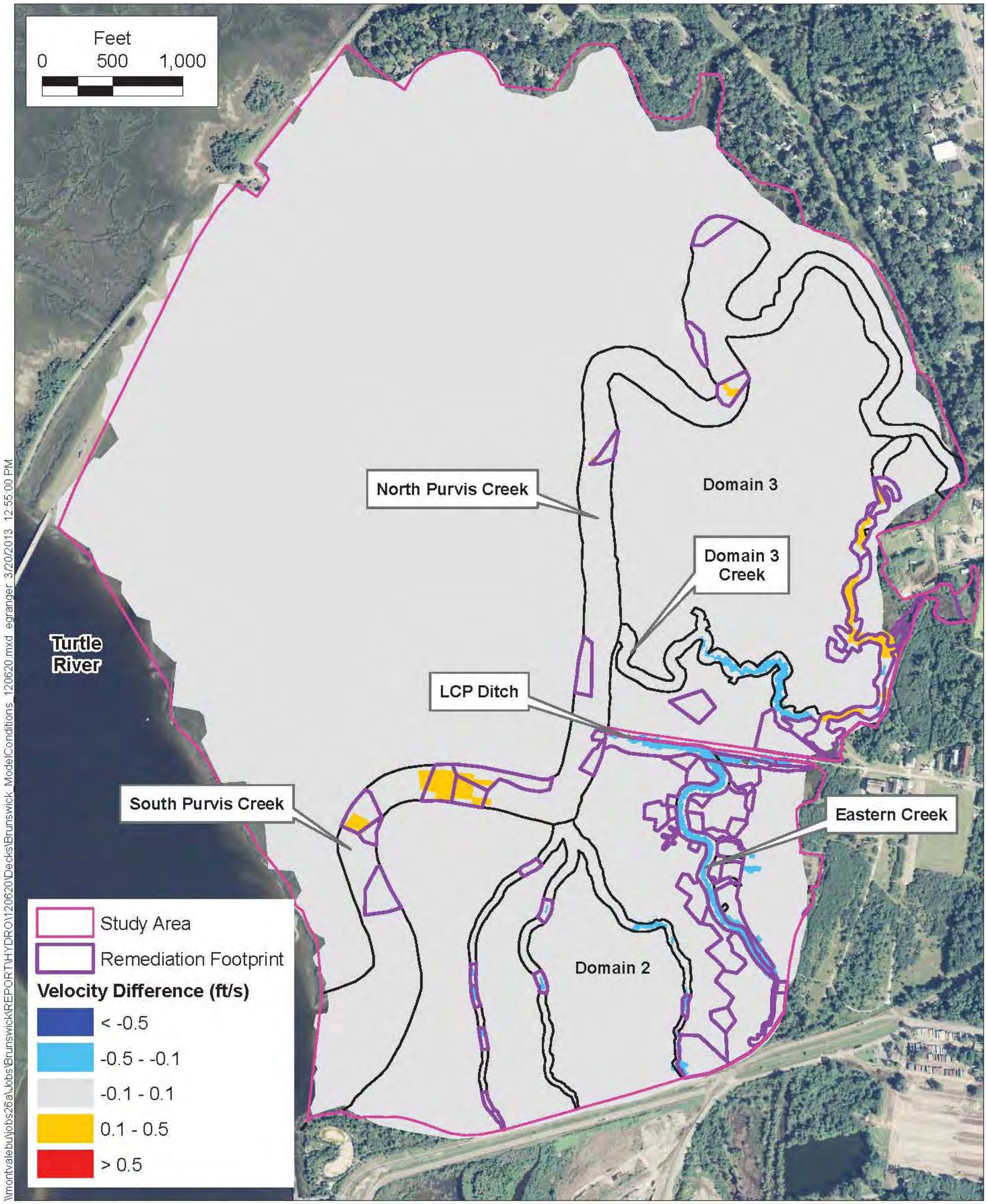
Difference in Maximum Predicted Current Velocity between Sediment Remedy Alternative 2 and Existing Conditions: 100-year Flood

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-13

PROJECT 02-27105C



ANCHOR QEA ENVIRON

DRAFTED BY: Anchor QEA

DATE: March 29, 2013

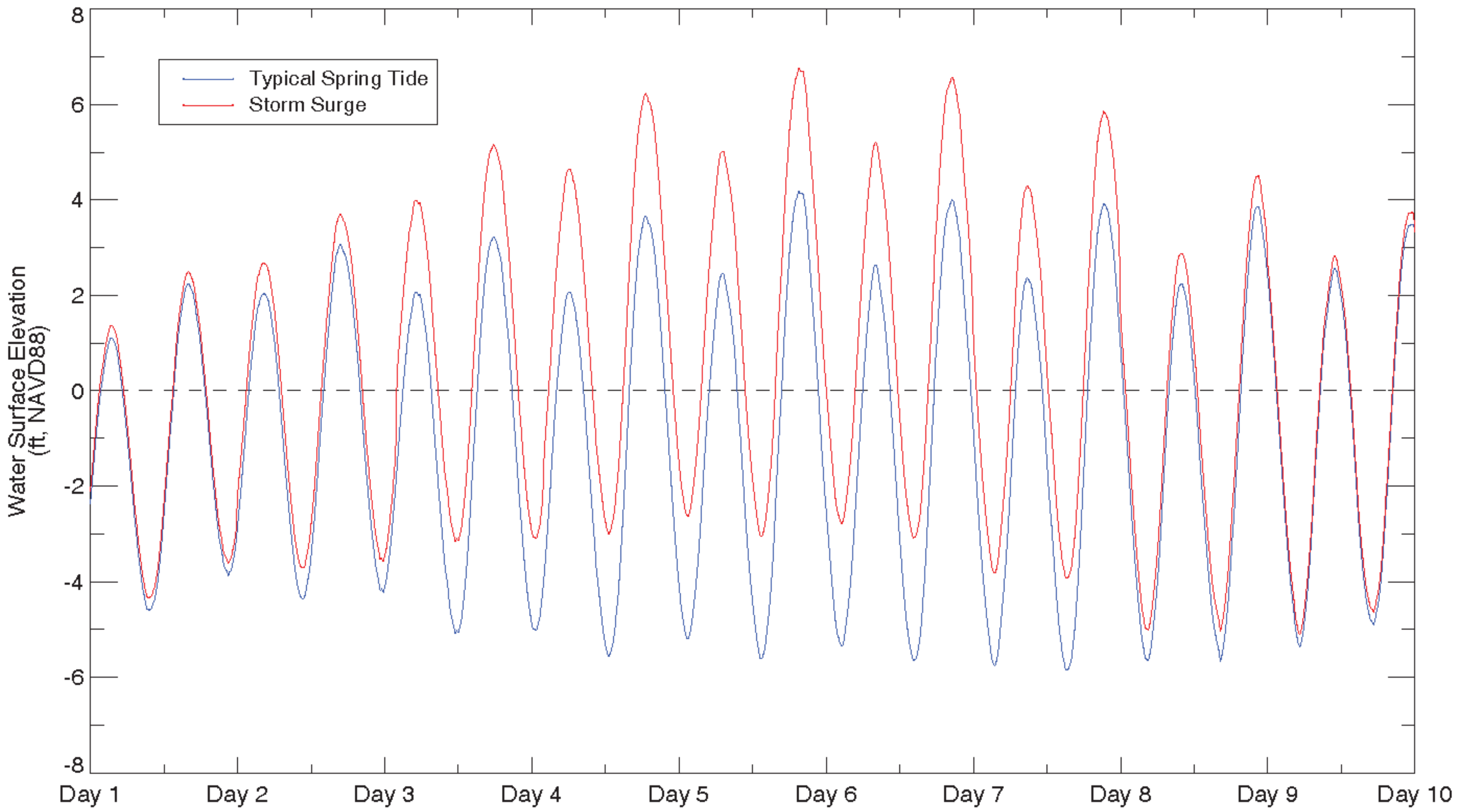
Difference in Maximum Predicted Current Velocity between Alternative 3 and Existing Conditions: 100-year Flood

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-14

PROJECT 02-27105C



Note: Relative difference is computed as the Alternative 3 inundated area minus the existing conditions inundated area, divided by the total study area.

ANCHOR QEA ENVIRON

Water Surface Elevation at Downstream Boundary
during Hurricane Storm Surge Simulation

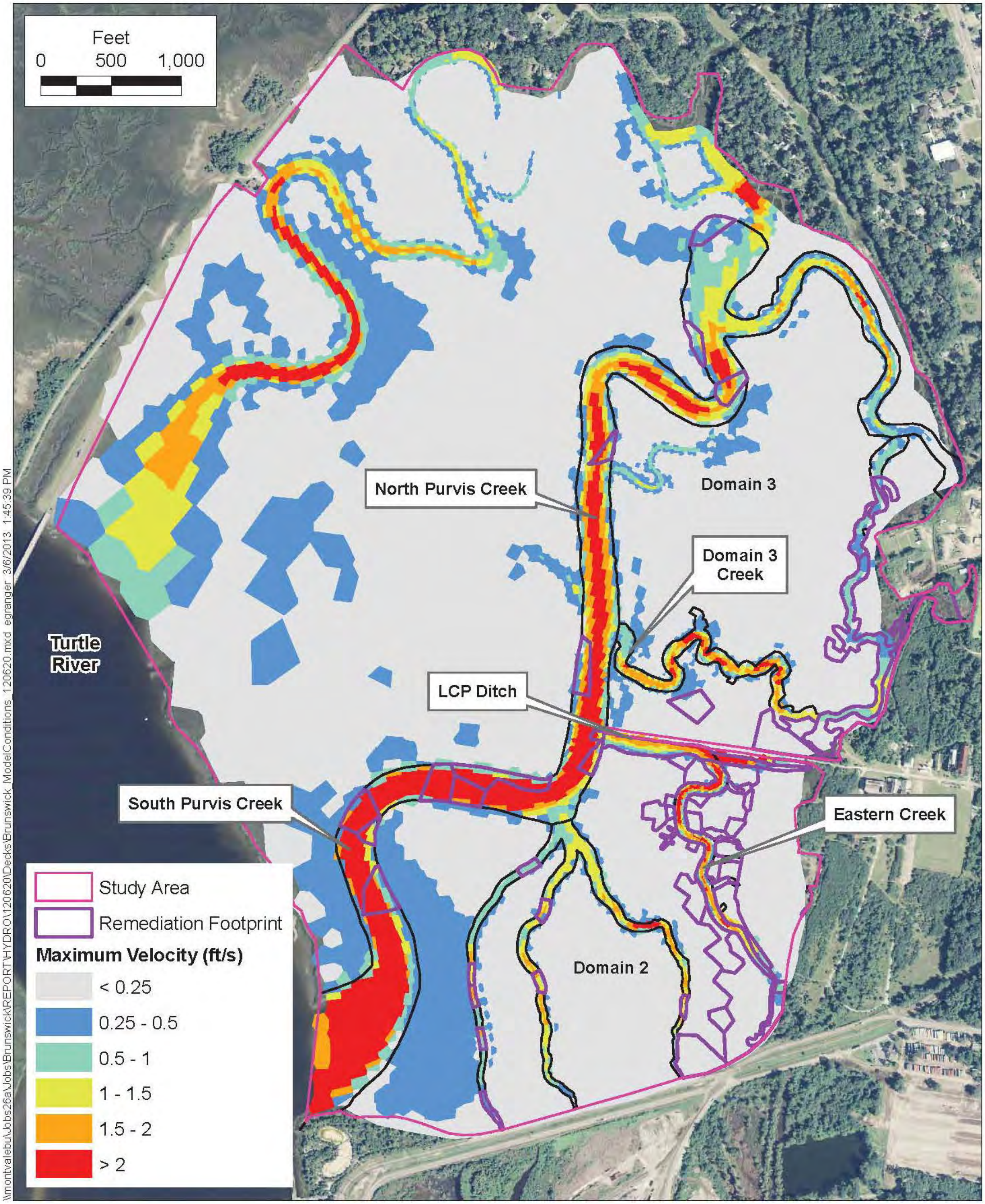
LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-15

DRAFTED BY: Anchor QEA | DATE: March 29, 2013

PROJECT 02-27105C



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ANCHOR QEA ENVIRON

DRAFTED BY: Anchor QEA

DATE: March 29, 2013

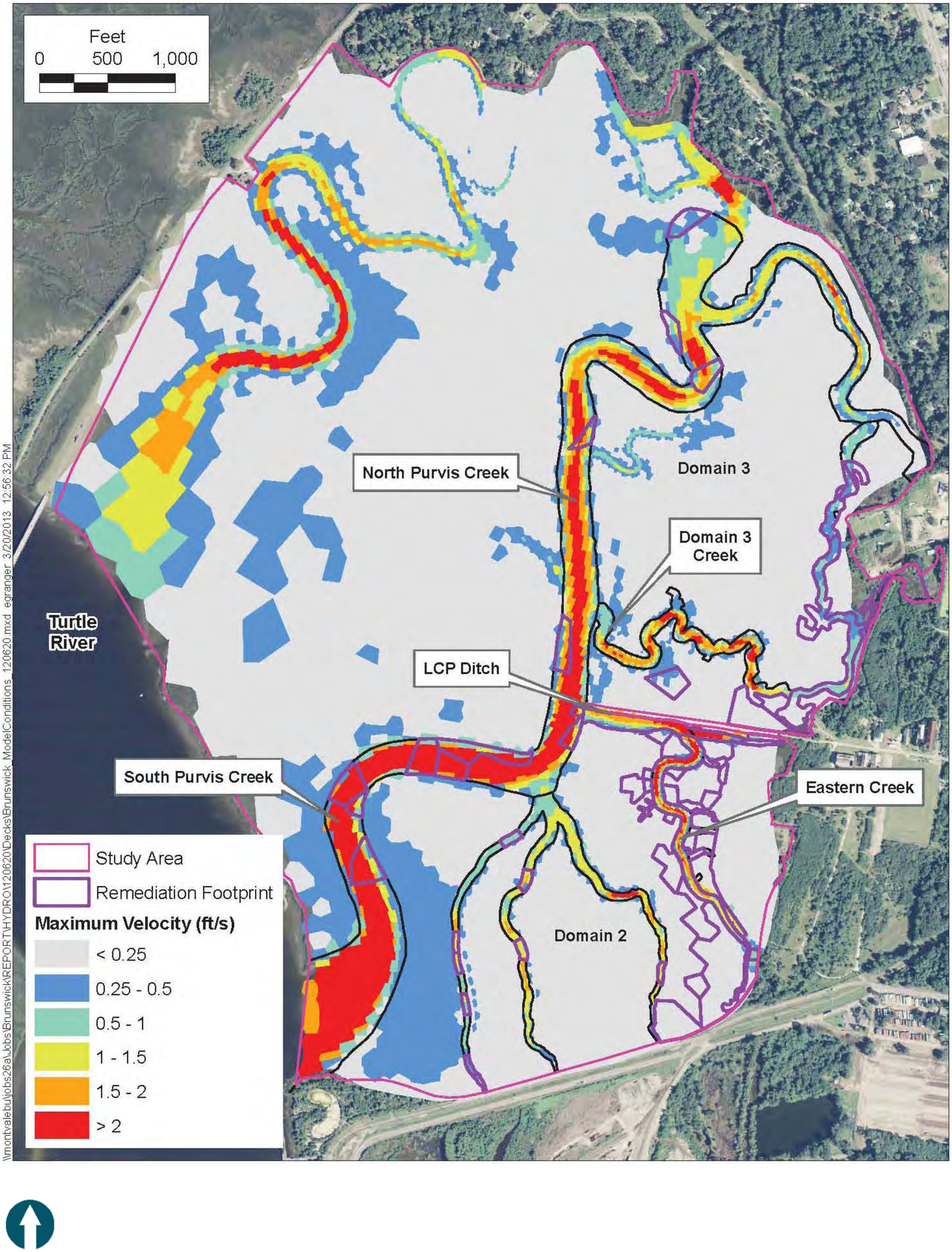
Maximum Predicted Current Velocity
for Existing Conditions: Hurricane Storm Surge

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-16

PROJECT 02-27105C



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ANCHOR QEA ENVIRON

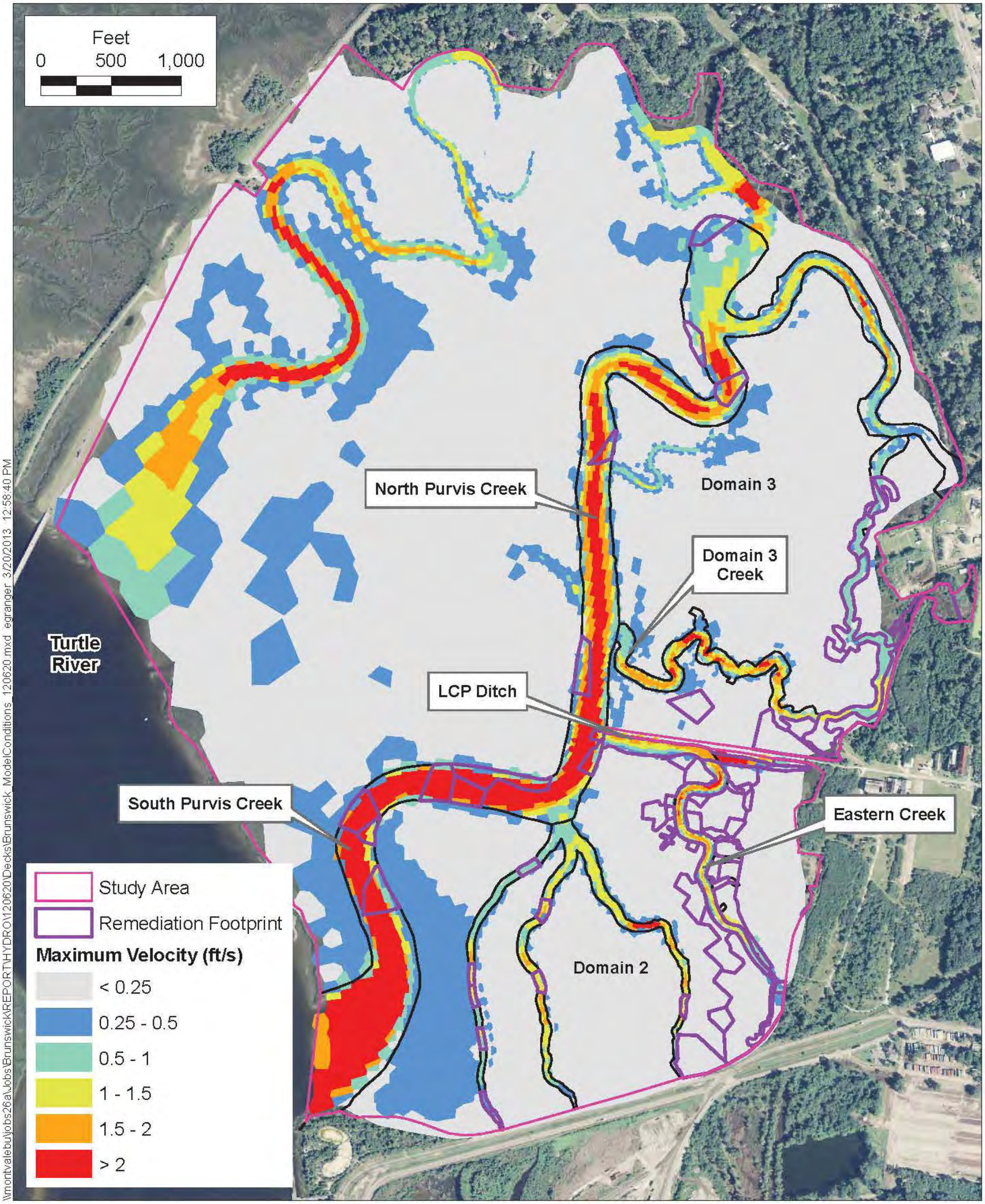
Maximum Predicted Current Velocity for
Alternative 2: Hurricane Storm Surge

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-17

DRAFTED BY: Anchor QEA | DATE: March 29, 2013

PROJECT 02-27105C



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ANCHOR QEA ENVIRON

DRAFTED BY: Anchor QEA

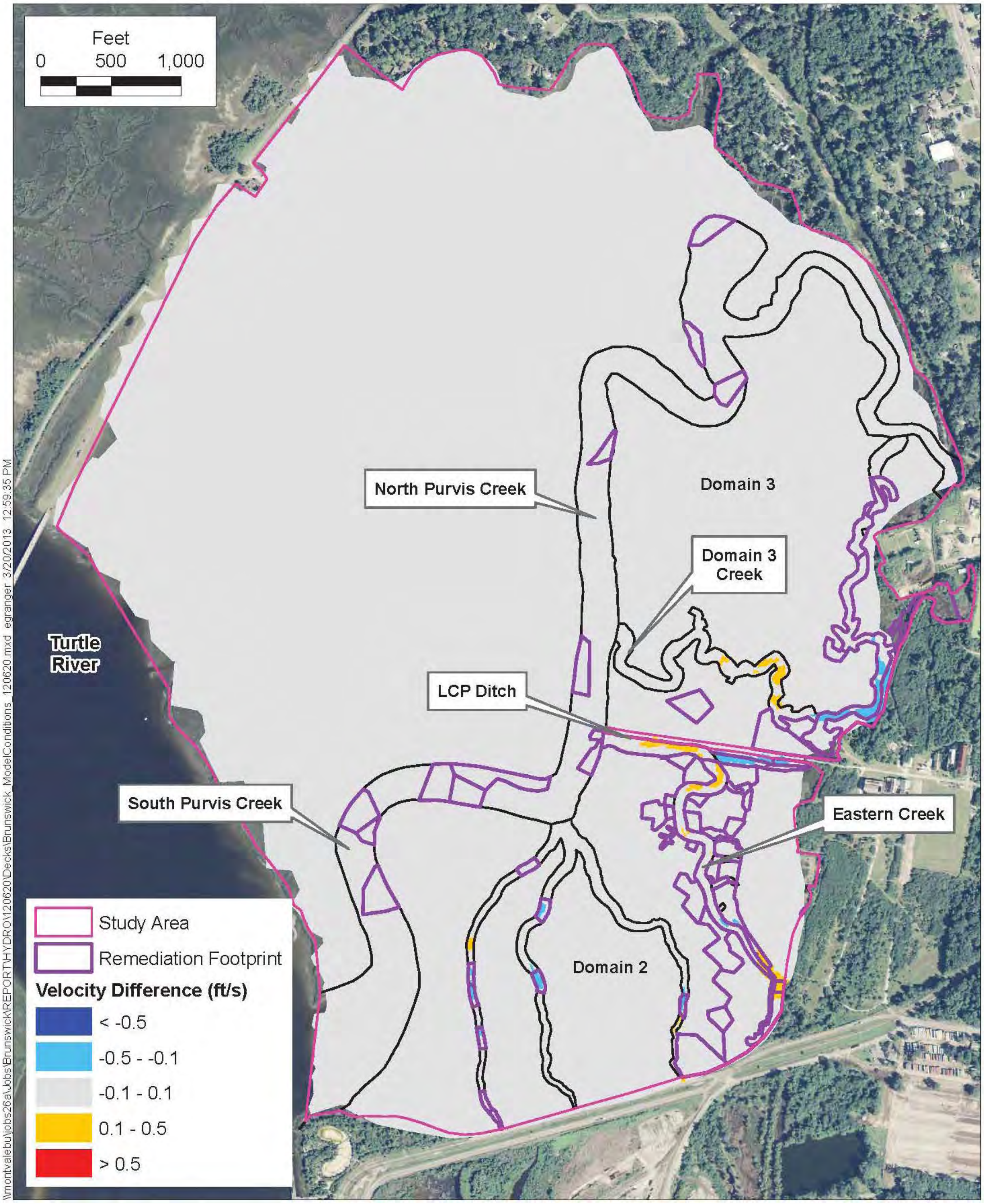
DATE: March 29, 2013

Maximum Predicted Current Velocity for Alternative 3: Hurricane Storm Surge

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-18

PROJECT 02-27105C



ANCHOR QEA ENVIRON

DRAFTED BY: Anchor QEA

DATE: March 29, 2013

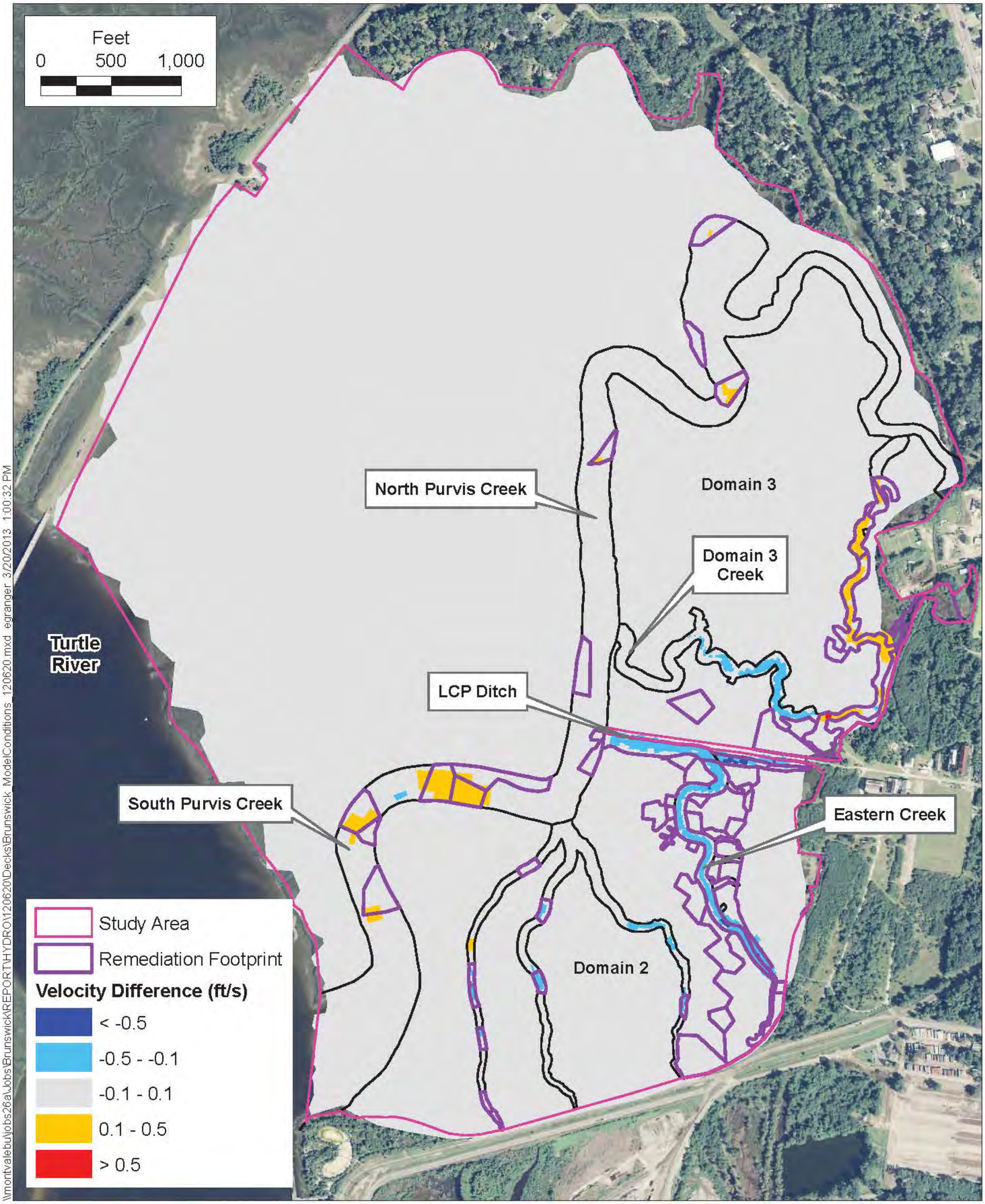
Difference in Maximum Predicted Current Velocity between Alternative 2 and Existing Conditions: Hurricane Storm Surge

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE

B3-19

PROJECT 02-27105C



ANCHOR QEA ENVIRON

Difference in Maximum Predicted Current Velocity between Alternative 3 and Existing Conditions: Hurricane Storm Surge

LCP CHEMICAL SITE
BRUNSWICK, GA

FIGURE
B3-20

DRAFTED BY: Anchor QEA | DATE: March 29, 2013

PROJECT 02-27105C

DRAFT

Appendix C
2012 Analytical Data Summary

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

Appendix C: 2012 Analytical Data Summary

Analytical data is provided electronically in the Feasibility Study Database.

DRAFT

Appendix D
Averaging for Purvis Creek and Western Creek Complex
(50 x 50 meters)

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

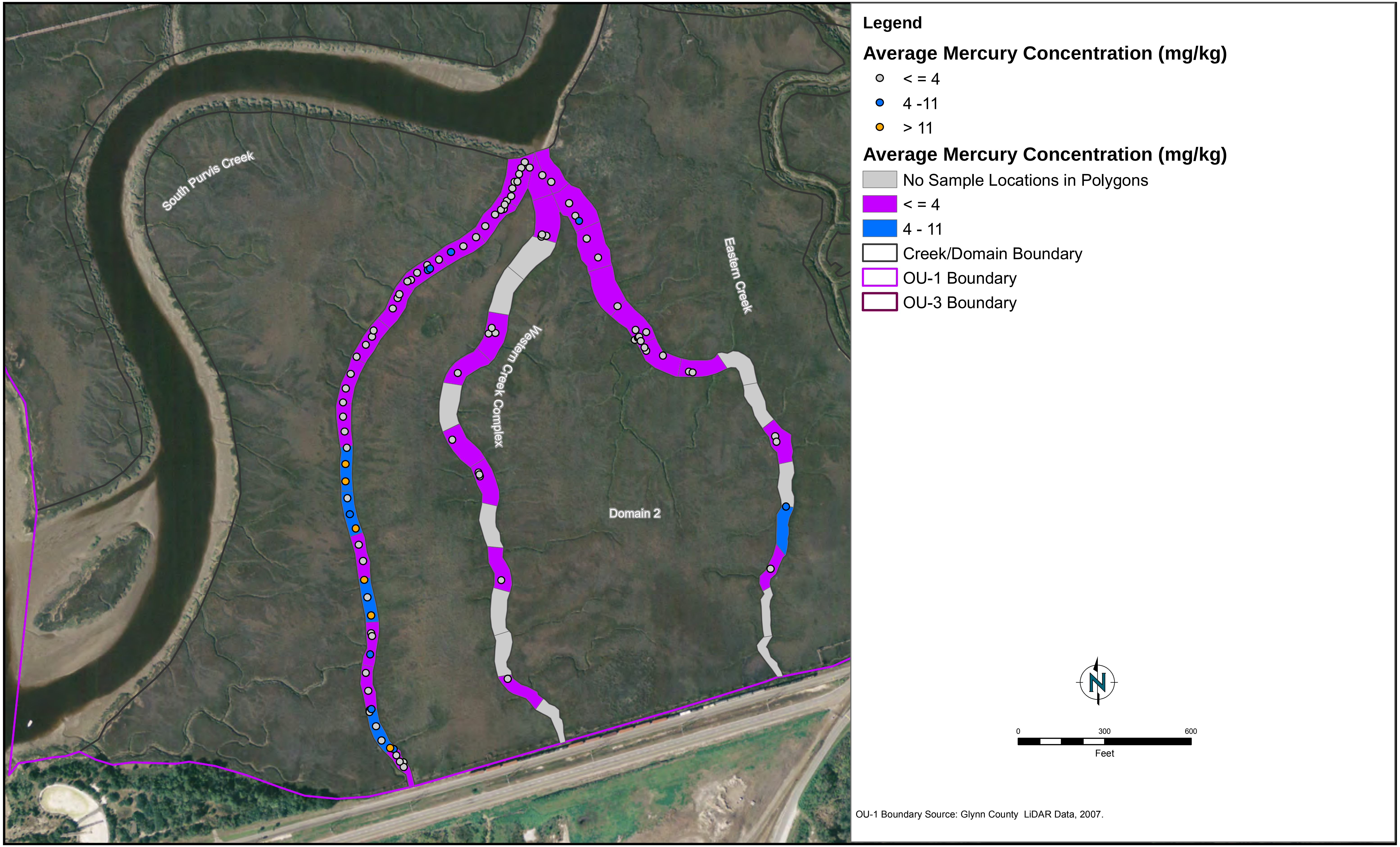
Georgia Power Company

Prepared by:
ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

Appendix D Contents:



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ

DATE: 03/28/2013

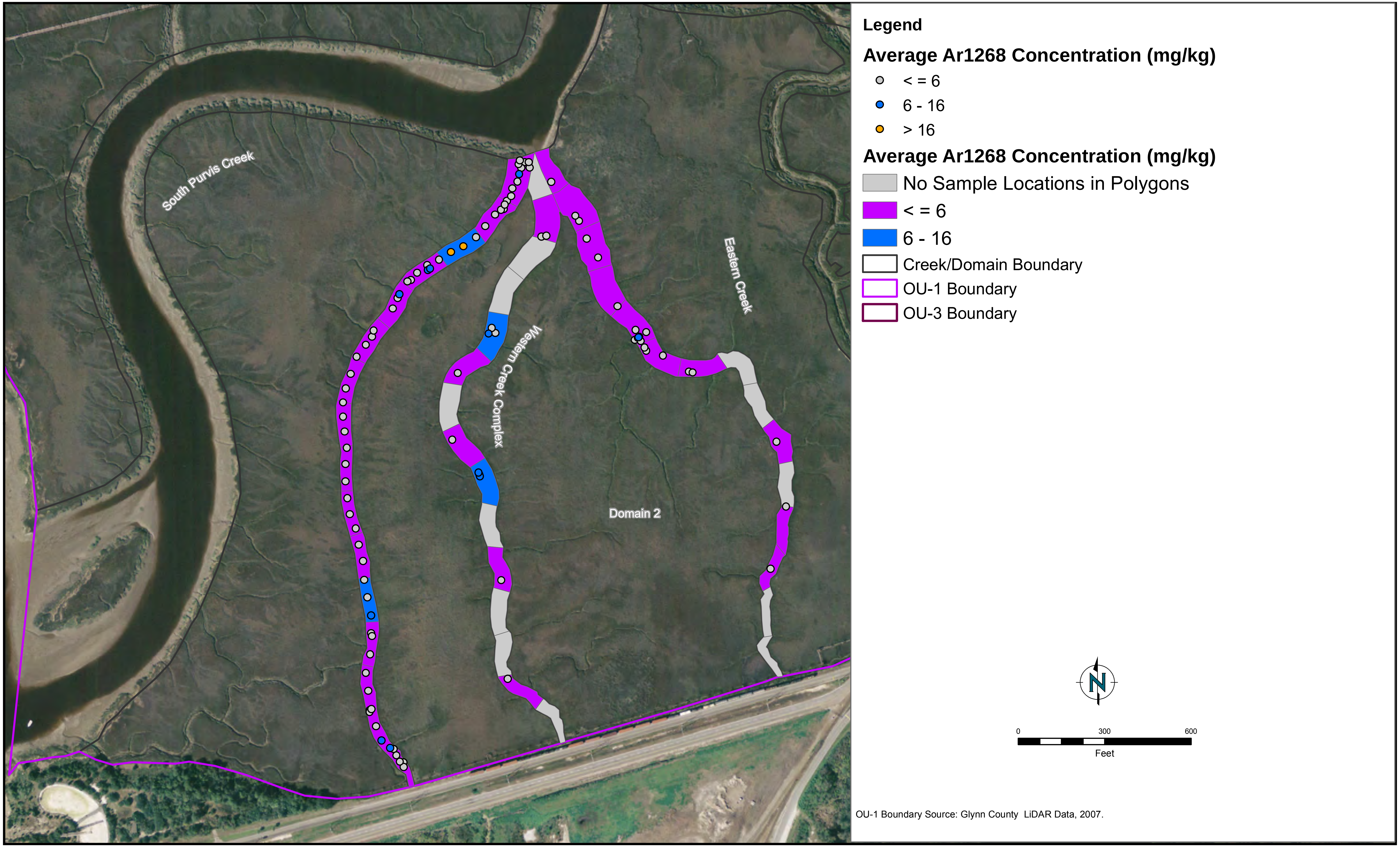
50x50 Meter Averaging of Mercury in Western Creek Complex

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
D-1

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ

DATE: 03/28/2013

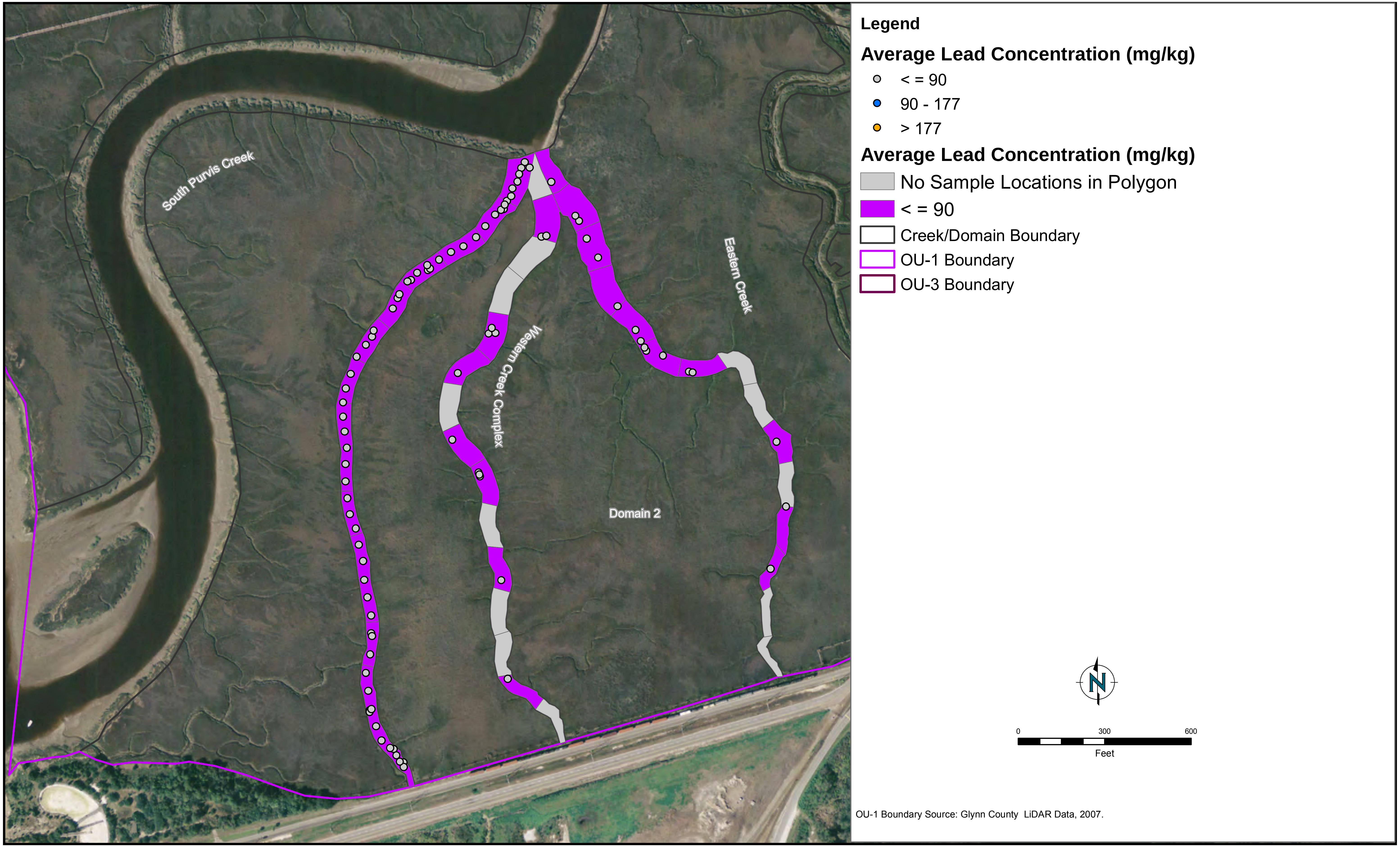
50x50 Meter Averaging of Aroclor 1268 in Western Creek Complex

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure D-2

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ

DATE: 03/28/2013

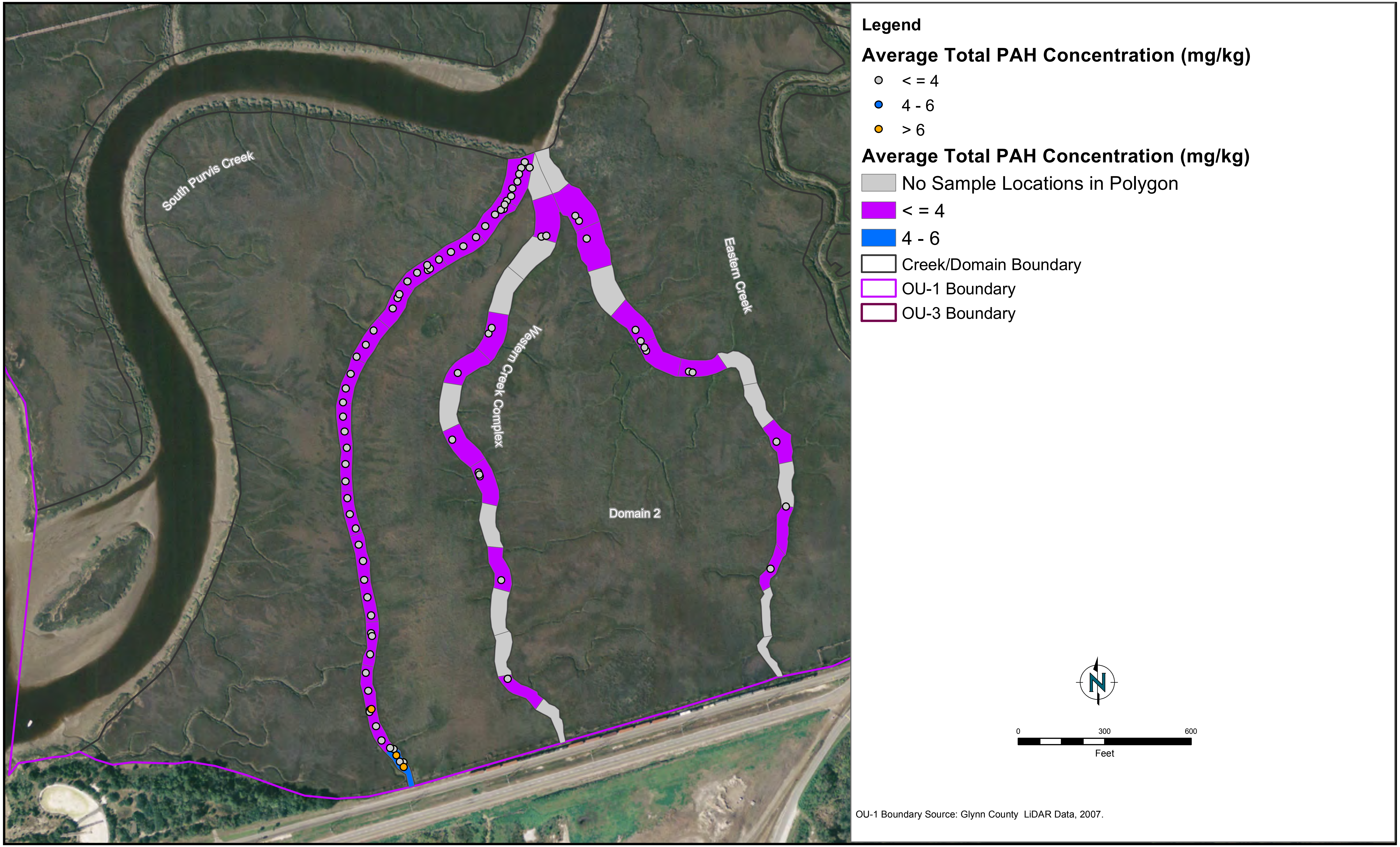
50x50 Meter Averaging of Lead in Western Creek Complex

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
D-3

PROJECT: 02-27105C



Legend

Average Total PAH Concentration (mg/kg)

- ● < = 4
- ● 4 - 6
- ● > 6

Average Total PAH Concentration (mg/kg)

- ▨ No Sample Locations in Polygon
- ▨ < = 4
- ▨ 4 - 6
- ☐ Creek/Domain Boundary
- ☐ OU-1 Boundary
- ☐ OU-3 Boundary

OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ

DATE: 03/28/2013

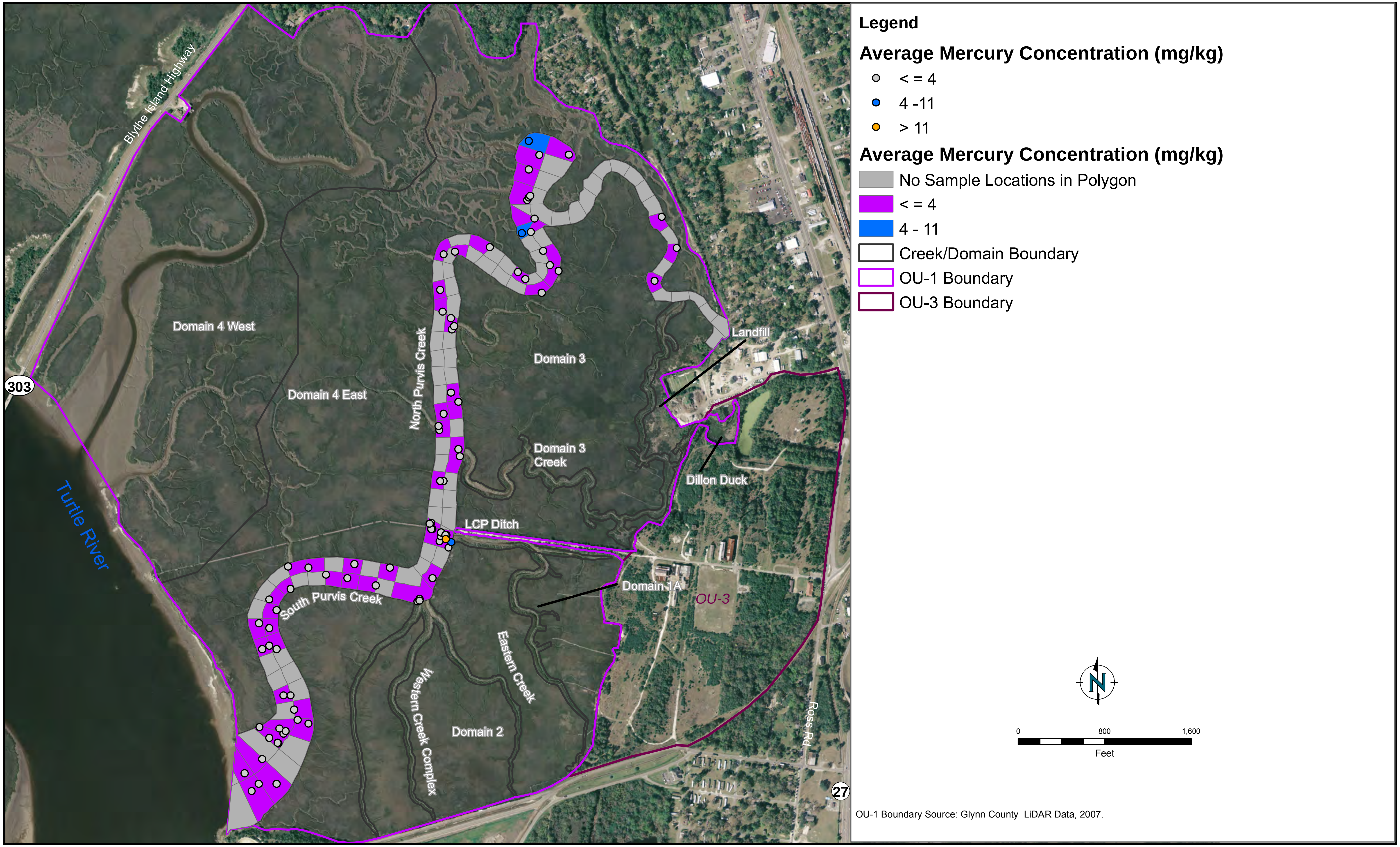
50x50 Meter Averaging of Total PAH in Western Creek Complex

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
D-4

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ

DATE: 03/28/2013

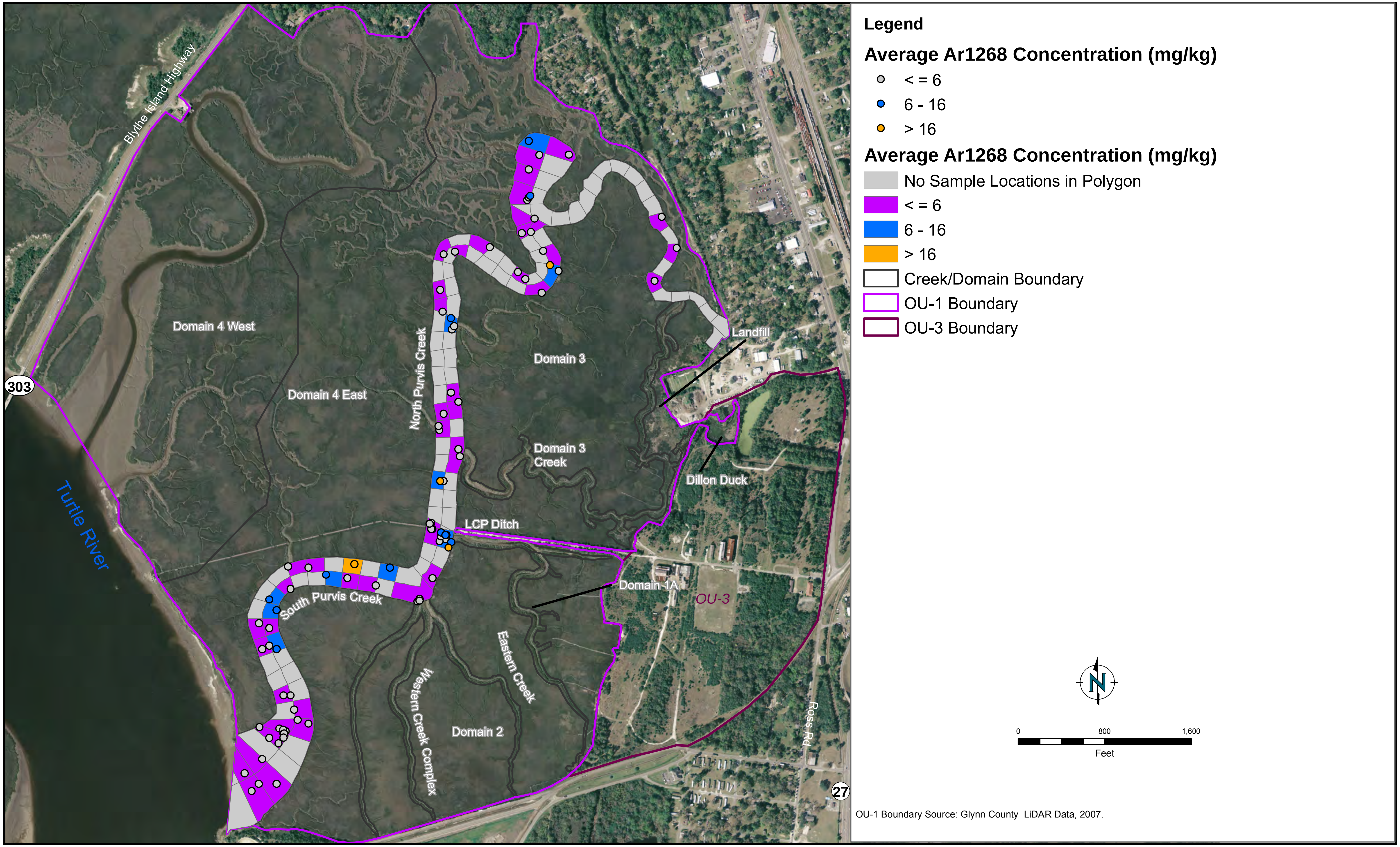
50x50 Meter Averaging of Mercury in Purvis Creek

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
D-5

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ

DATE: 03/28/2013

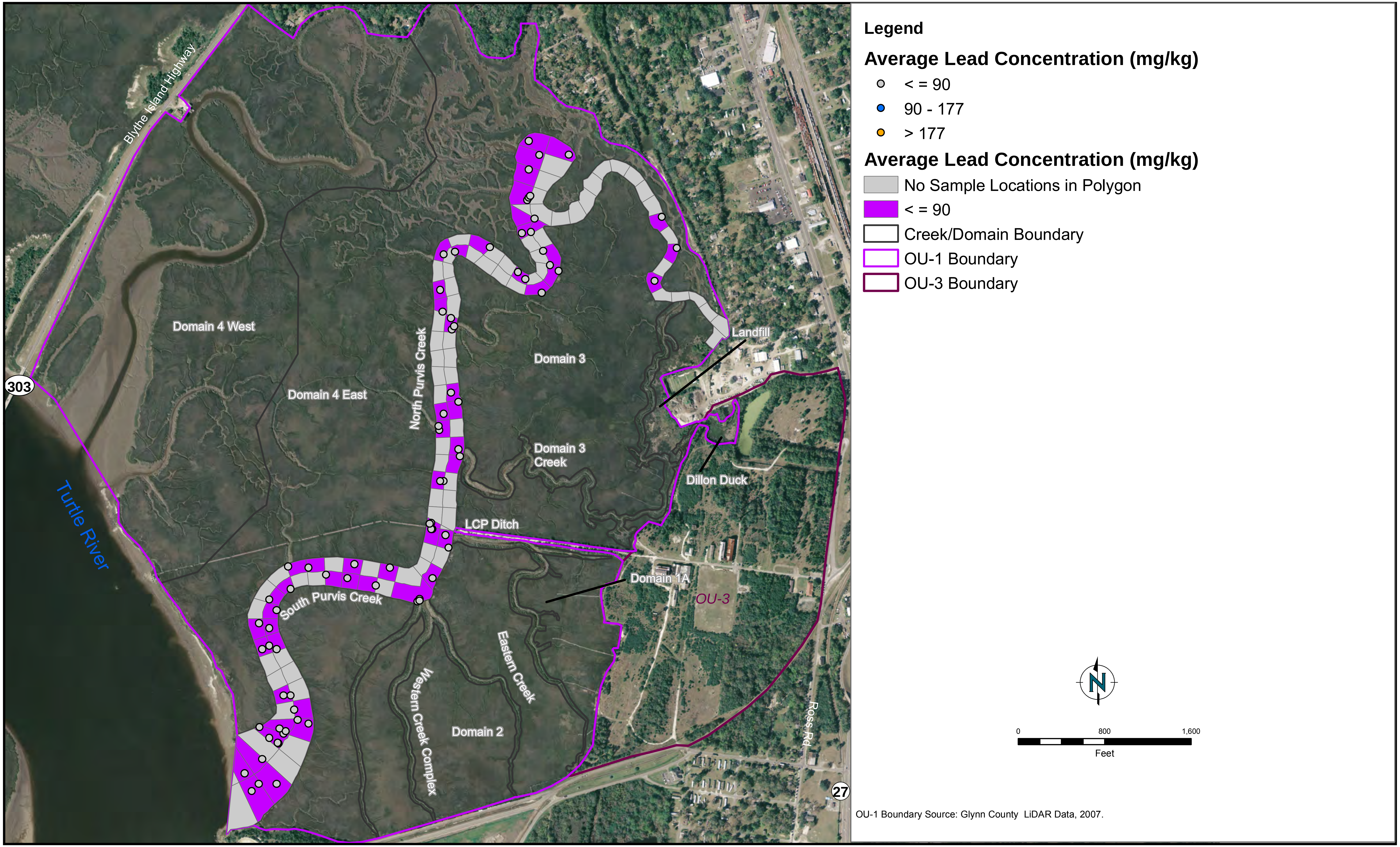
50x50 Meter Averaging of Aroclor 1268 in Purvis Creek

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
D-6

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ
DATE: 03/28/2013

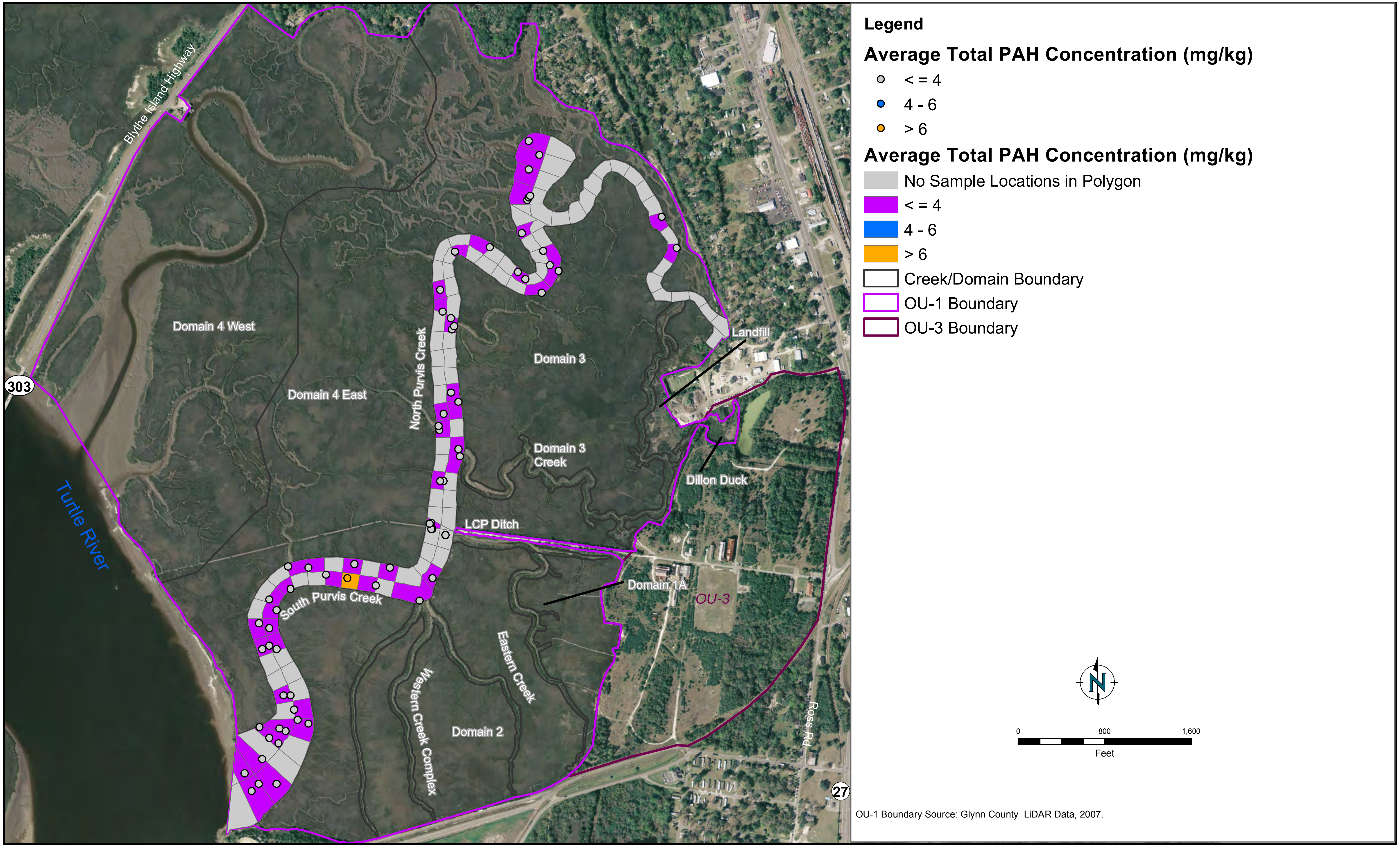
50x50 Meter Averaging of Lead in Purvis Creek

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
D-7

PROJECT: 02-27105C



OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

ENVIRON ANCHOR QEA

DRAFTED BY: MRJ

DATE: 03/28/2013

50x50 Meter Averaging of Total PAH in Purvis Creek

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
D-8

PROJECT: 02-27105C

DRAFT

Appendix E
Thin-Cover and Remedy Effectiveness

LCP Chemical Superfund Site, Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

Appendix E Contents: Thin Cover and Remedy Effectiveness Considerations

The information in this appendix is provided in support of the Feasibility Study of OU-1. The information is used to assist in remedy recommendations as well as to evaluate remedy effectiveness. This appendix is includes the following sections: Section E-1 a literature review of the feasibility salt marsh recovery after placement of a thin cover restoration layer and effects of bioturbation; Section E-2 presents a narrative explanation of risk calculations for wildlife and fish, and an analysis of the uncertainties associated with those risk calculations.

DRAFT

Appendix E1
Review of Technical Issues: Thin-Cover Placement in *Spartina* Marsh and Potential Bioturbation Effects

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

Contents

List of Attachments

Acronyms and Abbreviations

cm	Centimeter
cm^3	Cubic centimeter
EPA	Environmental Protection Agency
ft	Feet
$g \bullet m^{-2} \bullet yr^{-1}$	Gram per meter squared per year
ha	Hectare
in.	Inch
m^{-2}	Meters squared
MHW	Mean high water
MLW	Mean low water
μg/g	Microgram per gram
OU1	Operable Unit 1 (Estuary)
PAHs	Polycyclic aromatic hydrocarbons
SWAC	Surface weighted area concentrations
USACE	United States Army Corp of Engineers
USACE RDC	USACE Research and Development Center

1 Executive Summary

This appendix presents the results of a literature review regarding the feasibility of a smooth cordgrass (*Spartina alterniflora* or Spartina) salt marsh to naturally recover once the marsh has been remediated through the placement of a thin-cover restoration layer. The effectiveness of placing a thin layer of sediment to restore natural marshes and the subsequent marsh recovery patterns has been closely monitored by the U.S. Army Corps of Engineers Research and Development Center (USACE RDC) since the 1990's. Case studies found in peer-reviewed literature were summarized for the following topics: methods for the placement of a thin-cover layer of clean sediment material on a salt marsh, natural recovery time of smooth cordgrass through varying depths of sediment, Spartina tolerance characteristics, and potential issues related to bioturbation from fiddler crabs (*Uca* spp.) and other sediment dwelling organisms.

- Case studies indicated several methods can be used to apply clean sediment material to a salt marsh. The most common for larger scale applications are direct application of clean material onto the marsh as a slurry through a hydraulic pipeline or high-pressure spray equipment. In recent times, manual application using flexible pipelines as well as sprays from barges (where navigational drafts permit this) have also been utilized.
- Recovery times once a thin cover of sediment has been applied to a salt marsh varied depending on thickness of the layer and other site-specific factors, including hydrologic regime.
    - Marshes that received up to 23 cm (9 in.) of cover material reached stem densities comparable to reference areas within one to two growing seasons. It is conceivable that marshes where thinner layers are applied would recover even faster.
    - Sediment layers up to 38 cm (15 in.) of cover material had longer recovery times when compared to reference areas. This is because of the longer times required for the rhizomes to grow through a thicker layer.
- Spartina tolerance characteristics are discussed, as this information is directly linked to the local hydrologic regime, and can inform the successful placement of thin-cover material in the marsh. Site-specific data shows that the placement of a thin cover within the marsh is within limits of vegetation tolerance for OU1. Matching the characteristics of the cover material to existing conditions (e.g., total organic carbon or percent organic matter, particle size distribution such as percent fines, bulk density, and nutrient levels) may help accelerate Spartina regeneration and marsh recovery.
- Bioturbation can potentially influence the effectiveness of capping and thin-cover to the extent that the process allows mixing of contamination at depth with the cleaner material at the surface.
    - The burrowing activity of fiddler crabs is a type of bioturbation and burrowing can occur up to depths exceeding 30 cm (12 in.). However, the majority of fiddler crab burrows have been reported to be within 15 cm (6 in.). The deeper burrows are breeding burrows that are maintained and defended, so once established, there is little additional movement of sediment. In addition, the crabs forage and

feed at the sediment surface not at depth, so they do not cycle sediment from depth to the surface as part of feeding activities.

- Oligochaetes and polychaetes are sediment dwelling worms that are often considered significant with regard to bioturbation, as these organisms consume sediment at depth and release material at the surface. These organisms are predominantly within the upper 15 cm of the sediment column, often in the uppermost 3 to 10 cm. There are papers showing that some burrowing may occur to depths beyond 15 cm, but the vast majority of burrowing is not to those depths.

This review supports the use of a thin-cover restoration layer in the LCP marsh of 15 cm (6 in.) as a protective remedy alternative. Based upon the literature reviewed, natural recovery and regeneration of Spartina marsh is expected to occur within approximately one to two years following application of this thickness. Furthermore, the proposed elevation changes resulting from thin-cover placement are well within Spartina tolerance limits. Recovery within one to two years is likely less than it would take for a much more intrusive remediation including excavation of contaminated sediments and replanting. Bioturbation will not diminish the effectiveness of thin-cover in the marsh, as the majority of bioturbation will not extend below the thin-cover. However, it is noted that bioturbation to depths below 15 cm cannot be prevented 100% of the time in 100% of the remediated area. The thin-cover is not intended as an absolute chemical barrier, but as a layer to jump start ongoing natural recovery processes, and therefore, some bioturbation beyond the cover depth does not diminish the effectiveness of this remedy and thus does not preclude its beneficial use as a protective remedy.

2 Introduction

This appendix provides a summary of case studies on the ability of a *Spartina alterniflora* (smooth cordgrass or Spartina) salt marsh to respond and recover following placement of thin layers of clean sediment material using different placement techniques.

Available information from published literature pertaining to thin-cover sediment placement on a salt marsh are compiled and reviewed here so as to evaluate its appropriate use as a remediation technique at the LCP site, Brunswick, Georgia. The information summarized herein will also be used to recommend a thin cover that is suitable for the receiving marsh. To ensure that the information is applicable to the Site, the review focused on case studies from Georgia and the Southeast United States (i.e., USEPA Region 4 when available. The following subjects are discussed:

The introduction to this appendix (**Section 2**) is followed by a discussion of case studies where thin-cover was placed on Spartina and the reported marsh recovery rates (**Section 3**). **Section 4** discusses methods for thin-cover placement and associated limitations, and **Section 5** lists smooth cordgrass tolerances and characteristics. Research on the composition of thin-cover materials to stimulate marsh recovery is summarized in **Section 5** and tidal channel influences on marsh recovery are discussed in **Section 6**. **Section 7** describes the impacts of bioturbation on thin-cover effectiveness. References are provided in **Section 8**. The document also includes the following attachments: **Attachment A** presents case studies for thin-cover; **Attachment B** provides additional citations for Spartina restoration; and **Attachment C** provides an overview of bioturbation data.

3 Thin-Cover Placement of Sediment on Spartina and Marsh Recovery Rates

The case studies reviewed here are primarily from the 2007 Army Corps of Engineers (USACE) Technical Summary Document, Thin Layer Placement of Dredged Material on Coastal Wetlands: A Review of Technical and Scientific Literature (Ray 2007). Methods for applying thin layers of clean sediment varied between studies and are discussed in the section below on placement techniques. A summary of these studies is provided in Attachment A. In general, thin-cover placement techniques emulate natural deposition events that occur in marsh systems during extreme storm surges. The technique was originally developed in Louisiana to mitigate losses of coastal wetlands due to natural causes such as alteration of natural sediment deposition patterns, marsh subsidence, and sea level rise. Key highlights of the case studies we reviewed are presented below:

- In Glynn County, Georgia, Spartina regrowth was monitored after placement of three types of sediment material (coarse sand, mixed sand and clay, or clay) at six thicknesses (8, 15, 23, 61, 91 cm) on undisturbed salt marsh plots. Reimold et al. (1978) applied sediment at different stages of plant growth (February, July, and November). Results indicated that Spartina was able to regrow and penetrate though 23 cm (9 in.) of sediment regardless of the sediment layer composition, whereas plots covered with ≥ 60 cm of sediment did not recover at all. The authors found that the Spartina regrowth in the less-than-60-cm plots was comparable to undisturbed reference marshes within one to two growing seasons.
- Two studies examined the effects of manually applied clean dredged materials (primarily medium sand) of varying thickness (0 to 10 cm, 4 in.) to sparsely vegetated Spartina and reference plots in Masonboro Island, North Carolina (Leonard et al. 2002, Croft et al. 2006). Both studies found that the placement of dredged material on sparsely vegetated plots stimulated plant growth. Before the placement of dredged material on the plots, Spartina densities were highest in reference plots (256 stems m^{-2}) when compared to the sparsely vegetative experimental plots (149 stems m^{-2}). Average stem density increased in all plots after the application of dredged material. By the end of the second summer, there was no statistically-significant difference in stem density between the reference plots (336 stems m^{-2}) and experimental plots (308 stems m^{-2}). In addition to stimulating growth, placement of dredged material stimulated benthic algal biomass.
- Cahoon and Cowan (1987, 1988) investigated the response of salt marsh wetlands to the application of thin layers of dredged material using high-pressure spraying at Lake Coquille and Dog Lake, Louisiana. Sediment layers of 10-15 cm (4-6 in.) and 18-38 cm (7-15 in.) were applied to salt marshes at Dog Lake and Lake Coquille, respectively, and growth of vegetation was monitored. The authors found that although vegetation on the plots was still buried after fourteen months, recolonization of representative marsh species was apparent. It was speculated that complete revegetation would likely occur within three years.
- LaSalle (1992) revisited the Lake Coquille and Dog Lake thin-cover placement sites originally sampled by Cahoon and Cowan. After 5 years, the salt marsh at Dog Lake was no longer distinguishable from nearby references sites with regard to percent coverage

of Spartina. *Salicornia virginica*, a subdominant plant, was most abundant at the experimental sites whereas *Distichlis spicata* and *Juncus roemerianus* were more abundant at the reference sites.

- DeLaune et al. (1990) looked at the effect of adding dredged material onto salt marsh plots in Barataria Bay, Louisiana. Dredged material was manually placed onto deteriorated salt marsh plots in two applications. In the first application, sediment was placed on the experimental plots to a thickness of 2-3 cm (0.8-1.2 in.) to 4-5 cm (1.5-2 in.). In the second application, sediment thickness ranged from 4-6 cm (1.5-2.4 in.) to 8-10 cm (3.1-3.9 in.). The authors reported that the addition of thin layers of sediment increased above-ground biomass and density of Spartina shoots when compared to control areas.
- Ford et al. (1999) examined the effects of spraying sediment material onto a salt marsh in Venice, Louisiana as a method of disposal for dredged material. Sediment was applied to a 0.5 ha salt marsh using a high-pressure spray to a thickness of 2.3 cm (~ 1 in.). Although the high-pressure spray initially flattened vegetation, plants quickly recovered with the percent coverage of Spartina increasing to above pre-application coverage values. Results indicated that the treated marsh was indistinguishable from control areas with respect to sediment and vegetation properties.
- In Venice, Louisiana, sediment was hydraulically dredged from the Gulf of Mexico and applied to a 43 hectare (106 acres) salt marsh to a thickness of approximately 60 cm (24 in.) (Mendelssohn and Kuhn 2003). Results indicated that the marsh recovered in two years after sediment application; that is, within two years total plant coverage, height, and biomass were comparable to reference areas. The magnitude of recovery was greater for areas that received > 30 cm (15 in.). Based on the results, the authors postulated that the added material acted as a fertilizer to the salt marsh. Although plant diversity was similar between the experimental and reference marsh, soil elevation and bulk density was higher in the experimental areas. Based on the study, it is uncertain if plants recolonized areas that received >30 cm (15 in.) of sediment or regenerated through it. Given the results of other case studies, the latter is more likely.
- Slocum et al. (2005) studied the effects of sediment enrichment over a seven-year period on the same marsh from the Mendelssohn and Kuhn (2003) study. This study was initiated to close information gaps by providing a larger scale and longer term sediment enrichment experiment. The authors found that sediments values reported by Mendelsohhn and Kuhn (2003) consolidated over time and ranged from 0-22 cm (0-9 in.). While the benefits of sediment addition included increased bulk density, nutrient availability, aeration, and reduced hydrogen sulfide, the authors reported that this fertilization effect of the added sediment was a relatively short-term benefit. In addition, a minor disadvantage of the sediment application was the creation of areas with a high sand content and increased elevation. These areas, however, were small when compared to areas that received moderate amounts of sediment. The authors concluded that sediment enrichment was an effective method for restoring degraded marshes that are affected by sea-level rise and subsidence.

Based on the literature reviewed, recovery of marshes after the addition of sediment layers varied depending on the thickness of the layers and the condition of the marsh at the time of application. Marshes generally recovered within 1 to 2 growing seasons (i.e., one to two years) following placement of dredge material layers up to 23 cm (9 in.); marshes that received layers of sediment between 23 cm (9 in.) and 38 cm (15 in.) took longer to recover, but still recovered within two to five years.

Case studies indicated that the placement of sediment on top of marsh vegetation may stimulate primary production depending on the physical characteristics and nutrient content of the added material. Although this “fertilizer effect” was found to be relatively short-lived (effects appeared to dissipate after approximately three years), the effect helped stimulate the rapid recovery of salt marsh vegetation after placement. Other benefits of sediment application to a marsh include positive impacts on wetland biogeochemistry as well as increased elevation, accretion rates, and sediment bulk density. In addition, mineral sediment enrichment precipitates hydrogen sulfide, a phytotoxin, by providing iron and manganese, which improves plant growth and organic matter production (King et al. 1982).

4 Methods for Placement and Limitations for Placement of Thin-Cover

There are several methods to place sediment onto a marsh, which have their own advantages and drawbacks. In the olden days, methods such as bucket dredging and low pressure spray techniques had limited physical ranges and tend to result in uneven layers of poorly mixed sediments (Ray 2007). Placement distances were also limited due to the fact that the material source (barge) had to be located near a water body. Cahoon and Cowan (1987) reported that the maximum distance that the materials could be placed onto a salt marsh from the water's edge using bucket dredge or low-pressure spray techniques was 61 m (200 ft) and that deposited materials were often poorly mixed and of uneven thickness. On the other hand, these authors reported a maximum application distance of 91 m (298 ft) using high-pressure spray equipment and deposited materials were more uniform when compared to the conventional bucket dredge and low-pressure spray techniques.

The USACE RDC research concluded that the optimal technique for thin layer placement was to spray a slurry of clean sediment onto a salt marsh using a modified hydraulic dredge with a high pressure nozzle (see the spray technique used in the USACE case studies in the photo at left). A cutter head suction dredge (a type of hydraulic dredge) is typically used and, in almost all cases, the cutter head, pump, and spray device are all located on the same vessel. However, sometimes the pump and spray device may be connected by a few hundred meters of piping to maximize their reach (see photo above which shows a marsh reconstruction project in Louisiana that was recently implemented). The type of cutter head (e.g., horizontal auger or radial) used is based on the type of material to be dredged (i.e., fine material or sandy material) (Wilber 1993).

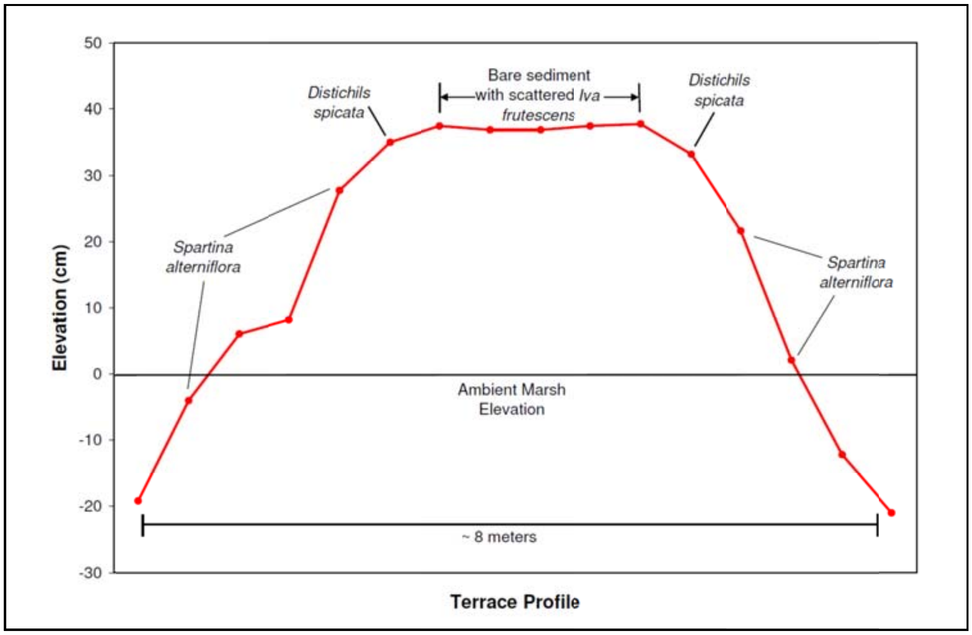
Hydraulic dredges are available in high- or low-pressure systems; however, high-pressure systems can spray material farther, which can increase the marsh area that can be used for placement. Controlling the direction of the spray device provides control over which areas receive sediments; however, precisely controlling the thickness of the placed material has proven difficult, and it is affected by several factors. The large amounts of water used in the slurry may accumulate in the placement area and make it difficult to monitor the thickness of the material being placed in real time. Trees and wind may deflect the spray away from the desired placement area. Material may also fallout along the trajectory of the spray, causing some unevenness in the depositional thicknesses; however, the use of a deflector plate a few centimeters from the spray nozzle can reduce this problem. In order to use thin layer placement successfully, the nature of the existing marsh bottom must be well understood, including sediment characteristics and potential for settlement.

In considering placement methods, desired final sediment surface elevations should be taken into account as well as the drainage pattern of the receiving marsh as these are important components for natural regeneration and recovery of salt marsh vegetation after sediment application. Ray (2007) states that receiving marshes must have an adequate natural slope to ensure that water does not pond and drown salt marsh vegetation. In other words, an elevation gradient must be maintained with the upland being highest and a gentle, continuous slope down to the water's edge. In areas of low tidal range, care must be taken to ensure that sediment addition does not create sediment elevations that are above tidal elevations required by salt marsh plants. Addition of too much sediment can convert intertidal wetland habitat into upland habitat (Leonard et al. 2002). Other important considerations include characteristics of the new material (in comparison to existing marsh sediments), as well as distance from the receiving marsh to potentially sensitive receptors, such as oyster beds, seagrass meadows, or other submerged aquatic vegetation that can be sensitive to elevated turbidities and increased sedimentation. However, proper operation of equipment and use of silt curtains or other barriers should prevent potential adverse impacts to these sensitive receptors.

5 Spartina Tolerances and Characteristics

Below is a list of Spartina tolerances and characteristics summarized from McKee and Patrick (1988), White (2004), Bush and Houck (2008) and Mullens (2007).

- Spartina is a colonial, intertidal salt marsh plant that tends to grow parallel and continuous along coastal shorelines.
- The width and thickness of plant colonies is controlled by site-specific factors, including elevation and slope as well as the frequency, depth and duration of tidal inundation.
- It grows in sandy aerobic or anaerobic soils with pH ranging from 3.7 to 7.9.
- It can tolerate salinities ranging from 0 to 35 parts per thousand. White (2004) reported *S. alterniflora* was the dominant grass in the Altamaha River estuary at salinities >15 practical salinity units (psu), co-dominant with *S. cynosuroides* at salinities between 0.5 and 15 psu, and subdominant in oligohaline conditions (<0.5 psu).
- The optimum water depth for establishing plantings is approximately 3 to 46 cm (1 to 18 in.).
- In newly constructed salt marsh terraces composed of dredge materials in Louisiana, Mullens (2007) showed that Spartina flourished when the percent of time flooded was 50 to 60%.
- Tidal elevation range varies regionally based on mean tidal amplitude or range (McKee and Patrick 1988) and in relation to biotic and abiotic factors. Spartina reportedly occurs at elevations ranging from just above mean low water (MLW) to just above mean high water (MHW). According to the National Oceanic and Atmospheric Administration National Ocean Service datum for Howe Street Pier in Brunswick (Station 8677406), the corresponding elevation for MLW is 20.23 ft and for MHW is 27.36 ft.
- Mullens (2007) noted “solid stands of Spartina were found, on average, at 21.3 cm (± 5.6) above ambient marsh (see figure below). As elevations increased, occurrence of Spartina began to decline and volunteer colonization of *Distichlis spicata* and *Iva frutescens* was found. *D. spicata* was observed at 31.4 cm (± 6.82) above ambient marsh and *I. frutescens* was more commonly found in the higher elevations, at approximately 37.4 cm (± 11.17) above ambient marsh.”
- Mullens (2007) illustrated the change in vegetative species with elevation on constructed terraces as shown in the figure below. The Spartina tolerance in the study was approximately -5 cm to approximately +25 cm relative to the ambient marsh elevation (i.e., the starting elevation of the study).



- Matthews and Minello (1994) identified the following as being among the key factors for successfully restoring, creating, and enhancing Spartina marshes:
    - The soil must contain adequate nutrients. Graded down upland soils often need additions of fertilizer to supply sufficient nutrients, while dredged material or natural bay sediments usually have sufficient nutrients already.
    - Creating proper elevation (0.2-0.5 m above MLW) at the Site is critical. Reference should be made to the nearest flourishing natural marsh whenever possible. Smooth cordgrass will grow over a wider tidal range than where it grows best in the absence of competition. Success has also been achieved when plants are placed at the higher end of the elevation range and allowed to grow into lower elevations on their own.
    - Creating a gentle slope of 1-10% grade provides sufficient width for the marsh to develop. This slope should continue from the planted area to the water’s edge to dampen wave height and erosive forces.
    - Ensuring good water flow and tidal exchange are critical to the supply of nutrients and to prevent salt build-up in the sediment.

Additional citations regarding Spartina marsh restoration projects and conditions that foster optimal growth are provided in Attachment B.

6 Thin-Cover Composition to Maximize Recovery Potential

Matching the characteristics of the cover material to existing conditions (e.g., total organic carbon or percent organic matter, particle size distribution such as percent fines, bulk density, and nutrient levels) may help accelerate recovery. This section discusses research on the composition of the cover material, and discusses attempts of using amendments to stimulate marsh recovery.

Depending on the site-specific conditions and nature of marsh vegetation, addition of nutrient amendments are sometimes needed. Amendments may be necessary if the organic carbon, particle size distribution, bulk density, or nutrient characteristics of the cover material are not comparable to those found in the existing marsh. Tidal marsh soil properties in the southeast vary depending on salinity, geomorphic position, tidal range, vegetation type, and other factors (Pennings et al. 2012). OU1 may be most comparable to southeast riverine salt marshes, which include the following characteristics (Pennings et al. 2012):

- Total nitrogen (percent) in the top 30 cm of sediment is 0.36 ± 0.05 and total phosphorus (µg/g) is 530 ± 100.
- Percent organic matter in riverine salt marshes in the southeast is 12 ± 2.
- Bulk density (g/cm^3) is 0.56 ± 0.09.
- Percent sand is 57 ± 10, percent silt is 20 ± 7, and percent clay is 11 ± 4.

For Brunswick, given the nature of the existing marsh system, nutrient additions or amendments may not be necessary provided the thin-cover material is composed of finer sands and silts similar to those found in typical clean dredged materials. This is further substantiated by the following studies:

- Mendelssohn and Kuhn (2003) reported a short-lived fertilizer effect to thin-cover sediment additions, which dissipated after three years.
- Broome et al. (1975) and Sullivan and Daiber (1974) reported positive biomass responses to fertilizer additions where these nutrients were limiting S. alterniflora marshes. Gibson et al. (1994) have not reported increases in biomass from nitrogen and organic matter additions in cordgrass-dominated marshes.
- In a comparison of constructed (25 year old) and reference marshes in North Carolina, Craft et al. (1999) reported much higher nitrogen accumulation rates in constructed marshes (7-12 g• m^{-2}•yr^{-1}) compared to natural marshes (2-5 g• g• m^{-2}•yr^{-1}).
- Tidal circulation typically provides a natural source of nutrients necessary for plant growth.

In summary, to promote rapid regeneration of Spartina and marsh recovery, the characteristics of the cover material should be similar to the physical characteristics of existing marsh soils to the extent possible.

7 Bioturbation Related to the Effectiveness of Thin-Cover

Bioturbation is the transport process by which a wide range of macrofaunal behavior such as burrowing, feeding, and tube excavation result in the mixing of particles within a sediment column (Kristensen et al. 2012). Bourdreau (1998) estimated that the affected bioturbation depth worldwide was 9.7 cm (<4 inches) from the surface. At the Site, fiddler crabs, oligochaetes and polychaetes are the dominant species present (Black and Veatch 2011; Horne et al. 1999). Scientific studies on these organisms and bioturbation in general is provided in Attachment C. As summarized in Attachment C, the majority of bioturbation in marshes like the Site is in the upper 15 cm of sediment. Attachment C acknowledges that some fiddler crab burrowing deeper than 15 cm can be expected. However, the thin-cover is not intended as an absolute chemical barrier, but as a layer to jump start ongoing natural recovery processes. Therefore, some bioturbation beyond the cover depth does not diminish the effectiveness of this remedy and thus does not preclude its beneficial use as a protective remedy. A thin-cover is a protective remedy for OU1 when the following elements are considered:

- Element 1: True bioturbators, like oligochaetes and polychaetes, that ingest sediments at depth and deposit materials at the surface, are predominantly in the upper 15 cm of the sediment surface, with the vast majority in the upper 3 to 10 cm. Fiddler crabs are different in their bioturbation characteristics, as described below:
    - The majority of fiddler crab burrows is within the top 15 cm of the marsh surface and when at higher densities can contribute to significant sediment turnover. Less frequently, burrows extend to depths of 30 cm.
    - Shallow burrows (sometimes referred to as temporary burrows) are the typical burrows <15 cm of depth that are used for refuge from the tide or predators. As the tide rises, the crabs plug the burrows and remain inside until the next low tide.
    - The deeper burrows are the breeding burrows, which are defended and maintained once created, which would inherently limit further movement of sediment from depth to the surface, particularly given that the burrows are plugged during high tide (so the input of water and sediments that might otherwise fill the burrow is limited).
    - There is also a relationship between burrow depth and plant stem and root density. There are fewer burrows in areas with the greatest root density.
- Element 2: The organisms exposed directly to the burrows will not have an adverse impact even if some burrows exceed the 15 cm thin restoration cover.
    - Fiddler crabs are not particularly sensitive to mercury and Aroclor 1268 even in current conditions.
    - Fiddler crab males aggressively defend their burrows, limiting exposures to other species.
    - Fiddler crabs are deposit feeders, so the majority of food intake occurs at the sediment surface, which would be in the clean restoration layer.
    - The species that are more sensitive will not be in the burrows (e.g., grass shrimp, amphipods, green heron, and fish).

- Element 3: Bioaccumulation to upper trophic level mammals and birds should be very limited even if some burrows exceed the 15 cm thin restoration cover.
    - Fiddler crabs feed on decaying plant material generally at the sediment surface, thus, the majority of feeding will occur in the portion of the clean thin restoration cover, limiting the potential for bioaccumulation.
    - If deeper burrows exist, those burrows provide aeration and thus reduce the potential for mercury methylation or methyl-mercury migration, even in the unlikely event of limited “percolation”.
    - Some fish species eat fiddler crabs but again, significant bioaccumulation in the fiddler crabs is not expected and therefore, bioaccumulation in fish and piscivorous species is not expected. Furthermore, there are no fish species that exclusively eat fiddler crabs and there is no reason to expect that fish will preferentially consume fiddler crabs from areas with thin restoration covers. For these reasons, the thin layer is protective of fish species, including those that include fiddler crabs in their diet.
- Element 4: The physical movement of some mercury and Aroclor 1268 from depth to the surface could occur if the infrequent establishment of burrows deeper than 15 cm should occur; however, this will affect a very small amount of sediment given the overall mass of the clean layer.
    - The overall surface weighted average concentrations (SWACs) in thin-cover areas will be much lower than the current SWACs for OU1.
    - Bioturbation associated with oligochaetes and polychaetes is primarily confined to the upper 10 cm of sediment, and thus will not contribute to mixing of buried contaminated sediment with the clean cover material.
    - For the following reasons, contaminant mass transfer due to bioirrigation in fiddler crab burrows is expected to be very small:
        - Burrows are concentrated in the upper 15 cm.
        - The very low aqueous solubility of Aroclor 1268 and PAHs will limit their dissolved mass transfer in burrows.
        - Methyl mercury is very unstable under aerobic conditions, limiting the potential for methyl mercury mass transfer.
        - Dissolved total mercury and lead mass transfer is limited by their relatively low solubility in sediment porewater and the relatively less frequent burrowing to depths beneath 15 cm.

- Element 5: The thin restoration cover will achieve acceptable risk reduction while causing the least amount of harm to the marsh.
    - Studies have shown that Spartina can regenerate through thin-cover in approximately 1 to 2 years creating stands similar to reference conditions.
    - Alternatives such as removal and backfill would have even greater impacts to the marsh due to heavy construction, destruction of creeks and channels, and challenges associated with returning the sediment bed to its existing bathymetry, as well as successful reestablishment of marsh vegetation to preexisting densities.

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Attachment A

Thin-Cover Placement Projects Summary

Attachment A:
Thin-Cover Placement Projects Summary

Project Name	Material Volume (CY)	Placement Thickness (inches)	Project Outcome	Reference
St. Simons Sound, Georgia	Unknown	3, 6, 9, 12, 24, and 36	Spartina alterniflora was able to penetrate up to 9 inches of each type of placed material and exhibited biological growth and production nearly equal to that in undisturbed reference marsh areas. Plots covered with 24 inches or more of sediments did not recover. There was little variation in vegetation abundance due to discharge time (stage of plant growth).	Reimold et al. 1978
St. Bernard Parish (Lake Coquille), Louisiana	10,500	7 to 15	14 months after placement, vegetation was still smothered. Approximately 6 years after placement, no difference between placement sites and reference site in terms of percent cover by dominant plant species. There were some differences in plant species composition.	Cahoon and Cowan 1987, 1988; LaSalle 1992
Terrebonne Parish (Dog Lake), Louisiana	18,900	4 to 6		
Marshes near Venice, Louisiana	Unknown	1	One year after placement, no difference between the placement areas and the reference sites in terms of the extent of marsh accretion, marsh elevation, soil bulk density and organic content, and vegetative characteristics.	Ford et al. 1999

Project Name	Material Volume (CY)	Placement Thickness (inches)	Project Outcome	Reference
Hydraulic pipeline spill near Venice, Louisiana	Unknown	Less than 6 up to 24	Two years after spill, the total vegetative cover, plant height, and plant biomass was higher at marshes that received material compared to reference marsh areas. Seven years after spill, sites that received 5 to 12 cm of material continued to maintain increased vegetative growth and better soil conditions than reference marshes.	Mendelssohn and Kuhn 2003
Barataria Bay, Louisiana	unknown	0.75 to 2 after 1st lift; 1.6 to 4 after 2nd lift	Material addition resulted in increased above-ground biomass, plant shoot density, leaf-area, above-ground biomass, and culm regeneration. Transpiration rates and leaf conductance were also higher in areas receiving material.	DeLaune et al. 1990
Masonboro Island, North Carolina	unknown	0 to 4	At end of the second summer after placement, deteriorated marsh plots had the same stem density as reference marsh plots. Benthic microalgal biomass tended to be higher in placement areas.	Leonard et al. 2002, Croft et al. 2006
Lake Landing Canal, North Carolina	10,500 to 15,700	0.4 to 4 at one site; 0.4 to 8 at one site	Some decrease in plant shoot density observed. However, the soil bulk densities, organic contents, and faunal distributions indicated productive marshes.	Wilber et al. 1992

Notes:

CY = cubic yards

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Attachment B

Additional Citations for Spartina Restoration

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Additional Citations for Spartina Restoration

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Attachment C

Overview of Bioturbation Literature

Attachment C:
Overview of Bioturbation Literature

Overview of scientific studies of fiddler crabs, annelids, and bioturbation models.

C.1 Fiddler Crabs

Fiddler-crab burrowing has been identified as being responsible for increasing aerobic decomposition, carbon cycling, drainage, and primary production in *Spartina* salt marshes in areas where they are abundant. Depending on cover thickness, densities of burrowing crustaceans, and depths of burrows, there is a potential for burrowing through the cover and into sediments below the cover. However, this burrowing does not preclude the effectiveness for a thin-cover to be protective in OU1 for the following reasons:

- Gribsholt et al. (2003) examined the impact of fiddler crabs and plant roots on sediment biogeochemistry in a Georgia saltmarsh. They found that smooth cordgrass influenced biogeochemical processes through root respiration and stimulated carbon cycling through microbial decomposition in the root zone (i.e., iron reducing bacteria). Crabs were found to excavate and maintain permanent burrows in the marsh, which altered sediment biogeochemistry through aerobic processes. Sediments became progressively more oxidized near burrow walls thereby making iron reduction the most important organic carbon oxidation pathway rather than sulfate reduction. Although the extensive root system and efficient oxygen diffusion capacity of smooth cordgrass roots appeared to have greater impact on sediment biogeochemistry than fiddler crabs, crab burrowing was clearly influential on sediment biogeochemistry and cycling of iron, sulfur, and carbon, particularly in areas where crab burrows were densest.
- Kostka et al. (2002) investigated the rates and pathways of carbon oxidation in saltmarsh sediments in a salt marsh located on Skidaway Island, Georgia. Sediment geochemistry, rates of microbial metabolism, and abundance of anaerobic respiratory bacteria were determined in areas with different fiddler crab burrow abundance and *Spartina* coverage. The authors concluded that iron (III) reduction was the dominant microbial respiration process coupled to carbon oxidation in vegetated salt marsh sediments, whereas sulfate reduction was the dominant process in sediments not affected by macrofauna or macrophytes. Even in areas reported to be in the middle of the range of fiddler crab burrows and *Spartina* coverage, significant impacts on sediment biogeochemistry were observed when compared to adjacent environments where there were fewer to no crabs.
- McCraith et al. (2003) explored the effect of fiddler crab burrowing on sediment mixing in a South Carolina salt marsh by looking at the distribution of two isotopes (^{210}Pb and ^{137}Cs) in salt marsh sediments. Burrow densities ranged from between 40 and 300 m^2 with the highest densities reported to be by the creek bank. Results indicated that crab burrowing mixed the top 8 to 15 cm (3 to 6 in.) of salt marsh sediment thereby influencing sediment composition and salt marsh biogeochemistry.

- Bertness (1985) demonstrated the importance of fiddler crabs to Spartina primary production at a salt marsh in Rhode Island. Reduction of fiddler crabs for a single growing season in tall forms (1-2m, approximately 3-7 ft.) of smooth cordgrass at intermediate tidal elevations decreased aboveground production by 47 percent and increased root density by 35%. Results indicated that crab burrows increased soil drainage, soil oxidation-reduction potential, and decomposition of belowground organic matter. The authors found that burrows typically extended 5 to 25 cm (approximately 2 to 10 in.) below the surface in salt marsh sediments with densities between 224 – 480 burrows m^{-2}.
- Katz (1980) studied Spartina marsh sediment turnover rate and the amount of surface area increase due to fiddler crab (*U. pugnax*) burrowing in a Massachusetts salt marsh. Quantitative measurements of burrow volume and surface area were measured in three 5 m^2 quadrats. Depth of fiddler crab burrows were predominantly 15 cm (6 in.) or less. With an average adult crab density of approximately 42 crabs m^{-2}, it was estimated that over 18% of the sediment in the upper 15 cm (6 in.) was turned over by crab burrowing.
- Allen and Curran (1974) examined the sedimentary structures produced by fiddler crabs in protected lagoon and salt marsh environments near Beaufort, North Carolina. Results indicated that crab distribution was determined primarily by substrate characteristics, salinity, and vegetation cover in the intertidal zone. Fiddler crab (*Uca* spp.) and other crab burrows were reported to be up to 15 to 20 cm (6 to 8 in.) in depth. Dimensions and shapes of burrows were variable depending on the species.

C.2 Annelids: Oligchaetes and Polychaetes

Annelid worms, such as oligochaetes and polychaetes, are important agents of bioturbation in salt marsh ecosystems. Although studies specific to the salt marshes of the southeast United States were not readily available, a literature review indicated that bioturbation depth of oligochaetes and polychaetes were similar between various study areas.

- Shull (2001) prepared a bioturbation model using published data on benthic organisms collected in Narragansett Bay, Rhode Island. Data for polychaetes and oligocahetes indicated that the bioturbation depth was 15 cm or less.
- Two studies on the polychaete *Nereis diversicolor* in the laboratory indicated that bioturbation depth was within the top 15 of the sediment column (Gribsholt and Kristensen 2002).
- Quantitative measurements of vertical displacement of cadmium due to the bioturbation effect of the deposit-feeding polychaetes, *N. diversicolor* and *Arenicola marina,* indicated that cadmium maximum vertical displacement was 13 cm (Petersen et al. 1998).
- Leorri et al. (2009) examined overall bioturbation in salt marshes from the Bombay Hook National Wildlife Refuge in Delaware. Beads were distributed over the surface of plots of high marsh and low marsh, monitored seasonally for seven years. Results indicated that sediment mixing was greatest in late spring and early summer with maximum bioturbation occurring in the low marsh at 13 cm depth. The study also concluded that

sediment found in the low marsh was also more likely to be subject to physical reworking.

- ENVIRON (2007) conducted a study in a New Jersey estuary examining bioturbation through the use of sediment profile imagery at more than 75 locations. The study demonstrated that bioturbation by oligochaetes and polychaetes occurred within 15 cm with a mean depth being 2.2 and 3.5 cm. There were only two occasions over 75 sample locations with a depth slightly exceeding 15 cm.
- A study of a superfund site in New York by Thomann et al. (1993) indicated that bioturbation of sediment occurred in the upper 10 cm.
- Francois et al. (2002) also showed that the majority of burrowing occurs in the upper 15 cm of sediment, but some limited burrowing was observed up to a maximum depth of 19 cm.

This evaluation supports the conclusion that the majority of studies show that oligochaetes and polychaetes burrow in the upper 15 cm of the sediment column, often even in the upper 3 to 10 cm.

C.3 Bioturbation Models

There are a variety of bioaccumulation models that are referred to in literature (e.g., Thoms et al. 1995; Kristensen et al. 2012). Models may be categorized as:

- Diffusive Mixing Models - Appropriate for local random burrowing of organisms (over time scales much shorter than that of observed changes that leads to rapid exchange of neighboring particles and pore water within the mixing zone (See Figure A).

- Advective Mixing Models - Appropriate for transport by conveyor-belt feeders in preferential direction (see Figures B, C, D).

- Generalized Mixing Models (Robbins 1986) - Considered both diffusive and advective terms.

Fiddler crabs would show characteristics of B (upward conveyor) as the initial burrows are established, but would show characteristics of C and D thereafter (i.e., sediments from the surface more likely to encroach into the burrow). Other organisms, like oligochaetes and polychaetes would show characteristics of A, B, C, and D, however, as was stated, the vast majority of those interactions would occur in the upper 15 cm of sediment so would not extend below the thin layer.

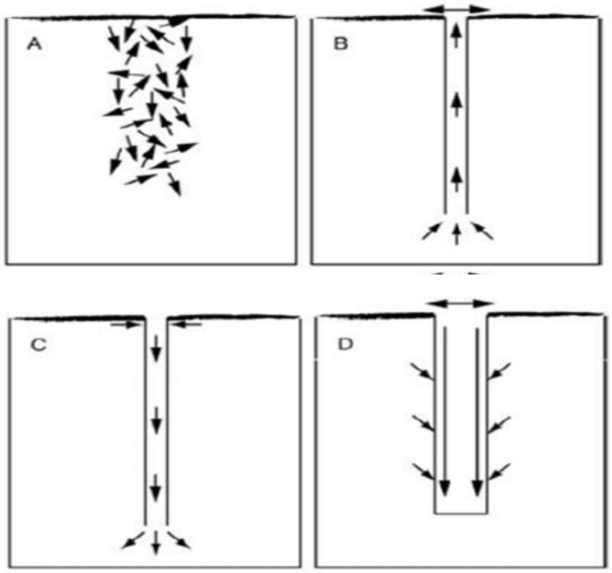

Figure A- Major Type of Bioturbation (adapted from Kristensen et al. 2012)

A- Biodiffusers
B- Upward conveyors
C- Downward conveyors
D- Regenerator

Attachment C References:

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DRAFT

Appendix E2
Technical Approach for Remedy Evaluation and Uncertainty Evaluation

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

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Acronyms and Abbreviations

BAF	Bioaccumulation factors
BERA	Baseline Ecological Risk Assessment
BW	Body weight of wildlife
CBC	COPC in blue crab
CMC	COPC in mummichog
COPC	Constituent of potential concern
CS	COPC in sediment
CW	COPC in water
CFC	COPC in fiddler crab
FIR	Food ingestion rate
FS	Feasibility Study
HQ	Hazard quotients
kg	Kilogram
L	Liter
LOAEL	Lowest observable adverse effect level
mg	Milligram
NOAEL	No observable adverse effect level
OU1	Operable Unit 1
PBC	Proportion of blue crabs in diet
PFC	Proportion of fiddler crabs in diet
PMC	Proportion of mummichogs in diet
RGO	Remedial Goal Option
SIR	Sediment ingestion rate
SMA	Sediment Management Area
SWAC	Surface-weighted area concentrations
TDI	Total daily intake
TRV	Toxicity reference values
UCL	Upper confidence limit on the mean
USEPA	United States Environmental Protection Agency
WIR	Water ingestion rate

1 Introduction

This appendix to the Operable Unit 1 (OU1) Feasibility Study (FS) provides supporting information for the remedy effectiveness evaluation provided in **Section 6** of the FS, for the six Alternatives:

- Alternative 1: No Action
- Alternative 2: Sediment Removal in Sediment Management Area (SMA)-1
- Alternative 3: Sediment Removal, Capping, and Thin-cover Placement in SMA-1
- Alternative 4: Sediment Removal in SMA-2
- Alternative 5: Sediment Removal, Capping, and Thin-cover Placement in SMA-2
- Alternative 6: Sediment Removal, Capping, and Thin-cover Placement in SMA-3

The remedy effectiveness evaluation is based on surface-weighted average concentrations (SWACs) (**FS Section 3, Table 3-5)** and the methods and calculations developed by the United States Environmental Protection Agency (USEPA) in the Baseline Ecological Risk Assessment (BERA) for Operable Unit 1 (OU1) (Black and Veatch 2011) as well as discussions with USEPA in the development of this FS. The evaluation documented in **FS Section 6** and supported in this appendix identifies baseline conditions in a manner consistent with the BERA.

This appendix includes the following sections:

- **Section 2:** Mammal and bird remedy effectiveness evaluation approach
- **Section 3** Finfish remedy effectiveness evaluation approach
- **Section 4** Supporting information related to the sediment-dwelling community
- **Section 5** Additional uncertainties related to the remedy effectiveness evaluation
- **Section 6** References

2 Mammal and Bird Remedy Effectiveness Evaluation

Data supporting the remedy effectiveness evaluation (**FS Section 6**) originates from the BERA or was generated with BERA formulae and supporting technical information. This appendix includes information supporting the following figures in **FS Section 6**:

- **FS Figure 6-1A** BERA Risk Assessment Findings for Mammals and Birds Exposed to Mercury
- **FS Figure 6-1B** BERA Risk Assessment Findings for Mammals and Birds Exposed to Aroclor 1268
- **FS Figure 6-2A** Remedy Effectiveness Evaluation for the Mercury Exposures and the Green Heron Exposed to All Areas
- **FS Figure 6-2B** Remedy Effectiveness Evaluation for Mercury and the Green Heron In Areas with Hazard Quotients Exceeding a Threshold Value of 1

2.1 Technical Supporting Information for FS Figures 6-1A and 6-1B

FS Figures 6-1A and **6-1B** summarize conditions associated reflect current conditions, as documented by the BERA, and thus represent No Action Alternative. The BERA estimated mercury and Aroclor 1268 risks for six mammal and bird receptors (BERA Section 4.11, and BERA Appendix H):

- Clapper Rail (*Rallus longirostris*)
- Green Heron (*Butorides striatus*)
- Marsh Rabbit (*Sylvilagus palustris*)
- Raccoon (*Procyon lotor*)
- Red Winged Blackbird (*Agelaius phoeniceus*)
- River otter (*Lutra canadensis*)

FS Figures 6-1A and **6-1B** are based on lowest observable adverse effect level (LOAEL) hazard quotients (HQs). These data are summarized in **Table E2-1** (BERA Appendix H, Tables H-1 through H-7).

Green heron is the most sensitive species to mercury, with LOAEL HQs exceeding 1 (**FS Section 6**, **Figure 6-1A**). LOAEL HQs for other mammals and birds were less than 1. Therefore, the green heron was the focus of the mercury remedy effectiveness evaluation (**FS Figures 6-2A** and **6-2B).** The LOAEL HQs for mammals and birds did not exceed 1 for Aroclor 1268, so a similar risk reduction evaluation is not provided for Aroclor 1268.

2.2 Remedy Effectiveness Calculations Used in FS Figures 6-2A and 6-2B

Remedy effectiveness was evaluated for the No Action Alternative (Remedy Alternative 1), SMA-1 (Alternatives 2 and 3), SMA-2 (Alternatives 4 and 5), and SMA-3 (Alternative 6) by comparing No Action conditions (LOAEL HQs described in **Section 2.1**) to estimated HQs calculated using the SWACs for each of the SMAs (**FS Table 3-5)**.

2.2.1 Green Heron Intake Estimates

The SWACs for SMA-1, SMA-2, and SMA-3 were used in the food web daily intake formula described below (BERA Section 4.11 (Page 59)).

$$TDI = \frac{\{[(\mathrm{CF1}*\mathrm{P1})+(\mathrm{CF2}*\mathrm{P2})+(\mathrm{CF3}*\mathrm{P3})]*\mathrm{FIR}+(\mathrm{CS}*\mathrm{SIR})+(\mathrm{CW}*\mathrm{WIR})\}\{\mathrm{AUF}\}\{\mathrm{TUF}\}}{\mathrm{BW}} \tag{1}$$

And:

$$\mathrm{HQ} = \frac{TDI}{TRV} \tag{2}$$

Where:

AUF	area-use factor
BW	body weight of wildlife (kg/wet weight)
CF1	mean concentrations of COPC in fiddler crabs (mg/kg, dry weight)
CF2	mean concentrations of Constituent of potential concern (COPC) in blue crab (mg/kg, dry weight)
CF3	mean concentrations of COPC in mummichog (mg/kg, dry weight)
CS	mean concentration of COPC in sediment (mg/kg, dry weight)
CW	mean concentration of COPC in water (mg/L)
FIR	food ingestion rate (kg dry weight/day)
P1	proportion of fiddler crabs in diet (unitless)
P2	proportion of blue crabs in diet (unitless)
P3	proportion of mummichogs in diet (unitless)
SIR	sediment ingestion rate (kg dry weight/day);
TDI	total daily intake (mg/kg wet weight/day)
TRV	toxicity reference value (mg/kg wet weight/day)
TUF	time-use factor
WIR	water ingestion rate (L/day)

Concentrations and other parameters in the total daily intake formula (1) for the green heron (i.e., CF1, CF2, and CF3) are based on BERA bioaccumulation relationships, calculations, and methods (BERA Section 7.1, BERA Table 7-6: Bioaccumulation Factors for Biota, BERA Table 7-7: Key Parameters for Wildlife Food Chain Models). The BERA table of bioaccumulation factors (BAFs) is reproduced here as **Table E2-2**. The table of green heron receptor parameters is reproduced here as **Table E2-3**.

2.2.2 TRVs

LOAEL TRVs for the green heron are listed in **Table E2-4** (BERA Table 4-27).

2.2.3 Post-remedy Estimated HQ Tabular Results

Results for the green heron are calculated in **Table E2-5,** including predicted dietary items for fiddler crabs, blue crabs, and mummichogs for each Alternative. **Table E2-6** summarizes the HQs from Table E2-5 and this summary of HQs were used to create **FS Figures 6-2A** and **6-2B**.

2.3 Uncertainties in the Green Heron Remedy Effectiveness Evaluation

FS Figures 6-2A and **6-2B** provide HQs for the Domain 3 Creek and also provide the HQs for the average of the Domain 3 Creek, the Domain 3 marsh, and Purvis Creek because Domain 3 Creek is too small to support green heron. Herons spend time in different areas of the marsh due to changes in tides and prey availability. Averaging the Purvis Creek, Domain 3, and Domain 3 Creek areas realistically estimates of risks for herons, particularly when the tide is in or out, as the mummichogs that are 90 percent of the green heron diet move in and out of Domain 3 Creek with the tide.

Estimates of uptake into mummichogs, blue crabs, and fiddler crabs are uncertain; however, remedy effectiveness evaluation methods were consistent with the BERA to ensure a sound basis for comparison with baseline values.

3 Finfish Remedy Effectiveness Evaluation Approach

This section provides the supporting information for the following figures in **Section 6** of the FS, based on information from the BERA (Black and Veatch 2011):

- **FS Figure 6-3A** Remedy Effectiveness Evaluation for Aroclor 1268 and Finfish
- **FS Figure 6-3B** Striped Mullet Fish Tissue Concentrations of Aroclor 1268 Over Time
- **FS Figure 6-4A** Remedy Effectiveness Evaluation for Mercury and Finfish
- **FS Figure 6-4B** Striped Mullet Fish Tissue Concentrations of Aroclor 1268 Over Time

3.1 Technical Information Supporting FS Section 6 Finfish Figures

FS Figures 6-3A and **6-4A** summarize conditions under the six Alternatives. The No Action Alternative conditions are based on BERA-estimated mercury and Aroclor 1268 risks for five fish species (BERA Table 4-11A, BERA Table 4-11B, and BERA Table 4-29). The BERA data are from samples collected during 2000 to 2007 and includes whole-body concentrations for these species:

- Black Drum (*Pogonias cromis*)
- Red Drum (*Sciaenops ocellatus*)
- Silver Perch (*Bairdiella chrysoura*)
- Spotted Seatrout (*Cynoscion nebulosus)*
- Striped Mullet (*Mugil cephalus*)

The finfish No Action Alternative values reflect the LOAEL HQs from the BERA and are reproduced on **Table E2-7**. Note that the 2011 whole body fish tissue data are not included in this summary, as these data are from a collection effort that occurred after the BERA was completed. Rather, the 2011 whole body fish tissue data are discussed as an uncertainty. Appendix F of this FS provides a compilation of whole body fish tissue data graphically illustrated over time.

3.2 Remedy Effectiveness Calculation Approach for Finfish

In order to assess remedy effectiveness associated with Alternatives 2 through 6, the No Action Alternative HQs for finfish from the BERA were scaled in proportion to sediment concentration reduction for each SWAC. This Linear Reduction approach assumes that fish tissue concentrations will be reduced proportionally with reductions in sediment concentrations. Fish tissue concentrations were scaled based on the Total Creeks SWACs because fish are expected to be exposed to all creeks, as they migrate under tidal ebbs and flood (**FS Table 3-5)**. The fish likely spend a greater proportion of time in Purvis Creek than the other creeks and this uncertainty is discussed further in **Section 3.3** and **Section 5** of this appendix.

The Linear Reduction approach is:

(3) $Linear\ Reduction\ in\ HQ = (No\ Action\ Alternative\ HQ)\ X\ (\%SWAC\ Reduction)$

Fish tissue concentrations (**Table E2-8**) were calculated the same way (multiplying the No Action Alternative fish tissue concentration by the % SWAC reduction).

For example, the original concentration of Aroclor 1268 in Red Drum is 1.43 mg/kg dry weight (**Table E2-7**), so the predicted fish tissue concentration for SMA-1 for red drum is 0.37 mg/kg dry weight (1.43 mg/kg dry weight x 26 percent). **FS Figure 6-3A** and **6-4A** show the HQs for mercury and Aroclor 1268 in finfish. **Table E2-8** identifies the SWAC reductions and estimated HQs with each of the Alternatives.

3.3 Uncertainties in the Fish Estimation Approaches

The Linear Reduction approach discussed above was agreed upon with USEPA during discussions of how remedy effectiveness would be presented in the FS. Because this approach is uncertain, it was also agreed that this appendix would address some of those uncertainties.

- There is a difference between BERA fish tissue data and more recent fish tissue data. BERA data was collected between 2000 and 2007 (BERA Table 4-11A). **FS Figures 6-4B** shows data for fish tissue body residues for striped mullet (Aroclor 1268) collected in 2011.[1] **Figures E2-1A** and **E2-1B** show measured fish tissue concentrations from the BERA. The 95% Upper confidence limit on the mean (UCL) and mean concentrations are compared to the no observable adverse effects levels (NOAEL) and LOAEL TRVs[2]. Consideration of only the 2000-2007 data over-predict constituent concentrations for some species, as Appendix F shows that concentrations for some species have declined over time for samples collected from OU1.
- There are multiple approaches that can be used to estimate fish tissue concentrations. This appendix and discussions in Section 6 of the FS focus on the Linear Reduction approach. The BERA used two types of BAFs to explore potential risks, the Area-Weighted approach and the Yearly-Average approach (BERA Section 7). The BERA explains the uncertainties associated with its fish tissue models (BERA Section 7.1.4). The different models are not congruent with the measured fish tissue concentration. **Figures E2-2A** and **E2-2B** compare measured fish tissue concentrations to three different modeling approaches (Linear Reduction, Area-Weighted, and Yearly Average). The data supporting these graphics are provided in **Tables E2-7** and **E2-9**. These figures indicate that there is variability in any approach considered. The Yearly-Average approach consistently overestimates HQs for Aroclor 1268. The Area-Weighted and Linear Reduction approaches provide similar estimates for mercury and Aroclor 1268.
- Figures E2-3A and E2-3B show the uncertainty evaluation for the Remedial Alternatives comparing the three estimation approaches (i.e., Linear Reduction, Area-Weighted, and Yearly-Average). These graphics are based on data provided in **Tables E2-9**, **E2-10**, and **E2-11.**

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[1] A full set of whole-body fish tissue graphics for all species with available data is provided in **Appendix F**.

[2] NOAEL and LOAEL TRVs are in dry weight so they are not directly comparable to wet-weight tissue data presented in Appendix F.

4 Sediment-dwelling Community Supporting Information

FS Section 2 refers to studies of the sediment-dwelling community, described in the BERA (**FS Section 2.4**), which are summarized below:

- Two *in situ* studies of indigenous grass shrimp discussed in the BERA (BERA Appendix J, **Figures E2-4A,** and **E2-4B)** showed that shrimp embryos hatched with the same success from OU1 as from reference areas, even when collected from locations with levels of mercury and Aroclor 1268 meeting or exceeding the Remedial Goal Options (RGOs) (**FS Section 3.3)**. Study locations are shown in **Figure E2-4A**; only two locations showed toxic responses between 2000 and 2007, and those locations were in LCP Ditch and Eastern Creek, where COC concentrations are highest in OU1. The areas where toxicity was observed are included in the SMAs addressed by Alternatives 2 through 6. A further study of indigenous grass shrimp is illustrated in **Figure E2-4B** and it shows that, except for the two locations where toxicity was observed, grass shrimp measurements were similar to those at reference locations even in areas with elevated chemical concentrations above the RGO range specified in **FS Section 3 (**BERA Appendix J).
- The indigenous grass shrimp studies also provide valuable information about how organisms use the estuary. Grass shrimp are mobile and unlikely to be exposed to any single location for long periods. As tides ebb, grass shrimp follow the tides. They prefer to live atop submerged grasses and carry their broods against their bodies, which limits their exposure to sediment contaminants. Therefore, indigenous grass shrimp are likely to be less prone to toxic effects predicted by laboratory toxicity studies, which tend to keep grass shrimp in direct contact with sediments for prolonged periods.
- An additional *in situ* study presented in the BERA is illustrated in **Figure E2-5**. This study included four locations; two of the four locations showed lower species diversity than the reference location (BERA Appendix J). These two locations, which exceed RGOs, are host to five to nine species compared to the 12 to 23 species seen at the Cresent River and Troop Creek reference areas, respectively. Both locations are included in the SMAs addressed by Alternatives 2 through 6. A location that performed better than the reference location is also included in the SMAs because it exceeds RGOs (Location C7 in Eastern Creek). Thus, RGO exceedance does not necessarily indicate impairment of the sediment-dwelling community.
- **Figure E2-6** summarizes of the BERA discussion of a mysid shrimp surface water toxicity study. Survival and growth were evaluated. No impacts to survival were observed at any locations (all survival was 94-100%). Shrimp growth was greater than or equal to that seen in reference areas (BERA Section 4.3.1).

5 Additional Uncertainties Related to the Remedy Effectiveness Evaluation

Some uncertainties in the remedy effectiveness evaluation apply to both the wildlife and fish risk assessments. Although many of these uncertainties are adequately explained in the BERA (Black and Veatch 2011) some are worth additional consideration.

- Methyl mercury accumulation in tissues is highly variable on spatial and temporal scales. The accumulation of mercury was predicted using the methods from the BERA which was based on fish collection from OU1.
- Risk estimates based on the HQ approach are insensitive to spatial variability of contamination in sediment/biota and insensitive to habitat considerations. SWACs account for some of this variability in sediment concentrations.
- Purvis Creek represents approximately 85 percent of fish habitat during both low and high tides; Eastern Creek represents approximately 10 percent of finfish habitat mostly during high tide. The Total Creeks SWAC integrates sediment concentrations throughout the creeks into a single range; however, exposure differences among different species with different movement and habitat use patterns are not accounted for when predicting tissue concentrations.
- BAFs may vary between less contaminated areas and moderate or heavily contaminated areas. The BERA BAFs may underestimate or overestimate tissue concentrations compared to measured finfish tissue concentrations (**Figures E2-2A** and **E2-2B** and **Table E2-11**).
- The mean measured tissue concentrations in biota (finfish, crabs, and mummichogs) have large standard deviations and high coefficients of variance that result in large uncertainty around the mean. The elevated 95% UCLs should equal or exceed the true mean of the tissue concentrations 95 percent of the time.
- SWACs are tied to SMAs such that Alternatives 2 and 3 share SWACs and Alternatives 4 and 5 share SWACs. The SWACs used for SMA-1 and SMA-2 were not subdivided into SWACs for Remedial Alternatives 2 and 3 (SMA-1) and Remedial Alternatives 4 and 5 (SMA-2) because an uncertainty evaluation showed that this subdivision was not likely to significantly impact SWAC values. **Table E2-12** shows the uncertainty evaluation. In Table E2-12, for thin cover placement areas, the values used in the uncertainty evaluation were 10 percent of the initial SWACs (based on the initial Thiessen Polygon values). Use of 10 percent SWAC values was considered a reasonable estimated value that accounts for some mixing of the thin cover with the existing sediment. The numbers change the most for Domain 1, but are still well below the SWAC RGOs identified in **Section 3.3** of the FS.
- As was discussed in **FS Section 2.4**, the total PAH sediment concentrations were determined by summing the concentrations of the 18 individual PAHs analyzed during the remedial investigation sediment sampling. For non-detect results, half the detection limit was used. During the 1995-1999 sampling events, elevated detection limits greater than 400 µg/kg were frequently reported; these non-detect results were not included in the total PAH summation. The approach for summing total PAH concentrations with non-detect results was briefly reviewed with the Agencies during a conference call on August 2, 2012.

Non-detect samples with elevated detection limits (greater than 400 µg/kg) were not included in the summation, because if half the detection limits were used, it could result in the exceedance of the total PAH Remedial Goal, even though no PAH compounds were actually detected. An uncertainty analysis related to this topic is considered in **Figure E2-7**. Results show among the approximately 450 samples where PAH data were analyzed, approximately five percent had elevated detection limits where an individual detection limit exceeded 400 µg/kg. This uncertainty had no significant impact on the characterization of PAHs, decisions about Remedy Alternatives, or an understanding of remedy effectiveness because locations with elevated PAHs were sampled in subsequent events with lower detection limits and at nearby locations with lower detection limits.

6 References

Black & Veatch. 2011. Baseline Ecological Risk Assessment for the Estuary at the LCP Chemical Site in Brunswick, GA – Site Investigation and Risk Characterization (Revision 4). Prepared for EPA Region 4 by Black & Veatch Special Projects Corp, April.

Tables

Table E2-1: Wildlife Hazard Quotients From The BERA

LCP Chemical, Brunswick, GA

95%UCL Methyl Mercury LOAEL Hazard Quotients from The BERA

Area	Green Heron	Clapper Rail	Red-winged blackbird	Raccoon	River otter	Marsh rabbit	Diamondback terrapin
Domain 1	**2.77**	0.99	0.33	0.135	0.02	0.01	0.0006
Domain 2	0.78	0.29	0.14	0.1	0.07	0.005	0.0002
Domain 3	0.83	0.28	0.14	0.1	0.08	0.003	0.0002
Domain 4	0.59	0.23	0.13	0.1	0.22	0.002	0.0001
Purvis Creek	0.58	0.14	0.1	0.09	0.03	0.001	0.0001
Main Canal	**1.48**	0.58	0.22	0.11	0.001	0.04	0.0004
Eastern Creek	**3.53**	0.86	0.29	0.13	0.003	0.009	0.0006
Western Creek Complex	0.78	0.29	0.14	0.1	0.001	0.005	0.0002

Aroclor 1268 LOAEL 95% UCL Hazard Quotients from the BERA

Area	Green Heron	Clapper Rail	Red-winged blackbird	Raccoon	River otter	Marsh rabbit	Diamondback terrapin
Domain 1	0.2	0.11	0.043	0.26	0.034	0.3	0.004
Domain 2	0.07	0.04	0.01	0.11	0.139	0.09	0.002
Domain 3	0.1	0.03	0.009	0.1	0.169	0.05	0.002
Domain 4	0.04	0.02	0.007	0.08	0.39	0.05	0.001
Purvis Creek	0.04	0.03	0.01	0.1	0.058	0.09	0.002
Main Canal	0.17	0.16	0.07	0.37	0.002	0.32	0.007
Eastern Creek	0.25	0.21	0.09	0.49	0.009	0.48	0.008
Western Creek Complex	0.07	0.03	0.01	0.1	0.002	0.08	0.002

These values are from Appendix H of the BERA, Tables H-1 through H-7.
The areas shown are ones that are approximately analogous to areas for which remedial SWACs are calculated.

95% UCL	95% upper confidence level of the mean.
BERA	Baseline ecological risk assessment (USEPA, 2011).
LOAEL	Lowest observed apparent effects level.
MeHg	Methyl mercury.
PCB	Polychlorinated biphenyl, aroclor 1268.

Table E2-2: Bioaccumulation Factors For Biota From The BERA

LCP Chemical, Brunswick, GA

	Total Mercury in Sediment to Total Mercury in Biota (a)					**Aroclor 1268 in Sediment to Aroclor 1268 in Biota**				
Receptor	**a**	**b**	**R^2**	**Curve Fit Type**	**Source from BERA**	**a**	**b**	**R^2**	**Curve Fit Type**	**Source from BERA**
Cordgrass	Not Evaluated					0.022	0		Linear	Figure 7-20
Fiddler Crabs	0.2187	0.4733	0.8725	Power	Figure 7-2	0.1995	0	0.9167	Linear	Figure 7-3
Blue Crabs	1.303	0		Linear	Figure 7-9	0.426	0		Linear	Figure 7-8
Mummichogs	0.2348	0.4706	0.884	Power	Figure 7-7	1.2188	0.4918	0.8117	Power	Figure 7-6
BAFs formed from Plots of Data Aggregated by Years										
Silver Perch	1.6511	0.7371	0.7917	Power	Figure 7-15	2.4556	0.8834	0.8876	Power	Figure 7-14
Red Drum	1.2095	0.7002	0.7205	Power	Figure 7-11	0.7748	0.6803	0.7492	Power	Figure 7-10
Black Drum	0.9084	1.0323	0.8967	Power	Figure 7-13	2.5436	0.9589	0.8972	Power	Figure 7-12
Spotted Seatrout	1.9818	0.8641	0.7301	Power	Figure 7-17	2.1172	0.8997	0.913	Power	Figure 7-16
Striped Mullet	0.2144	0.8472	0.8657	Power	Figure 7-19	3.9936	1.0458	0.8887	Power	Figure 7-18

Area-Weighted BAFs

Receptor	**BAF**	**Source**		**BAF**	**Source**	
Silver Perch	0.584	Table 7-4	BERA (USEPA 2011).	0.762	Table 7-4	BERA (USEPA 2011).
Red Drum	0.416	Table 7-4	BERA (USEPA 2011).	0.192	Table 7-4	BERA (USEPA 2011).
Black Drum	0.307	Table 7-4	BERA (USEPA 2011).	0.741	Table 7-4	BERA (USEPA, 2011).
Spotted Seatrout	0.829	Table 7-4	BERA (USEPA 2011).	0.661	Table 7-4	BERA (USEPA 2011).
Striped Mullet	0.084	Table 7-4	BERA (USEPA 2011).	1.775	Table 7-4	BERA (USEPA 2011).

Curve Fit Type:

Linear	y = a x + b
Logarithmic (Log)	y = a ln(x) + b
Power	y = a xb

BAF	Bioaccumulation Factor.
BERA	Baseline ecological risk assessment (USEPA 2011).

(a) These values are from Table 7-6 of the BERA.

Table E2-3: Key Parameters For Green Heron Wildlife Food Chain Model

LCP Chemical, Brunswick, GA

Receptor	Food Ingestion Rate (kg dry wt/day)	Body Weight (kg wet weight)	Fraction Incidental Ingestion of dry food rate Unitless	Sediment Ingestion Rate (kg dry wt/d)	Water Ingestion Rate (L/day)	Dietary Fraction			Area Use Factor Unitless
						Blue Crabs	Fiddler Crabs	Mummi-chogs	
Green Heron	0.024	0.2	0.12	0.00048	0.023	0.05	0.05	0.9	1

These values are from Table 7-7 of the BERA.

BERA	Baseline ecological risk assessment (USEPA 2011).
kg/dry wt/day	Kilogram per dry weight per day.
kg wet weight	Kilogram per wet weight.
L/day	Liter per day.

Table E2-4: Toxicity Reference Values For Finfish And Birds

LCP Chemical, Brunswick, GA

Birds

Methyl Mercury	LOAEL = 0.06	Spalding et al. 2000 growth reduction in great egret.
Aroclor 1268	LOAEL = 3.9	NOAEL-to-LOAEL adjustment factor of 3 applied to chicken NOAEL

Fishes

Methyl Mercury	LOAEL = 0.30	Median highest LOAEL reported for 7 species of mostly freshwater fishes (as reviewed by Dillon, 2006b) (1.2 mg/kg dry weight conversion).
Aroclor 1268	LOAEL = 1.3	LOAEL value from Matta et al. (2001). (5.2 mg/kg dry weight conversion)

These values are from Table 4-27 of the BERA.

BERA	Baseline ecological risk assessment (USEPA, 2011).
LOAEL	Lowest observed apparent effects level.

Table E2-5: Calculation Of Green Heron Mercury LOAEL Hazard Quotients

LCP Chemical, Brunswick, GA

				Fiddler Crabs			Blue Crabs			Mummichogs							
Preremedy	**Total Hg Sediment Conc. mg/kg**	**MeHg Sediment Conc. mg/kg**	**Sediment Ingestion Rate kg/day**	Predicted Total Hg Conc. mg/kg dry	Predicted MeHg Conc. mg/kg	Fraction of Diet	Predicted Total Hg Conc. mg/kg dry	Predicted MeHg Conc. mg/kg	Fraction of Diet	Predicted Total Hg Conc. mg/kg dry	Predicted MeHg Conc. mg/kg	Fraction of Diet	**Food Ingestion Rate kg/day**	**Body Weight kg**	**Total Dose mg/kg /day**	**MeHg LOAEL mg/kg /day**	**LOAEL Hazard Quotient**
Dillon Duck	1.43E+00	1.07E-02	0.00048	2.59E-01	1.76E-01	0.05	1.86E+00	1.86E+00	0.05	2.78E-01	2.56E-01	0.9	0.024	0.2	3.99E-02	0.06	0.66
Domain 1	5.11E+00	3.83E-02	0.00048	4.73E-01	3.22E-01	0.05	6.66E+00	6.66E+00	0.05	5.06E-01	4.65E-01	0.9	0.024	0.2	9.22E-02	0.06	**1.5**
Domain 2	2.55E+00	1.91E-02	0.00048	3.40E-01	2.32E-01	0.05	3.32E+00	3.32E+00	0.05	3.65E-01	3.35E-01	0.9	0.024	0.2	5.76E-02	0.06	0.96
Domain 3	1.73E+00	1.30E-02	0.00048	2.83E-01	1.93E-01	0.05	2.25E+00	2.25E+00	0.05	3.04E-01	2.80E-01	0.9	0.024	0.2	4.49E-02	0.06	0.75
Domain 4 East	1.98E+00	1.49E-02	0.00048	3.02E-01	2.06E-01	0.05	2.58E+00	2.58E+00	0.05	3.24E-01	2.98E-01	0.9	0.024	0.2	4.89E-02	0.06	0.82
Domain 4 West	6.89E-01	5.17E-03	0.00048	1.83E-01	1.25E-01	0.05	8.98E-01	8.98E-01	0.05	1.97E-01	1.81E-01	0.9	0.024	0.2	2.57E-02	0.06	0.43
Total Domains	1.70E+00	1.27E-02	0.00048	2.81E-01	1.91E-01	0.05	2.21E+00	2.21E+00	0.05	3.01E-01	2.77E-01	0.9	0.024	0.2	4.44E-02	0.06	0.74
Domain 3 Creek	5.94E+00	4.45E-02	0.00048	5.08E-01	3.46E-01	0.05	7.74E+00	7.74E+00	0.05	5.43E-01	5.00E-01	0.9	0.024	0.2	1.03E-01	0.06	**1.7**
Eastern Creek	1.46E+01	1.09E-01	0.00048	7.77E-01	5.29E-01	0.05	1.90E+01	1.90E+01	0.05	8.29E-01	7.62E-01	0.9	0.024	0.2	2.00E-01	0.06	**3.3**
LCP Ditch	7.67E+00	5.76E-02	0.00048	5.74E-01	3.90E-01	0.05	1.00E+01	1.00E+01	0.05	6.13E-01	5.64E-01	0.9	0.024	0.2	1.23E-01	0.06	**2.1**
Purvis Creek	1.17E+00	8.79E-03	0.00048	2.36E-01	1.60E-01	0.05	1.53E+00	1.53E+00	0.05	2.53E-01	2.33E-01	0.9	0.024	0.2	3.53E-02	0.06	0.59
Western Creek Complex	2.14E+00	1.60E-02	0.00048	3.13E-01	2.13E-01	0.05	2.78E+00	2.78E+00	0.05	3.36E-01	3.09E-01	0.9	0.024	0.2	5.13E-02	0.06	0.86
Total Creek	2.59E+00	1.94E-02	0.00048	3.43E-01	2.33E-01	0.05	3.37E+00	3.37E+00	0.05	3.67E-01	3.38E-01	0.9	0.024	0.2	5.82E-02	0.06	0.97
Total Estuary	1.81E+00	1.36E-02	0.00048	2.90E-01	1.97E-01	0.05	2.36E+00	2.36E+00	0.05	3.11E-01	2.86E-01	0.9	0.024	0.2	4.63E-02	0.06	0.77
SMA 1																	
Dillon Duck	3.00E-01	2.25E-03	0.00048	1.24E-01	8.41E-02	0.05	3.91E-01	3.91E-01	0.05	1.33E-01	1.23E-01	0.9	0.024	0.2	1.61E-02	0.06	0.27
Domain 1	6.31E-01	4.73E-03	0.00048	1.76E-01	1.20E-01	0.05	8.22E-01	8.22E-01	0.05	1.89E-01	1.74E-01	0.9	0.024	0.2	2.44E-02	0.06	0.41
Domain 2	8.60E-01	6.45E-03	0.00048	2.04E-01	1.38E-01	0.05	1.12E+00	1.12E+00	0.05	2.19E-01	2.01E-01	0.9	0.024	0.2	2.93E-02	0.06	0.49
Domain 3	1.48E+00	1.11E-02	0.00048	2.63E-01	1.79E-01	0.05	1.93E+00	1.93E+00	0.05	2.83E-01	2.60E-01	0.9	0.024	0.2	4.08E-02	0.06	0.68
Domain 4 East	1.98E+00	1.49E-02	0.00048	3.02E-01	2.06E-01	0.05	2.58E+00	2.58E+00	0.05	3.24E-01	2.98E-01	0.9	0.024	0.2	4.89E-02	0.06	0.82
Domain 4 West	6.89E-01	5.17E-03	0.00048	1.83E-01	1.25E-01	0.05	8.98E-01	8.98E-01	0.05	1.97E-01	1.81E-01	0.9	0.024	0.2	2.57E-02	0.06	0.43
Total Domains	1.22E+00	9.15E-03	0.00048	2.40E-01	1.63E-01	0.05	1.59E+00	1.59E+00	0.05	2.58E-01	2.37E-01	0.9	0.024	0.2	3.62E-02	0.06	0.6
Domain 3 Creek	1.05E+00	7.87E-03	0.00048	2.24E-01	1.52E-01	0.05	1.37E+00	1.37E+00	0.05	2.40E-01	2.21E-01	0.9	0.024	0.2	3.30E-02	0.06	0.55
Eastern Creek	3.00E-01	2.25E-03	0.00048	1.24E-01	8.41E-02	0.05	3.91E-01	3.91E-01	0.05	1.33E-01	1.23E-01	0.9	0.024	0.2	1.61E-02	0.06	0.27
LCP Ditch	3.16E-01	2.37E-03	0.00048	1.27E-01	8.62E-02	0.05	4.12E-01	4.12E-01	0.05	1.37E-01	1.26E-01	0.9	0.024	0.2	1.66E-02	0.06	0.28
Purvis Creek	8.70E-01	6.53E-03	0.00048	2.05E-01	1.39E-01	0.05	1.13E+00	1.13E+00	0.05	2.20E-01	2.02E-01	0.9	0.024	0.2	2.95E-02	0.06	0.49
Western Creek Complex	1.24E+00	9.31E-03	0.00048	2.42E-01	1.65E-01	0.05	1.62E+00	1.62E+00	0.05	2.60E-01	2.39E-01	0.9	0.024	0.2	3.65E-02	0.06	0.61
Total Creek	8.88E-01	6.66E-03	0.00048	2.07E-01	1.41E-01	0.05	1.16E+00	1.16E+00	0.05	2.22E-01	2.04E-01	0.9	0.024	0.2	2.99E-02	0.06	0.5
Total Estuary	1.18E+00	8.83E-03	0.00048	2.36E-01	1.61E-01	0.05	1.53E+00	1.53E+00	0.05	2.53E-01	2.33E-01	0.9	0.024	0.2	3.54E-02	0.06	0.59

Table E2-5: Calculation Of Green Heron Mercury LOAEL Hazard Quotients

LCP Chemical, Brunswick, GA

				Fiddler Crabs			**Blue Crabs**			**Mummichogs**							
	Total Hg Sediment Conc. mg/kg	**MeHg Sediment Conc. mg/kg**	**Sediment Ingestion Rate kg/day**	Predicted Total Hg Conc. mg/kg dry	Predicted MeHg Conc. mg/kg	Fraction of Diet	Predicted Total Hg Conc. mg/kg dry	Predicted MeHg Conc. mg/kg	Fraction of Diet	Predicted Total Hg Conc. mg/kg dry	Predicted MeHg Conc. mg/kg	Fraction of Diet	**Food Ingestion Rate kg/day**	**Body Weight kg**	**Total Dose mg/kg /day**	**MeHg LOAEL mg/kg /day**	**LOAEL Hazard Quotient**
SMA 2																	
Dillon Duck	3.00E-01	2.25E-03	0.00048	1.24E-01	8.41E-02	0.05	3.91E-01	3.91E-01	0.05	1.33E-01	1.23E-01	0.9	0.024	0.2	1.61E-02	0.06	0.27
Domain 1	1.63E+00	1.22E-02	0.00048	2.76E-01	1.87E-01	0.05	2.12E+00	2.12E+00	0.05	2.95E-01	2.72E-01	0.9	0.024	0.2	4.33E-02	0.06	0.72
Domain 2	1.25E+00	9.39E-03	0.00048	2.43E-01	1.65E-01	0.05	1.63E+00	1.63E+00	0.05	2.61E-01	2.40E-01	0.9	0.024	0.2	3.67E-02	0.06	0.61
Domain 3	1.73E+00	1.30E-02	0.00048	2.83E-01	1.93E-01	0.05	2.25E+00	2.25E+00	0.05	3.04E-01	2.80E-01	0.9	0.024	0.2	4.49E-02	0.06	0.75
Domain 4 East	1.98E+00	1.49E-02	0.00048	3.02E-01	2.06E-01	0.05	2.58E+00	2.58E+00	0.05	3.24E-01	2.98E-01	0.9	0.024	0.2	4.89E-02	0.06	0.82
Domain 4 West	6.89E-01	5.17E-03	0.00048	1.83E-01	1.25E-01	0.05	8.98E-01	8.98E-01	0.05	1.97E-01	1.81E-01	0.9	0.024	0.2	2.57E-02	0.06	0.43
Total Domains	1.36E+00	1.02E-02	0.00048	2.53E-01	1.72E-01	0.05	1.77E+00	1.77E+00	0.05	2.71E-01	2.50E-01	0.9	0.024	0.2	3.86E-02	0.06	0.64
Domain 3 Creek	3.73E+00	2.80E-02	0.00048	4.08E-01	2.77E-01	0.05	4.86E+00	4.86E+00	0.05	4.36E-01	4.01E-01	0.9	0.024	0.2	7.42E-02	0.06	**1.2**
Eastern Creek	3.00E-01	2.25E-03	0.00048	1.24E-01	8.41E-02	0.05	3.91E-01	3.91E-01	0.05	1.33E-01	1.23E-01	0.9	0.024	0.2	1.61E-02	0.06	0.27
LCP Ditch	3.90E-01	2.92E-03	0.00048	1.40E-01	9.52E-02	0.05	5.08E-01	5.08E-01	0.05	1.51E-01	1.39E-01	0.9	0.024	0.2	1.86E-02	0.06	0.31
Purvis Creek	1.17E+00	8.79E-03	0.00048	2.36E-01	1.60E-01	0.05	1.53E+00	1.53E+00	0.05	2.53E-01	2.33E-01	0.9	0.024	0.2	3.53E-02	0.06	0.59
Western Creek Complex	2.14E+00	1.60E-02	0.00048	3.13E-01	2.13E-01	0.05	2.78E+00	2.78E+00	0.05	3.36E-01	3.09E-01	0.9	0.024	0.2	5.13E-02	0.06	0.86
Total Creek	1.52E+00	1.14E-02	0.00048	2.67E-01	1.82E-01	0.05	1.99E+00	1.99E+00	0.05	2.86E-01	2.63E-01	0.9	0.024	0.2	4.15E-02	0.06	0.69
Total Estuary	1.38E+00	1.04E-02	0.00048	2.55E-01	1.73E-01	0.05	1.80E+00	1.80E+00	0.05	2.73E-01	2.51E-01	0.9	0.024	0.2	3.90E-02	0.06	0.65
SMA 3																	
Dillon Duck	3.00E-01	2.25E-03	0.00048	1.24E-01	8.41E-02	0.05	3.91E-01	3.91E-01	0.05	1.33E-01	1.23E-01	0.9	0.024	0.2	1.61E-02	0.06	0.27
Domain 1	1.06E+00	7.93E-03	0.00048	2.24E-01	1.53E-01	0.05	1.38E+00	1.38E+00	0.05	2.41E-01	2.22E-01	0.9	0.024	0.2	3.31E-02	0.06	0.55
Domain 2	1.25E+00	9.39E-03	0.00048	2.43E-01	1.65E-01	0.05	1.63E+00	1.63E+00	0.05	2.61E-01	2.40E-01	0.9	0.024	0.2	3.67E-02	0.06	0.61
Domain 3	1.73E+00	1.30E-02	0.00048	2.83E-01	1.93E-01	0.05	2.25E+00	2.25E+00	0.05	3.04E-01	2.80E-01	0.9	0.024	0.2	4.49E-02	0.06	0.75
Domain 4 East	1.98E+00	1.49E-02	0.00048	3.02E-01	2.06E-01	0.05	2.58E+00	2.58E+00	0.05	3.24E-01	2.98E-01	0.9	0.024	0.2	4.89E-02	0.06	0.82
Domain 4 West	6.89E-01	5.17E-03	0.00048	1.83E-01	1.25E-01	0.05	8.98E-01	8.98E-01	0.05	1.97E-01	1.81E-01	0.9	0.024	0.2	2.57E-02	0.06	0.43
Total Domains	1.34E+00	1.01E-02	0.00048	2.51E-01	1.71E-01	0.05	1.75E+00	1.75E+00	0.05	2.70E-01	2.48E-01	0.9	0.024	0.2	3.83E-02	0.06	0.64
Domain 3 Creek	3.73E+00	2.80E-02	0.00048	4.08E-01	2.77E-01	0.05	4.86E+00	4.86E+00	0.05	4.36E-01	4.01E-01	0.9	0.024	0.2	7.42E-02	0.06	**1.2**
Eastern Creek	3.00E-01	2.25E-03	0.00048	1.24E-01	8.41E-02	0.05	3.91E-01	3.91E-01	0.05	1.33E-01	1.23E-01	0.9	0.024	0.2	1.61E-02	0.06	0.27
LCP Ditch	3.90E-01	2.92E-03	0.00048	1.40E-01	9.52E-02	0.05	5.08E-01	5.08E-01	0.05	1.51E-01	1.39E-01	0.9	0.024	0.2	1.86E-02	0.06	0.31
Purvis Creek	1.06E+00	7.95E-03	0.00048	2.25E-01	1.53E-01	0.05	1.38E+00	1.38E+00	0.05	2.41E-01	2.22E-01	0.9	0.024	0.2	3.32E-02	0.06	0.55
Western Creek Complex	2.14E+00	1.60E-02	0.00048	3.13E-01	2.13E-01	0.05	2.78E+00	2.78E+00	0.05	3.36E-01	3.09E-01	0.9	0.024	0.2	5.13E-02	0.06	0.86
Total Creek	1.44E+00	1.08E-02	0.00048	2.60E-01	1.77E-01	0.05	1.88E+00	1.88E+00	0.05	2.79E-01	2.57E-01	0.9	0.024	0.2	4.01E-02	0.06	0.67
Total Estuary	1.35E+00	1.02E-02	0.00048	2.52E-01	1.72E-01	0.05	1.77E+00	1.77E+00	0.05	2.71E-01	2.49E-01	0.9	0.024	0.2	3.86E-02	0.06	0.64

Conc.	Concentration.
mg/kg dry	Miligrams per kilogram dry weight.
SMA	Sediment Management Area.

Table E2-6: Summary Green Heron Mercury LOAEL Hazard Quotients

LCP Chemical, Brunswick, GA

Green Heron Mercury LOAEL Hazard Quotients	Preremedy	SMA 1	SMA 2	SMA 3
Dillon Duck	0.66	0.27	0.27	0.27
Domain 1	**1.5**	0.41	0.72	0.55
Domain 2	0.96	0.49	0.61	0.61
Domain 3	0.75	0.68	0.75	0.75
Domain 4 East	0.82	0.82	0.82	0.82
Domain 4 West	0.43	0.43	0.43	0.43
Total Domains	0.74	0.6	0.64	0.64
Domain 3 Creek	**1.7**	0.55	**1.2**	**1.2**
Eastern Creek	**3.3**	0.27	0.27	0.27
LCP Ditch	**2.1**	0.28	0.31	0.31
Purvis Creek	0.59	0.49	0.59	0.55
Western Creek Complex	0.86	0.61	0.86	0.86
Total Creek	0.97	0.5	0.69	0.67
Total Estuary	0.77	0.59	0.65	0.64
Purvis Creek, Domain 3, and Domain 3 Creek Average	**1.0**	0.6	0.8	0.8

🟥	Hazard quotients equal to or above one.
LOAEL	Lowest observable adverse effects level toxicity reference value.

Table E2-7: No Action Alternative Fish Tissue Concentrations and HQs

LCP Chemical, Brunswick, GA

Constituent Measure	**Methyl Mercury**		**Aroclor 1268**	
	mg/kg dry weight	**HQ**	**mg/kg dry weight**	**HQ**
Red Drum	1.01	0.84	1.43	0.28
Black Drum	0.76	0.63	5.51	**1.1**
Silver Perch	1.6	**1.3**	5.67	**1.1**
Spotted Seatrout	2.27	**1.9**	4.92	0.95
Striped Mullet	0.09	0.075	13.2	**2.5**
LOAEL TRV	1.2		5.2	

Fish tissue concentrations are means from Table 4-29 in the BERA.
TRVs are from LOAELs from Table 7-8 of the BERA and Table E2-4: of this appendix.

LOAEL TRV	Lowest observable adverse effects level toxicity reference value.
HQ	Hazard Quotient
mg/kg	Milligrams per kilogram.

Table E2-8: Calculation Of Finfish Tissue Concentrations And Hazard Quotients

LCP Chemical, Brunswick, GA

REMEDY EVALUATION FOR Aroclor 1268

REMEDY	Total Creeks SWAC mg/kg sediment	% Of original constituent left	Fish Tissue LOAEL TRV mg/kg dry weight	
Preremedy/No Action	6.01	100%		
SMA 1	1.56	26%	5.2	(a)
SMA 2	3.26	54%		
SMA 3	2.67	44%		

CONCENTRATION	Fish Tissue Concentrations mg/kg dry weight					
	Red Drum	Black Drum	Silver Perch	Spotted Seatrout	Striped Mullet	
Preremedy/No Action	1.43	5.51	5.67	4.92	13.2	(b)
SMA 1	0.37	1.43	1.47	1.28	3.43	
SMA 2	0.78	2.99	3.08	2.67	7.16	
SMA 3	0.64	2.45	2.52	2.19	5.86	

HQ	Fish Tissue Hazard Quotients				
	Red Drum	Black Drum	Silver Perch	Spotted Seatrout	Striped Mullet
Preremedy/No Action	0.28	**1.1**	**1.1**	0.95	**2.5**
SMA 1	0.071	0.28	0.28	0.25	0.66
SMA 2	0.15	0.58	0.59	0.51	**1.4**
SMA 3	0.12	0.47	0.48	0.42	**1.1**

REMEDY EVALUATION FOR METHYL MERCURY

REMEDY	Total Creeks SWAC mg/kg sediment	% Of original constituent left	Fish Tissue LOAEL TRV mg/kg dry weight	
Preremedy/No Action	2.59	100%		
SMA 1	0.89	34%	1.2	(a)
SMA 2	1.52	59%		
SMA 3	1.44	56%		

CONCENTRATION	Fish Tissue Concentrations mg/kg dry weight					
	Red Drum	Black Drum	Silver Perch	Spotted Seatrout	Striped Mullet	
Preremedy/No Action	1.01	0.76	1.6	2.27	0.09	(b)
SMA 1	0.35	0.26	0.55	0.78	0.03	
SMA 2	0.59	0.45	0.94	1.34	0.05	
SMA 3	0.56	0.42	0.89	1.27	0.05	

HQ	Fish Tissue Hazard Quotients				
	Red Drum	Black Drum	Silver Perch	Spotted Seatrout	Striped Mullet
Preremedy/No Action	0.84	0.63	**1.3**	**1.9**	0.075
SMA 1	0.29	0.22	0.46	0.65	0.026
SMA 2	0.5	0.37	0.79	**1.1**	0.044
SMA 3	0.47	0.35	0.74	**1.1**	0.042

Table E2-8: Calculation Of Finfish Tissue Concentrations And Hazard Quotients

LCP Chemical, Brunswick, GA

HQ	Hazard quotient.
LOAEL	Lowest observable adverse effects level toxicity reference value.
mg/kg dry	Miligrams per kilogram dry weight.
SMA	Sediment management area.
SWAC	Surface Weighted Area Concentration.
TRV	Toxicity reference value.

(a) TRVs are from LOAELs from Table 7-8 of the BERA

(b) Preremedy/ not action alternative fish tissue concentrations are means from Table 4-29 in the BERA

Table E2-9: Calculation Of Predicted Finfish Tissue Concentrations and Hazard Quotients Using Two Models

LCP Chemical, Brunswick, GA

MERCURY RISKS: YEARLY AVERAGE METHOD/PURVIS CREEK

Remedy	Species	Area	Sediment Concentration mg/kg	Predicted Hg Concentration mg/kg dw fish tissue	Predicted MeHg Concentration mg/kg dw fish tissue	Methyl Mercury LOAEL mg/kg dw fish tissue	Ratio Body/ LOAEL	LOAEL HQ
No Action	Black Drum	Purvis Creek	1.172	1.070	0.974	1.2	0.812	0.81
No Action	Red Drum	Purvis Creek	1.172	1.352	1.203	1.2	1.003	1
No Action	Silver Perch	Purvis Creek	1.172	1.856	1.856	1.2	1.547	1.5
No Action	Spotted Seatrout	Purvis Creek	1.172	2.273	2.273	1.2	1.894	1.9
No Action	Striped Mullet	Purvis Creek	1.172	0.245	0.091	1.2	0.076	0.076
SMA 1	Black Drum	Purvis Creek	0.870	0.787	0.716	1.2	0.597	0.6
SMA 1	Red Drum	Purvis Creek	0.870	1.097	0.977	1.2	0.814	0.81
SMA 1	Silver Perch	Purvis Creek	0.870	1.490	1.490	1.2	1.242	1.2
SMA 1	Spotted Seatrout	Purvis Creek	0.870	1.757	1.757	1.2	1.464	1.5
SMA 1	Striped Mullet	Purvis Creek	0.870	0.191	0.071	1.2	0.059	0.059
SMA 2	Black Drum	Purvis Creek	1.172	1.070	0.974	1.2	0.812	0.81
SMA 2	Red Drum	Purvis Creek	1.172	1.352	1.203	1.2	1.003	1
SMA 2	Silver Perch	Purvis Creek	1.172	1.856	1.856	1.2	1.547	1.5
SMA 2	Spotted Seatrout	Purvis Creek	1.172	2.273	2.273	1.2	1.894	1.9
SMA 2	Striped Mullet	Purvis Creek	1.172	0.245	0.091	1.2	0.076	0.076
SMA 3	Black Drum	Purvis Creek	1.060	0.965	0.878	1.2	0.732	0.73
SMA 3	Red Drum	Purvis Creek	1.060	1.260	1.121	1.2	0.934	0.93
SMA 3	Silver Perch	Purvis Creek	1.060	1.724	1.724	1.2	1.436	1.4
SMA 3	Spotted Seatrout	Purvis Creek	1.060	2.084	2.084	1.2	1.737	1.7
SMA 3	Striped Mullet	Purvis Creek	1.060	0.225	0.083	1.2	0.069	0.069

Table E2-9: Calculation Of Predicted Finfish Tissue Concentrations and Hazard Quotients Using Two Models

LCP Chemical, Brunswick, GA

MERCURY RISKS: AREA WEIGHTED METHOD/TOTAL CREEKS

Remedy	Species	Area	Sediment Concentration mg/kg	Predicted Hg Concentration mg/kg dw fish tissue	Predicted MeHg Concentration mg/kg dw fish tissue	Methyl Mercury LOAEL mg/kg dw fish tissue	Ratio Body/ LOAEL	LOAEL HQ
No Action	Black Drum	Total Creeks	2.589	0.795	0.723	1.2	0.603	0.6
No Action	Red Drum	Total Creeks	2.589	1.077	0.958	1.2	0.799	0.8
No Action	Silver Perch	Total Creeks	2.589	1.512	1.512	1.2	1.260	1.3
No Action	Spotted Seatrout	Total Creeks	2.589	2.146	2.146	1.2	1.788	1.8
No Action	Striped Mullet	Total Creeks	2.589	0.217	0.080	1.2	0.067	0.067
SMA 1	Black Drum	Total Creeks	0.888	0.273	0.248	1.2	0.207	0.21
SMA 1	Red Drum	Total Creeks	0.888	0.370	0.329	1.2	0.274	0.27
SMA 1	Silver Perch	Total Creeks	0.888	0.519	0.519	1.2	0.432	0.43
SMA 1	Spotted Seatrout	Total Creeks	0.888	0.737	0.737	1.2	0.614	0.61
SMA 1	Striped Mullet	Total Creeks	0.888	0.075	0.028	1.2	0.023	0.023
SMA 2	Black Drum	Total Creeks	1.525	0.468	0.426	1.2	0.355	0.35
SMA 2	Red Drum	Total Creeks	1.525	0.634	0.564	1.2	0.470	0.47
SMA 2	Silver Perch	Total Creeks	1.525	0.890	0.890	1.2	0.742	0.74
SMA 2	Spotted Seatrout	Total Creeks	1.525	1.264	1.264	1.2	1.053	1.1
SMA 2	Striped Mullet	Total Creeks	1.525	0.128	0.047	1.2	0.039	0.039
SMA 3	Black Drum	Total Creeks	1.444	0.443	0.404	1.2	0.336	0.34
SMA 3	Red Drum	Total Creeks	1.444	0.601	0.535	1.2	0.446	0.45
SMA 3	Silver Perch	Total Creeks	1.444	0.844	0.844	1.2	0.703	0.7
SMA 3	Spotted Seatrout	Total Creeks	1.444	1.197	1.197	1.2	0.998	1
SMA 3	Striped Mullet	Total Creeks	1.444	0.121	0.045	1.2	0.037	0.037

Table E2-9: Calculation Of Predicted Finfish Tissue Concentrations and Hazard Quotients Using Two Models

LCP Chemical, Brunswick, GA

Aroclor 1268 RISKS: YEARLY AVERAGE METHOD/PURVIS CREEK

Remedy	Species	Area	Sediment Concentration mg/kg	Predicted Aroclor 1268 Concentration mg/kg dw fish tissue	Aroclor 1268 LOAEL mg/kg dw fish tissue	Ratio Body/ LOAEL	LOAEL HQ
No Action	Black Drum	Purvis Creek	3.552	8.577	5.2	1.649	1.6
No Action	Red Drum	Purvis Creek	3.552	1.835	5.2	0.353	0.35
No Action	Silver Perch	Purvis Creek	3.552	7.525	5.2	1.447	1.4
No Action	Spotted Seatrout	Purvis Creek	3.552	6.623	5.2	1.274	1.3
No Action	Striped Mullet	Purvis Creek	3.552	15.035	5.2	2.891	2.9
SMA 1	Black Drum	Purvis Creek	1.740	4.327	5.2	0.832	0.83
SMA 1	Red Drum	Purvis Creek	1.740	1.129	5.2	0.217	0.22
SMA 1	Silver Perch	Purvis Creek	1.740	4.006	5.2	0.770	0.77
SMA 1	Spotted Seatrout	Purvis Creek	1.740	3.485	5.2	0.670	0.67
SMA 1	Striped Mullet	Purvis Creek	1.740	7.128	5.2	1.371	1.4
SMA 2	Black Drum	Purvis Creek	3.552	8.577	5.2	1.649	1.6
SMA 2	Red Drum	Purvis Creek	3.552	1.835	5.2	0.353	0.35
SMA 2	Silver Perch	Purvis Creek	3.552	7.525	5.2	1.447	1.4
SMA 2	Spotted Seatrout	Purvis Creek	3.552	6.623	5.2	1.274	1.3
SMA 2	Striped Mullet	Purvis Creek	3.552	15.035	5.2	2.891	2.9
SMA 3	Black Drum	Purvis Creek	2.725	6.653	5.2	1.279	1.3
SMA 3	Red Drum	Purvis Creek	2.725	1.533	5.2	0.295	0.29
SMA 3	Silver Perch	Purvis Creek	2.725	5.954	5.2	1.145	1.1
SMA 3	Spotted Seatrout	Purvis Creek	2.725	5.218	5.2	1.004	1
SMA 3	Striped Mullet	Purvis Creek	2.725	11.396	5.2	2.192	2.2

Table E2-9: Calculation Of Predicted Finfish Tissue Concentrations and Hazard Quotients Using Two Models

LCP Chemical, Brunswick, GA

Aroclor 1268 RISKS: AREA WEIGHTED METHOD/TOTAL CREEKS

Remedy	Species	Area	Sediment Concentration mg/kg	Predicted Aroclor 1268 Concentration mg/kg dw fish tissue	Aroclor 1268 LOAEL mg/kg dw fish tissue	Ratio Body/ LOAEL	LOAEL HQ
No Action	Black Drum	Total Creeks	6.008	4.452	5.2	0.856	0.86
No Action	Red Drum	Total Creeks	6.008	1.154	5.2	0.222	0.22
No Action	Silver Perch	Total Creeks	6.008	4.578	5.2	0.880	0.88
No Action	Spotted Seatrout	Total Creeks	6.008	3.971	5.2	0.764	0.76
No Action	Striped Mullet	Total Creeks	6.008	10.665	5.2	2.051	2.1
SMA 1	Black Drum	Total Creeks	1.559	1.156	5.2	0.222	0.22
SMA 1	Red Drum	Total Creeks	1.559	0.299	5.2	0.058	0.058
SMA 1	Silver Perch	Total Creeks	1.559	1.188	5.2	0.229	0.23
SMA 1	Spotted Seatrout	Total Creeks	1.559	1.031	5.2	0.198	0.2
SMA 1	Striped Mullet	Total Creeks	1.559	2.768	5.2	0.532	0.53
SMA 2	Black Drum	Total Creeks	3.261	2.417	5.2	0.465	0.46
SMA 2	Red Drum	Total Creeks	3.261	0.626	5.2	0.120	0.12
SMA 2	Silver Perch	Total Creeks	3.261	2.485	5.2	0.478	0.48
SMA 2	Spotted Seatrout	Total Creeks	3.261	2.156	5.2	0.415	0.41
SMA 2	Striped Mullet	Total Creeks	3.261	5.789	5.2	1.113	1.1
SMA 3	Black Drum	Total Creeks	2.669	1.978	5.2	0.380	0.38
SMA 3	Red Drum	Total Creeks	2.669	0.513	5.2	0.099	0.099
SMA 3	Silver Perch	Total Creeks	2.669	2.034	5.2	0.391	0.39
SMA 3	Spotted Seatrout	Total Creeks	2.669	1.764	5.2	0.339	0.34
SMA 3	Striped Mullet	Total Creeks	2.669	4.738	5.2	0.911	0.91

HQ	Hazard quotient.
LOAEL	Lowest observed apparent effects level.
mg/kg dw	Miligrams per kilogram dry weight.
SMA	Sediment management area.

Table E2-10: Summary Of Predicted Finfish Tissue Concentrations and Hazard Quotients

LCP Chemical, Brunswick, GA

METHYL MERCURY CONCENTRATION (mg/kg dw)		Area	Black Drum	Red Drum	Silver Perch	Spotted Seatrout	Striped Mullet
Measured Fish Tissue Concentration (a)	95UCL	Meas	0.87	1.25	1.85	2.65	0.1
	Mean	Meas	0.76	1.01	1.6	2.27	0.09
Modeled No Action Alternative Concentrations	YA BAF	Purvis Creek	0.974	1.203	1.856	2.273	0.091
	AW BAF	Total Creeks	0.723	0.958	1.512	2.146	0.080
SMA 1 (c)	YA BAF	Purvis Creek	0.716	0.977	1.490	1.757	0.071
	AW BAF	Total Creeks	0.248	0.329	0.519	0.737	0.028
SMA 2 (c)	YA BAF	Purvis Creek	0.974	1.203	1.856	2.273	0.091
	AW BAF	Total Creeks	0.426	0.564	0.890	1.264	0.047
SMA 3 (c)	YA BAF	Purvis Creek	0.878	1.121	1.724	2.084	0.083
	AW BAF	Total Creeks	0.404	0.535	0.844	1.197	0.045

METHYL MERCURY HAZARD QUOTIENT		Area	Black Drum	Red Drum	Silver Perch	Spotted Seatrout	Striped Mullet
Measured Fish Tissue Concentration (a)	95UCL	Meas	0.73	1	1.5	2.2	0.083
	Mean	Meas	0.63	0.84	1.3	1.9	0.075
Modeled No Action Alternative Concentrations	YA BAF	Purvis Creek	0.81	1	1.5	1.9	0.076
	AW BAF	Total Creeks	0.6	0.8	1.3	1.8	0.067
SMA 1 (c)	YA BAF	Purvis Creek	0.6	0.81	1.2	1.5	0.059
	AW BAF	Total Creeks	0.21	0.27	0.43	0.61	0.023
SMA 2 (c)	YA BAF	Purvis Creek	0.81	1	1.5	1.9	0.076
	AW BAF	Total Creeks	0.35	0.47	0.74	1.1	0.039
SMA 3 (c)	YA BAF	Purvis Creek	0.73	0.93	1.4	1.7	0.069
	AW BAF	Total Creeks	0.34	0.45	0.7	1	0.037

Aroclor 1268 CONCENTRATION (mg/kg dw)		Area	Black Drum	Red Drum	Silver Perch	Spotted Seatrout	Striped Mullet
Measured Fish Tissue Concentration (a)	95UCL	Meas	6.45	1.87	7.05	5.91	21
	Mean	Meas	5.51	1.43	5.67	4.92	13
Modeled No Action Alternative Concentrations	YA BAF	Purvis Creek	8.577	1.835	7.525	6.623	15.035
	AW BAF	Total Creeks	4.452	1.154	4.578	3.971	10.665
SMA 1 (c)	YA BAF	Purvis Creek	4.327	1.129	4.006	3.485	7.128
	AW BAF	Total Creeks	1.156	0.299	1.188	1.031	2.768
SMA 2 (c)	YA BAF	Purvis Creek	8.577	1.835	7.525	6.623	15.035
	AW BAF	Total Creeks	2.417	0.626	2.485	2.156	5.789
SMA 3 (c)	YA BAF	Purvis Creek	6.653	1.533	5.954	5.218	11.396
	AW BAF	Total Creeks	1.978	0.513	2.034	1.764	4.738

Aroclor 1268 HAZARD QUOTIENT		Area	Black Drum	Red Drum	Silver Perch	Spotted Seatrout	Striped Mullet
Measured Fish Tissue Hazard Quotient (a)	95UCL	Meas	1.2	0.36	1.4	1.1	4
	Mean	Meas	1.1	0.28	1.1	0.95	2.5
Modeled No Action Alternative Hazard	YA BAF	Purvis Creek	1.6	0.35	1.4	1.3	2.9
	AW BAF	Total Creeks	0.86	0.22	0.88	0.76	2.1
SMA 1 (c)	YA BAF	Purvis Creek	0.83	0.22	0.77	0.67	1.4
	AW BAF	Total Creeks	0.22	0.058	0.23	0.2	0.53
SMA 2 (c)	YA BAF	Purvis Creek	1.6	0.35	1.4	1.3	2.9
	AW BAF	Total Creeks	0.46	0.12	0.48	0.41	1.1
SMA 3 (c)	YA BAF	Purvis Creek	1.3	0.29	1.1	1	2.2
	AW BAF	Total Creeks	0.38	0.099	0.39	0.34	0.91

Table E2-10: Summary Of Predicted Finfish Tissue Concentrations and Hazard Quotients
LCP Chemical, Brunswick, GA

95UCL	95% upper confidence limit on the mean.
AW BAF	Area weighted bioaccumulation factor from the baseline ecological risk assessment.
HQ	Hazard quotient
mg/kg dw	Miligrams per kilogram dry weight.
SMA	Sediment management area.
YA BAF	Yearly average bioaccumulation factor from the baseline ecological risk assessment.

(a) Measured fish tissue concentrations and HQs are from Table 4-29 in the BERA (USEPA, 2011).

(b) The modeled No Action alternative HQs and concentrations are calculated using the two models from the BERA (the Yearly Average BAF and the Area Weighted BAF).

(c) The modeled remedy HQs and concentrations are calculated using the two models from the BERA (the Yearly Average BAF and the Area Weighted BAF).

Table E2-11: Analysis of Model Over/Underprediction

LCP Chemical, Brunswick, GA

Model	Constituent	Comparison	Black Drum	Red Drum	Silver Perch	Spotted Seatrout	Striped Mullet	Average Ratio	Different?
Area Weighted BAF	Mercury	95% UCL	0.831	0.767	0.817	0.810	0.805	0.81	Underpredict
Area Weighted BAF	Mercury	Mean	0.952	0.949	0.945	0.945	0.894	0.94	Similar
Area Weighted BAF	Aroclor 1268	95% UCL	0.690	0.617	0.649	0.672	0.508	0.63	Underpredict
Area Weighted BAF	Aroclor 1268	Mean	0.808	0.807	0.807	0.807	0.820	0.81	Underpredict
Yearly Average BAF	Mercury	95% UCL	1.119	0.962	1.003	0.858	0.907	0.97	Similar
Yearly Average BAF	Mercury	Mean	1.281	1.191	1.160	1.001	1.008	1.13	Slight overpredict
Yearly Average BAF	Aroclor 1268	95% UCL	1.330	0.981	1.067	1.121	0.716	1.04	Similar
Yearly Average BAF	Aroclor 1268	Mean	1.557	1.283	1.327	1.346	1.157	1.33	Overpredict

BAF	Bioaccumulation factor.
Similar	Within 10% of the measured concentration
Slight	Within 20% of the measured concentration
UCL	Upper confidence limit.

Table E2-12: Estimated SWACs for the Different Remedy Alternatives

LCP Chemical, Brunswick, GA

Mercury

Domain	Domain Area (acres)	Before SWAC (mg/kg)	SMA 1 (Bkgd) After SWAC (mg/kg)	SMA 1 (Bkgd & 10% TLC) After SWAC (mg/kg)	SMA 2 (Bkgd) After SWAC (mg/kg)	SMA 2 (Bkgd & 10% TLC) After SWAC (mg/kg)	SMA 3 (Bkgd) After SWAC (mg/kg)	SMA 3 (Bkgd & 10% TLC) After SWAC (mg/kg)
Dillon Duck	1.8	1.43	0.30	0.30	0.30	0.30	0.30	0.30
Domain 1	21.0	5.11	0.63	0.97	1.63	1.93	1.06	1.38
Domain 2	114.6	2.55	0.86	1.00	1.25	1.37	1.25	1.37
Domain 3	107.7	1.73	1.48	1.49	1.73	1.73	1.73	1.73
Domain 4 East	191.9	1.98	1.98	1.98	1.98	1.98	1.98	1.98
Domain 4 West	224.5	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Landfill	NA	NA	NA	NA	NA	NA	NA	NA
Total Domains	661.5	1.70	1.22	1.26	1.36	1.39	1.34	1.37
Domain 3 Creek	12.4	5.94	1.05	1.05	3.73	3.73	3.73	3.73
Eastern Creek	4.2	14.58	0.30	0.30	0.30	0.30	0.30	0.30
LCP Ditch	2.5	7.67	0.32	0.32	0.39	0.39	0.39	0.39
Purvis Creek	70.5	1.17	0.87	0.87	1.17	1.17	1.06	1.06
Western Creek Complex	9.0	2.14	1.24	1.24	2.14	2.14	2.14	2.14
Total Creek	98.5	2.59	0.89	0.89	1.52	1.52	1.44	1.44
Total Estuary	760.0	1.81	1.18	1.21	1.38	1.41	1.35	1.38

Table E2-12: Estimated SWACs for the Different Remedy Alternatives

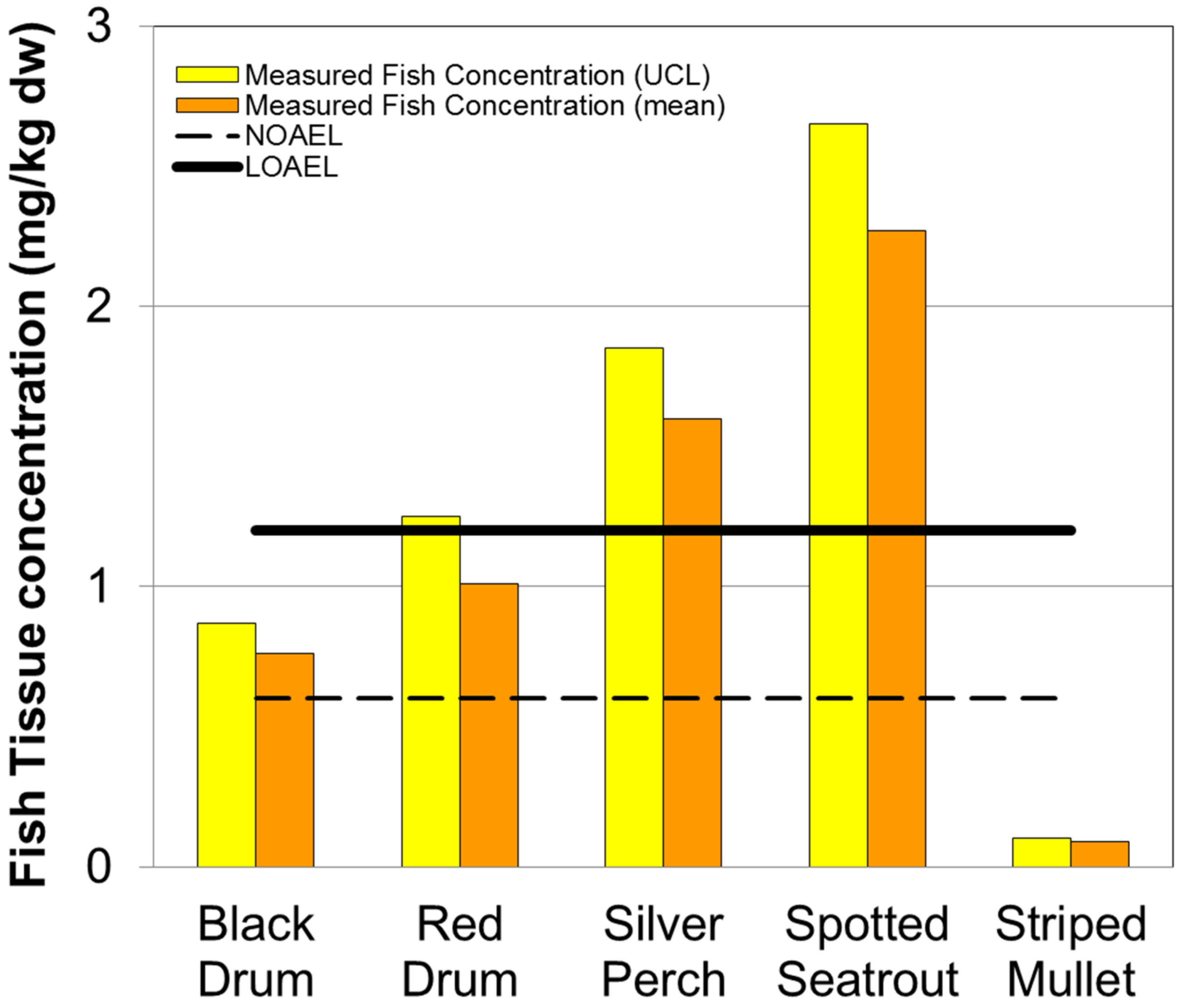
LCP Chemical, Brunswick, GA

Mercury			**SMA 1 (Bkgd)**	**SMA 1 (Bkgd & 10% TLC)**	**SMA 2 (Bkgd)**	**SMA 2 (Bkgd & 10% TLC)**	**SMA 3 (Bkgd)**	**SMA 3 (Bkgd & 10% TLC)**
Aroclor 1268			**SMA 1 (Bkgd)**	**SMA 1 (Bkgd & 10% TLC)**	**SMA 2 (Bkgd)**	**SMA 2 (Bkgd & 10% TLC)**	**SMA 3 (Bkgd)**	**SMA 3 (Bkgd & 10% TLC)**
Domain	**Domain Area (acres)**	**Before SWAC (mg/kg)**	**After SWAC (mg/kg)**	**After SWAC (mg/kg)**	**After SWAC (mg/kg)**	**After SWAC (mg/kg)**	**After SWAC (mg/kg)**	**After SWAC (mg/kg)**
Dillon Duck	1.8	2.12	0.20	0.20	0.20	0.20	0.20	0.20
Domain 1	21.0	3.15	0.65	0.83	1.16	1.32	0.89	1.06
Domain 2	114.6	1.89	1.36	1.39	1.52	1.54	1.52	1.54
Domain 3	107.7	1.72	1.54	1.55	1.72	1.72	1.72	1.72
Domain 4 East	191.9	2.12	2.12	2.12	2.12	2.12	2.12	2.12
Domain 4 West	224.5	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Landfill	NA	NA	NA	NA	NA	NA	NA	NA
Total Domains	661.5	1.59	1.38	1.39	1.45	1.46	1.45	1.45
Domain 3 Creek	12.4	5.72	1.15	1.15	3.42	3.42	3.42	3.42
Eastern Creek	4.2	43.46	0.20	0.20	0.20	0.20	0.20	0.20
LCP Ditch	2.5	25.36	0.24	0.24	0.33	0.33	0.33	0.33
Purvis Creek	70.5	3.55	1.74	1.74	3.55	3.55	2.73	2.73
Western Creek Complex	9.0	2.98	1.70	1.70	2.98	2.98	2.98	2.98
Total Creeks	98.5	6.01	1.56	1.56	3.26	3.26	2.67	2.67
Total Estuary	760.0	2.16	1.40	1.41	1.69	1.70	1.60	1.61

Bkgd	Background
mg/kg	Miligrams per kilogram.
SMA	Sediment management area.
SWAC	Suface weighted area concentration.
TLC	Thin-layer cap.

Figures

DRAFT



Fish tissue concentrations are in mg/kg dry weight

UCL	The 95% upper confidence level on the mean.
NOAEL	No observable adverse effects level toxicity reference value.
LOAEL	Lowest observable adverse effects level toxicity reference value.

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No Action Alternative Mercury Fish Tissue Concentrations

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-1A

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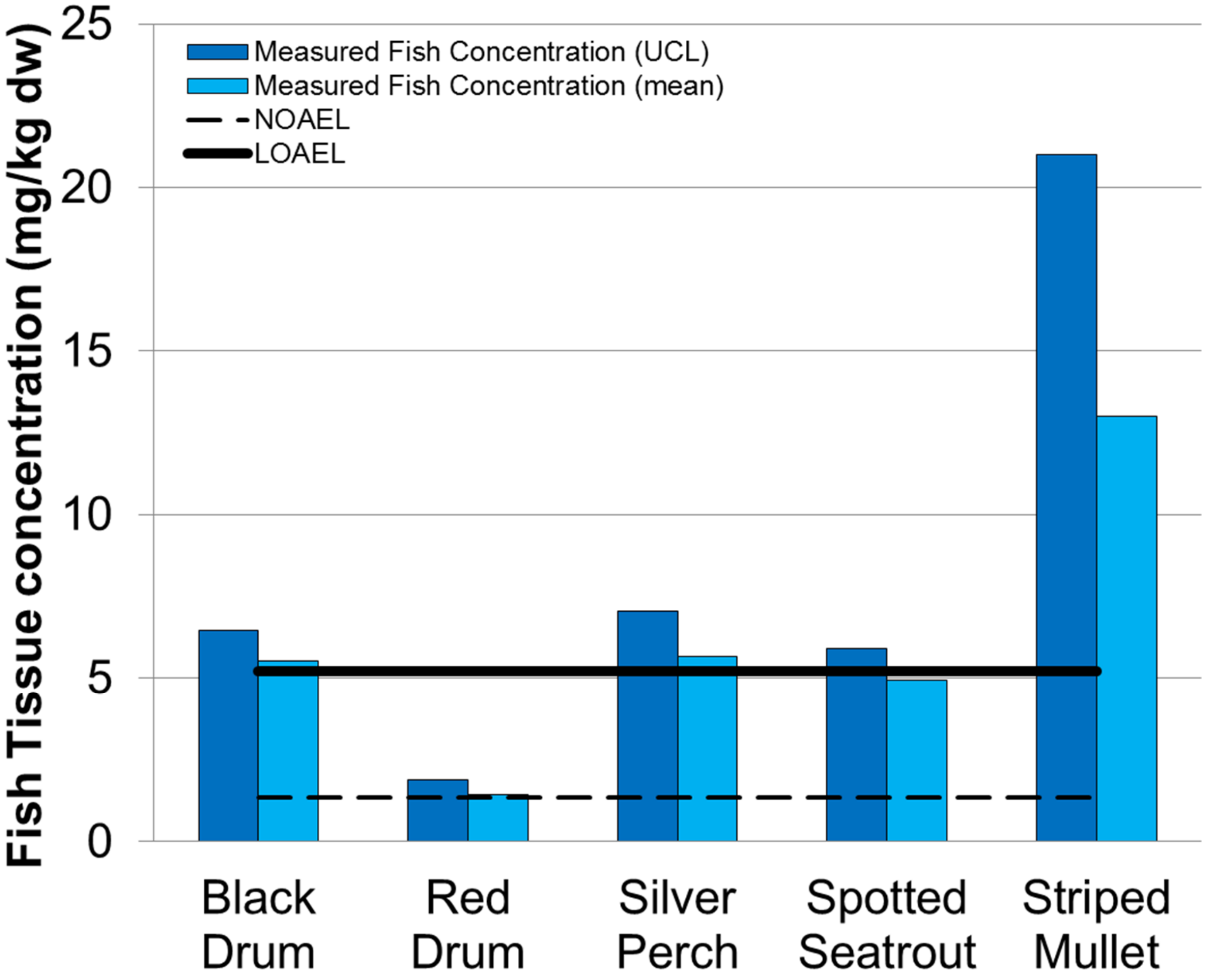

UCL	The 95% upper confidence level on the mean.
NOAEL	No observable adverse effects level toxicity reference value.
LOAEL	Lowest observable adverse effects level toxicity reference value.

Fish tissue concentrations are in mg/kg dry weight

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No Action Alternative Aroclor 1268 Fish Tissue Concentrations

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-1B

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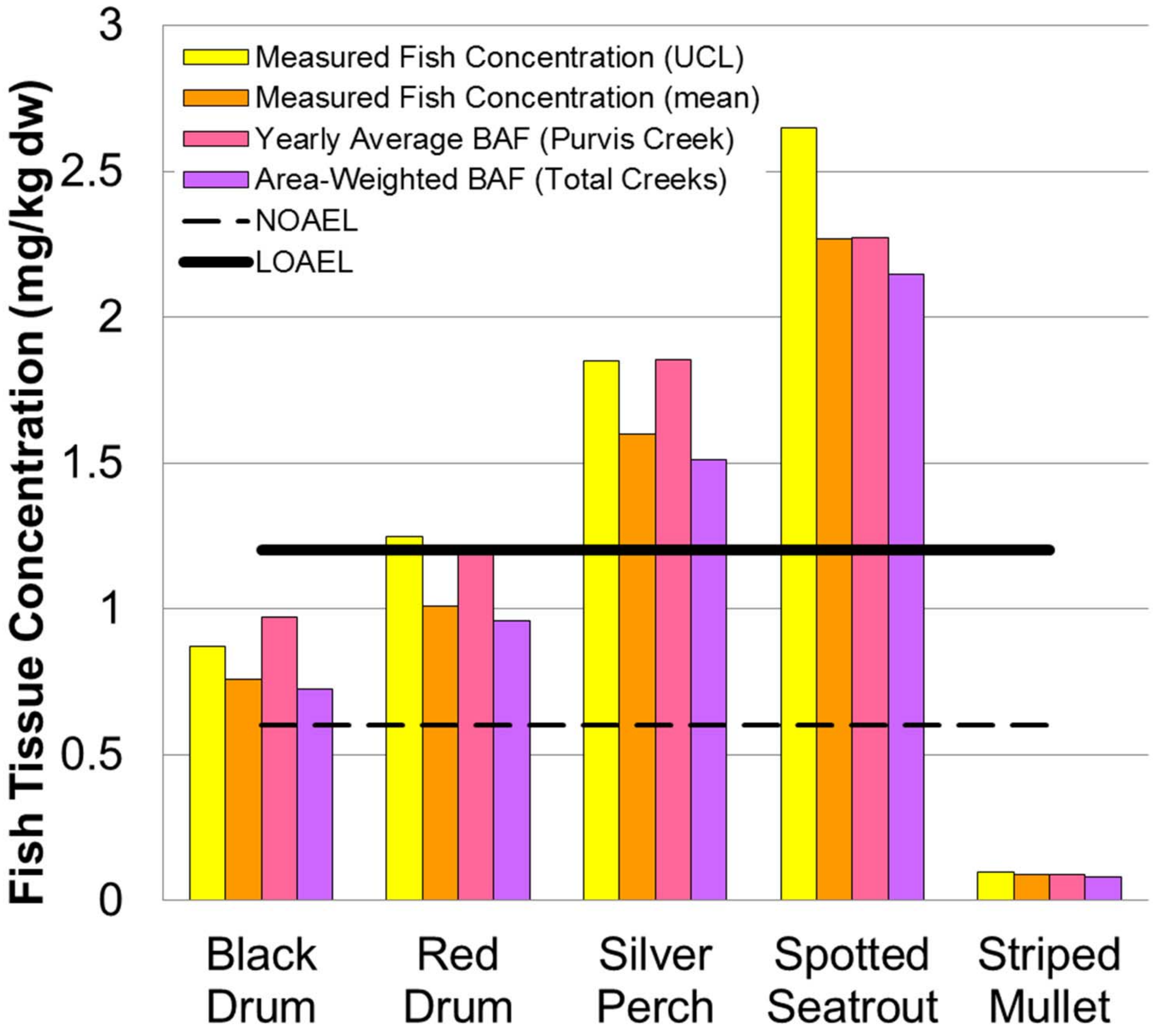

Fish tissue concentrations are in mg/kg dry weight

- The Yearly Average BAF and Area-Weighted BAF methods are described in the BERA.
- The Yearly Average BAF model is based on the Purvis Creek SWAC. The Area-Weighted BAF model is based on the Total Creeks SWAC sediment concentrations.

HQ	Hazard Quotient.
UCL	95% UCL on the mean.
BERA	Baseline ecological risk assessment.
BAF	Bioaccumulation factor.
mg/kg dw	Milligrams per kilogram dry weight.
NOAEL	No observable adverse effects level toxicity reference value.
LOAEL	Lowest observable adverse effects level toxicity reference value.

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Measured vs. Estimated Methyl Mercury Concentration in Finfish

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-2A

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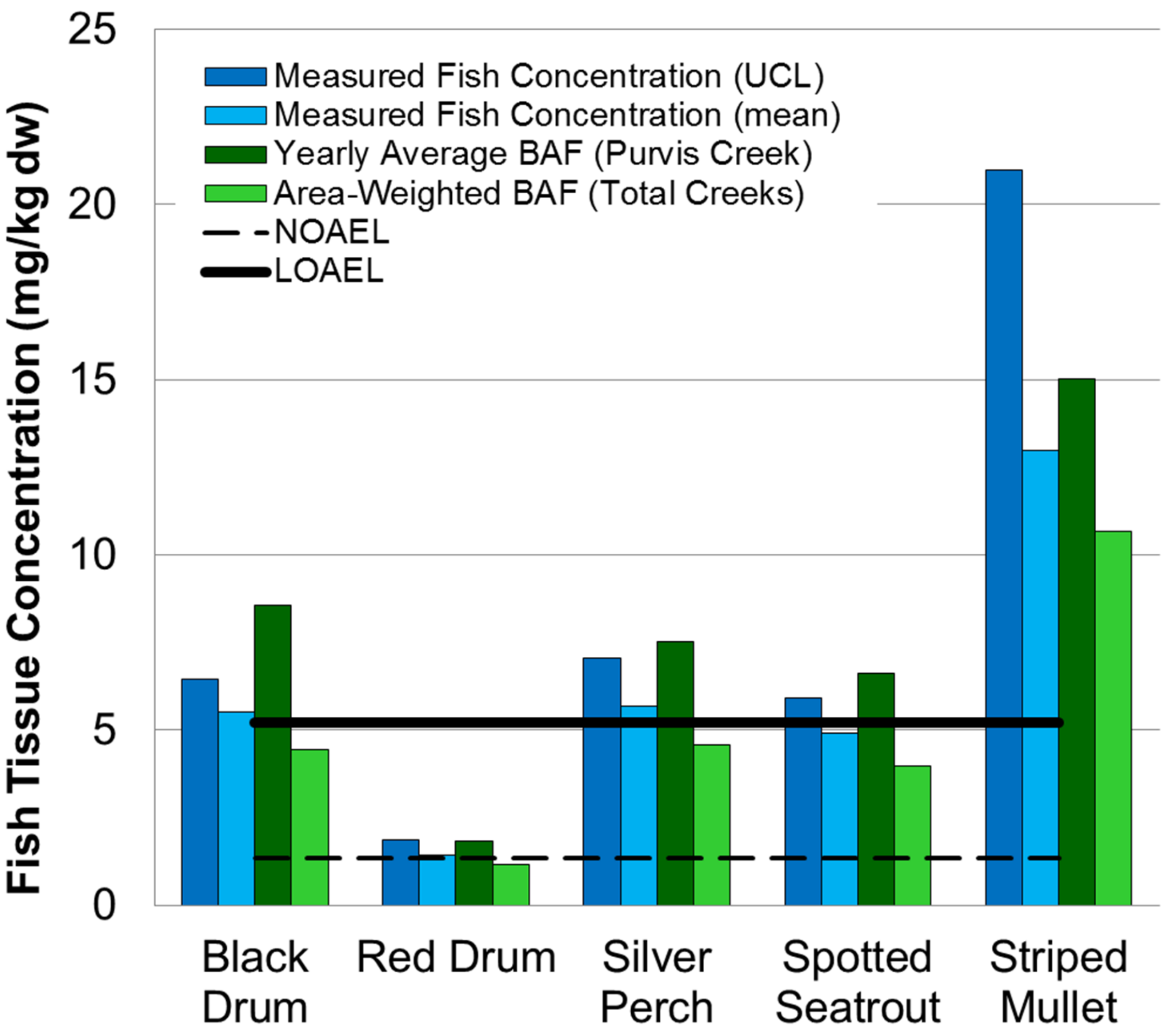

Fish tissue concentrations are in mg/kg dry weight

- The Yearly Average BAF and Area-Weighted BAF methods are described in the BERA.
- The Yearly Average BAF model is based on the Purvis Creek SWAC. The Area-Weighted BAF model is based on the Total Creeks SWAC sediment concentrations.

HQ	Hazard Quotient.
UCL	95% UCL on the mean.
BERA	Baseline ecological risk assessment.
BAF	Bioaccumulation factor.
mg/kg dw	Milligrams per kilogram dry weight.
NOAEL	No observable adverse effects level toxicity reference value.
LOAEL	Lowest observable adverse effects level toxicity reference value.

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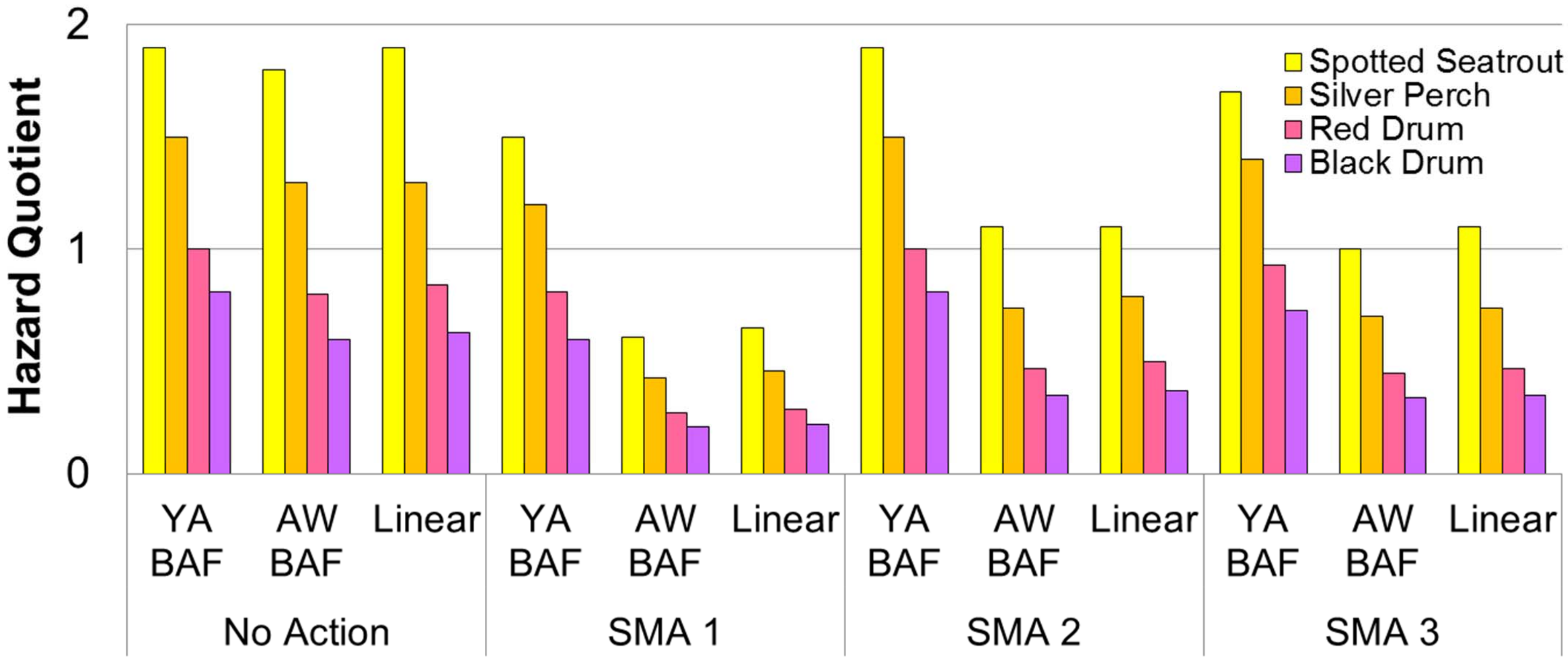
Measured vs. Estimated Aroclor 1268 Concentration in Finfish

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-2B

DRAFT



- This is a comparison of the hazard quotients in the four remedial options using three different models. This shows the potential range of predicted risks in the remedial alternatives.
- Striped mullet is not shown. LOAEL risks for this receptor are below 1 (see no-action values on Figure E2-2A).

- The YA BAF (Yearly Average) model is based on the Purvis Creek SWACs.
- The AW BAF (Area Weighted) model is based on the Total Creeks SWACs.

SMA 1	Remedy Alternatives 2 and 3
SMA 2	Remedy Alternatives 4 and 5
SMA 3	Remedy Alternative 6

AW	Area Weighted.
BAF	Bioaccumulation factor.
HQ	Hazard Quotient.
LOAEL	Lowest Observable Adverse Effects Value toxicity reference value.
PC	Based on the Purvis Creek SWAC.
SWAC	Surface Weighted Area Concentration.
SMA	Sediment Management Area.
TC	Based on the Total Creek SWAC.
YA	Yearly Average.

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Methyl Mercury Hazard Quotients in Finfish Using Three Models

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-3A

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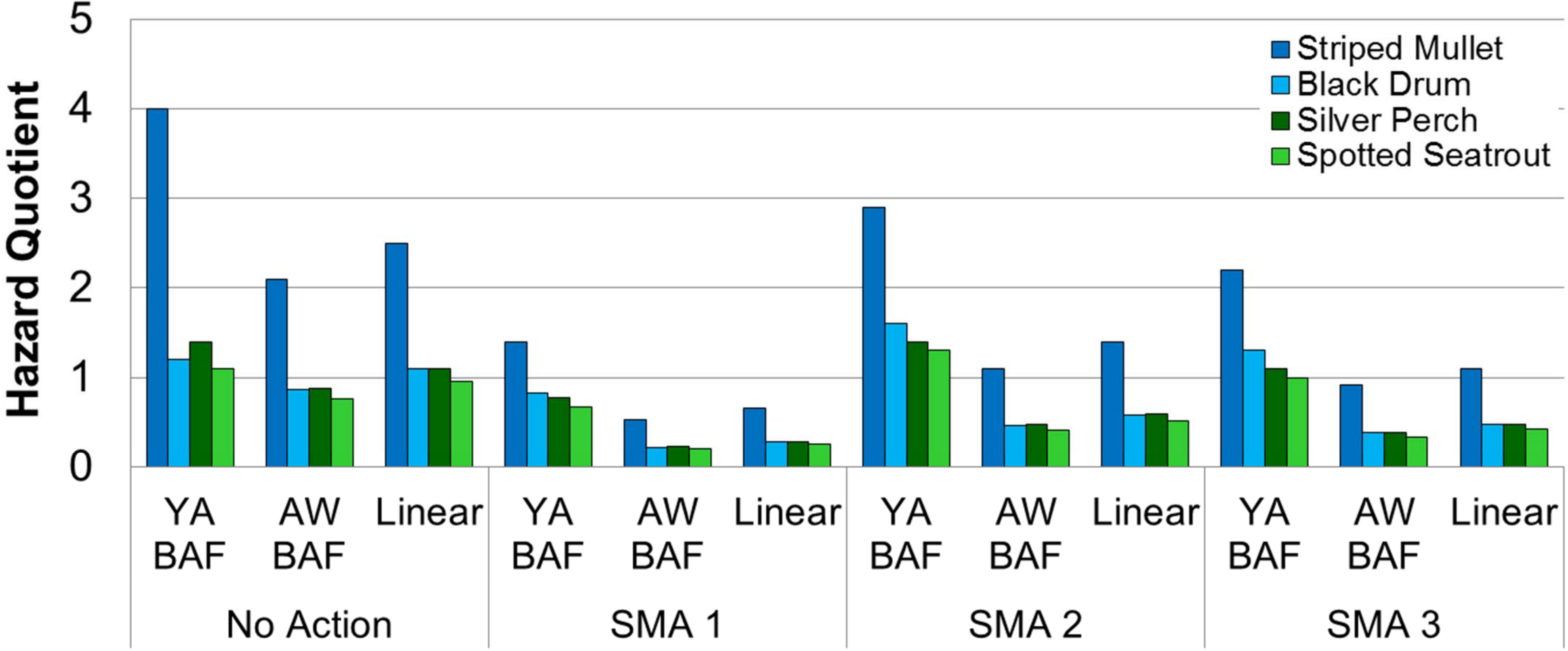

- This is a comparison of the hazard quotients in the four remedial options using three different models. This shows the potential range of predicted risks in the remedial alternatives.

- The YA BAF (Yearly Average) model is based on the Purvis Creek SWACs.
- The AW BAF (Area Weighted) model is based on the Total Creeks SWACs.

SMA 1	Remedy Alternatives 2 and 3
SMA 2	Remedy Alternatives 4 and 5
SMA 3	Remedy Alternative 6

AW	Area Weighted Site.
BAF	Bioaccumulation factor.
HQ	Hazard Quotient.
LOAEL	Lowest Observable Adverse Effects Value toxicity reference value.
PC	Based on the Purvis Creek SWAC.
SWAC	Surface Weighted Area Concentration.
SMA	Sediment Management Area.
TC	Based on the Total Creek SWAC.
YA	Yearly Average.

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Aroclor 1268 Hazard Quotients in Finfish Using Three Models

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-3B

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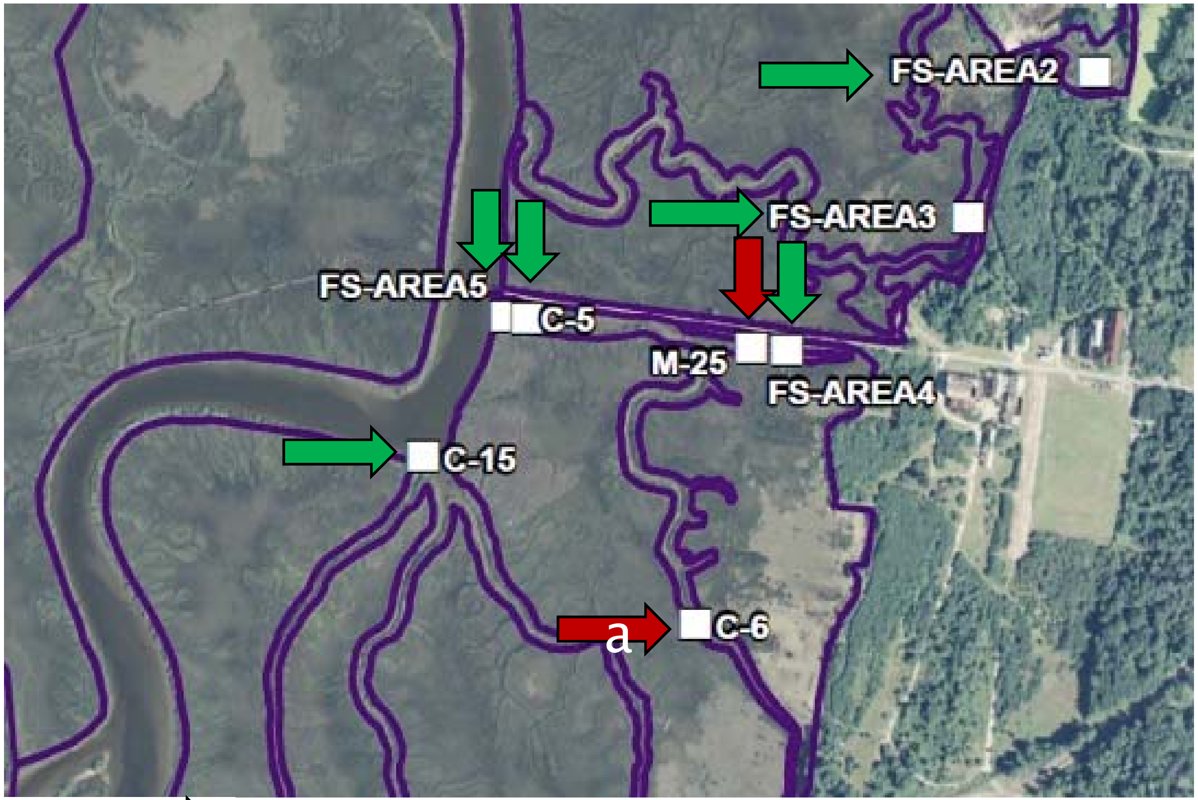
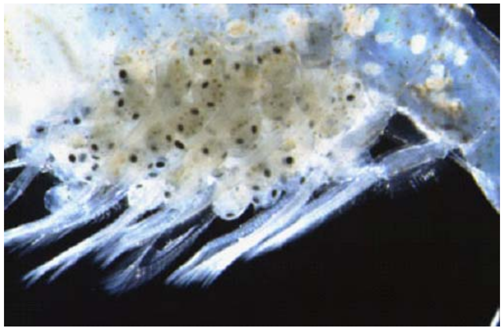


🟩 No significant difference from reference

🟥 Significant difference from reference

- Grass shrimp toxicity improved after the 1998-1998 removal action in Domain 1.
- Monitoring between 2000 and 2007 focused on endpoints of embryo hatching and DNA damage, which were not the most sensitive endpoints identified in the BERA, but do inform some understanding of improvements over time and areas of toxicity.
- Only 2 locations reported with results less than references and these areas are captured in all of the Remedy Alternatives 2 through 6.
- (a) observed less than reference on only 1 event.

- Figures to the right show female shrimp carrying developing embryos. Grass shrimp preferentially forage among the grasses and carry the embryos while doing so. This limits the direct exposure to sediment by the embryo life stage.



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Indigenous Grass Shrimp Monitoring Locations (2000 – 2007)

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-4A

DRAFT

Wall, et al. 2001.
Arch. Environ. Contam. Toxicol. 40 : 10-17.

Measurement Endpoints for Grass Shrimp in LCP Estuary and Reference Location (Wall *et al.*, 2001)

Grass Shrimp Measurement	***LCP Estuary***	***Reference (CR) Location***	***Statistical Significance (P Value)***
	Sediment concentration (mg/kg, dw; mean and standard deviation) -- Hg:18.4 ± 21.9 sd ; PCBs: 46.0 ± 52.7	Sediment concentration (mg/kg, dw; mean and standard deviation) -- (Hg:0.49 ± 0.08; PCBs: 0.32 ± 0.07)	
Length (mm)	35.2	32.7	0.0003
Female mass (g)	0.087	0.065	0.0001
Brood size (# eggs)	302.7	289.0	>0.05
Brood mass (mg)	16.3	16.3	>0.05
Individual egg mass (mg)	0.054	0.056	>0.05
Mean egg area (mm^2)	0.37	0.34	>0.05

Note: Four of the differences between the two areas are not statistically significant and both of the remaining differences (length of shrimp and female mass) appear to be advantageous to shrimp from the LCP Site

- Wall et al. (2001) performed an indigenous grass shrimp study , evaluated a variety of metrics as identified in the table above.
- All of the metrics were similar to slightly better than in the LCP Site estuary than the reference location.

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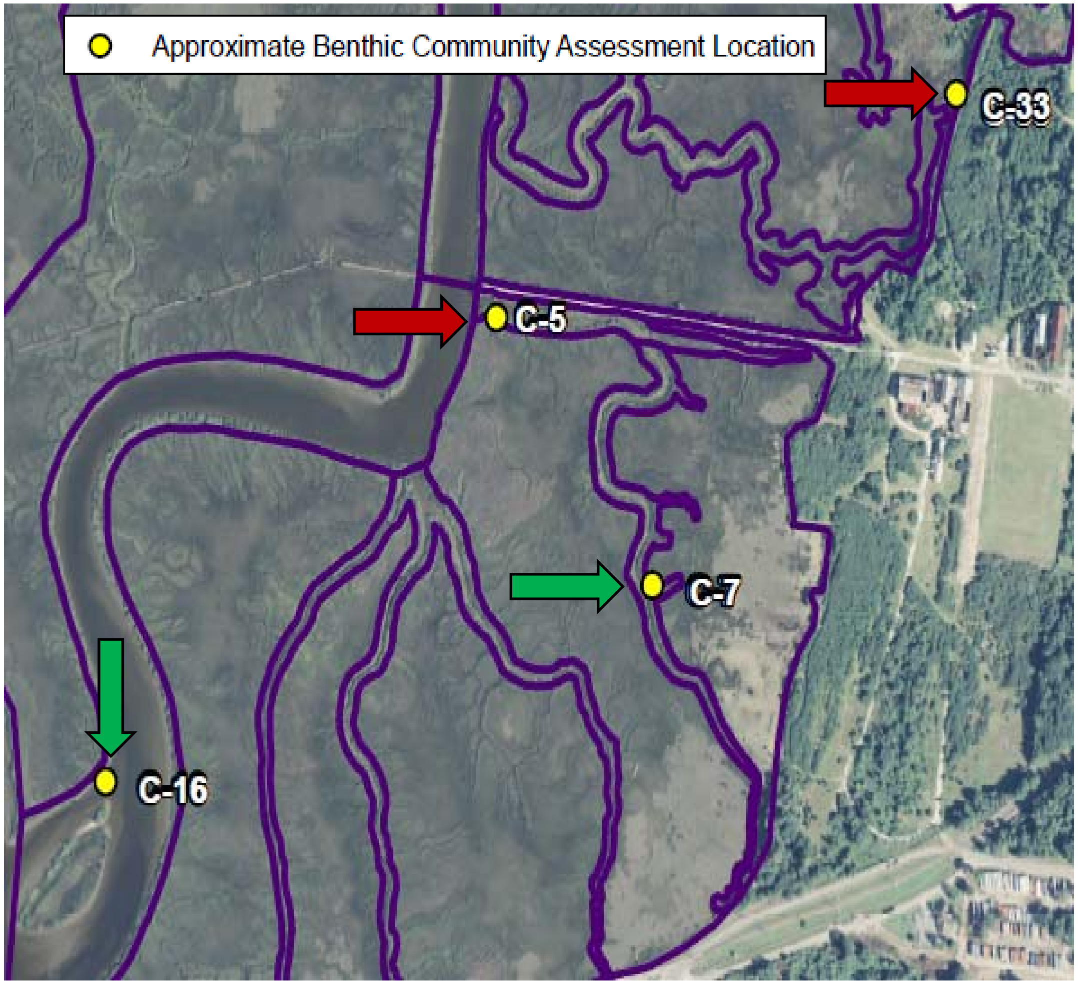
Indigenous Grass Shrimp
(Wall et al. 2001)

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-4B

- This benthic community assessment (2000) was described in the BERA but this figure is new.
- Two locations (C5 and C33) reported with lower diversity than reference. Even these two area showed five to nine species were present in areas that have been shown in the FS to be above RGOs.
- Both areas included in proposed alternatives. C7 in Eastern Creek performed better than the reference area and this area too is slated for removal in each of the Remedy Alternatives described in the FS.
- This information is provided to show that the exceedance of an RGO does not mean definitively that the sediment dwelling community is impaired. This insight can be used to inform the balance of remedies with significant short-term impacts against those with less significant short-term impacts.



🟩 No significant difference from reference

🟥 Significant difference from reference

Benthic Community Assessment (2000)

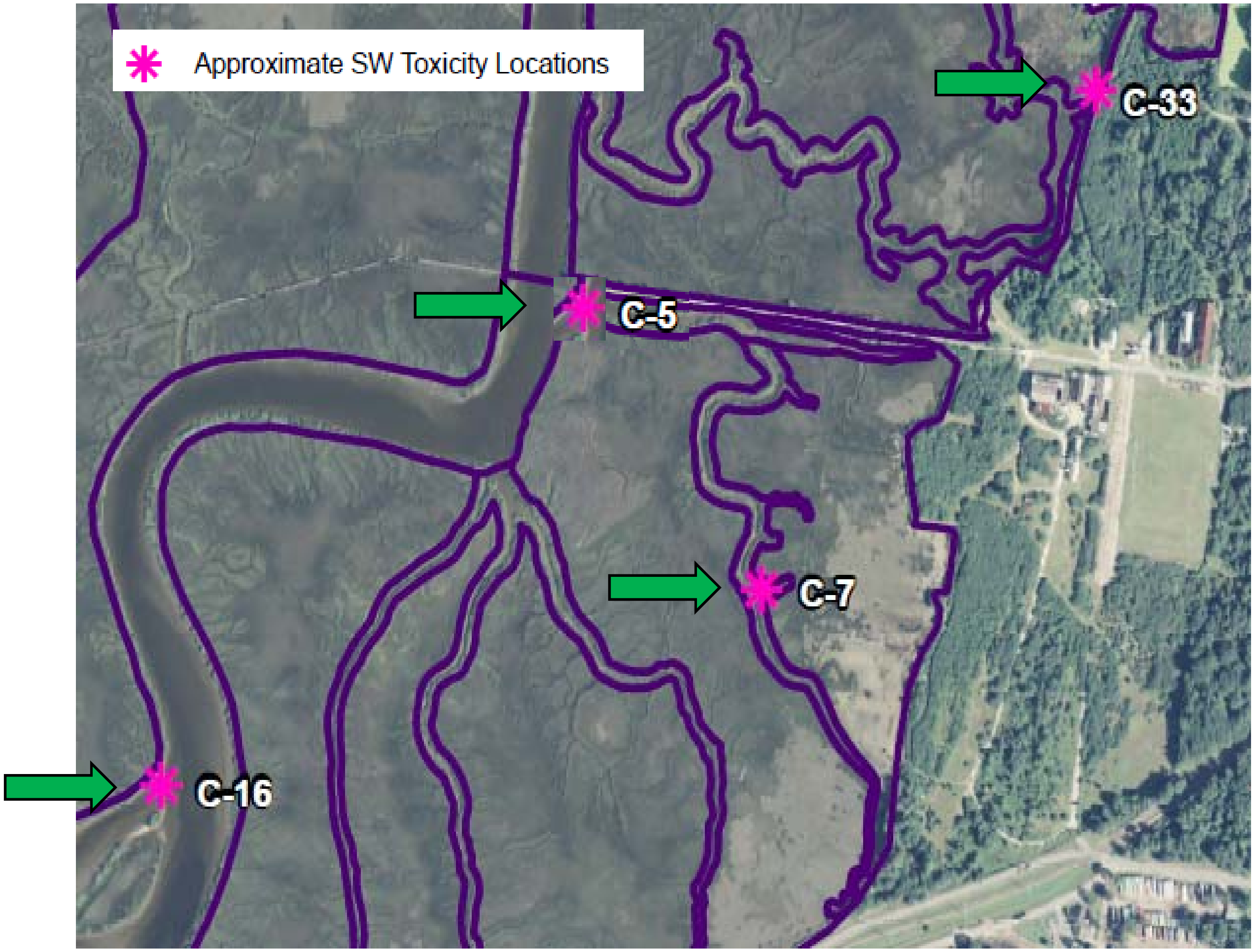
LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-5

DRAFT

- This surface water toxicity testing study was described in the BERA but this summary figure is new.
- A toxicity testing study was provided for mysid shrimp. Survival and growth was evaluated.
- No impacts to survival were observed (all survival was 94-100%). Growth was greater than or equal to that seen in reference areas.



🟩 No significant difference from reference

🟥 Significant difference from reference

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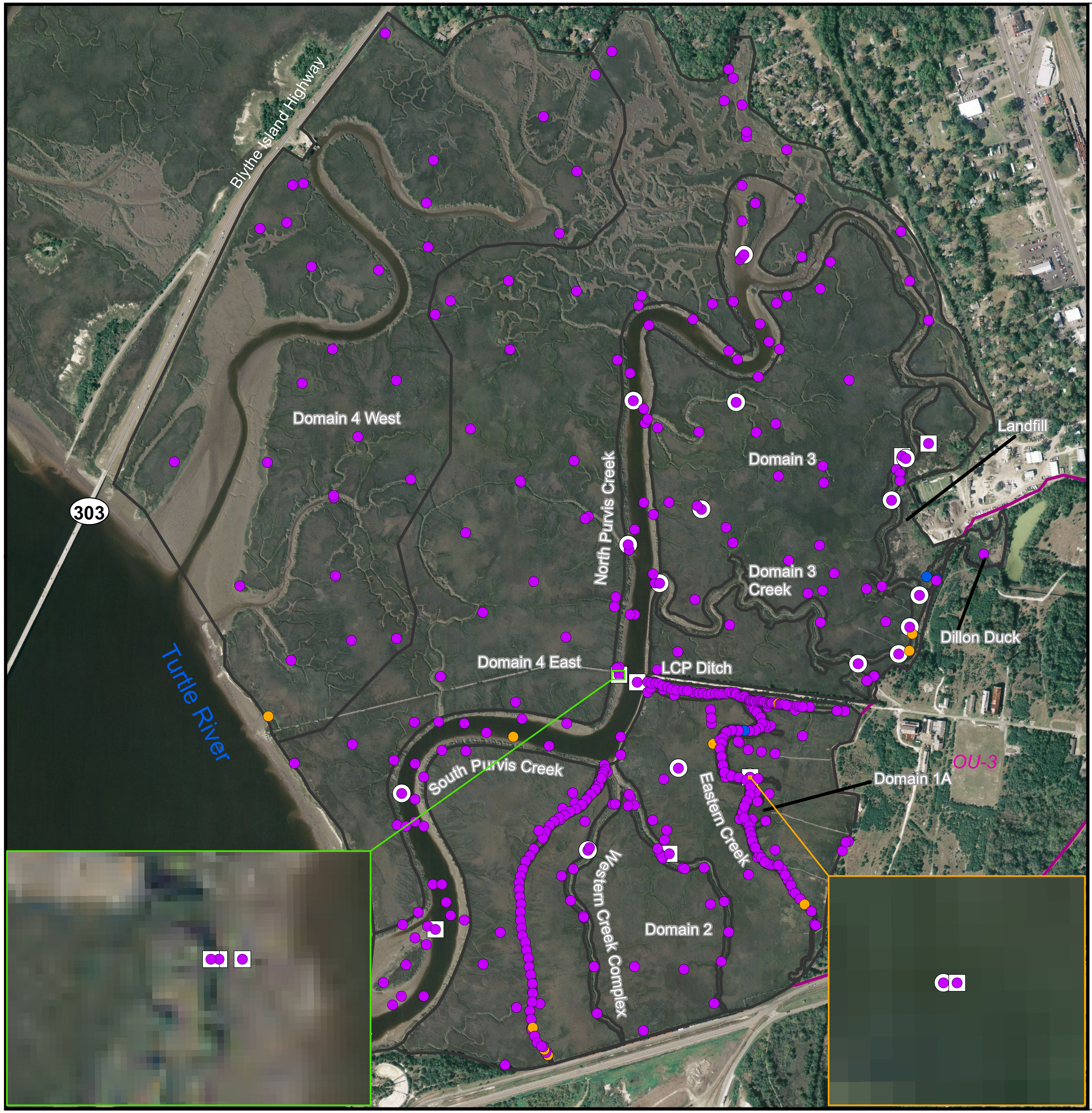
Surface Water Toxicity Testing

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure

E2-6



Legend

Total PAH Concentration (mg/kg)

- ● ≤4
- ● >4 - ≤6
- ● > 6

Total PAH Sample Locations with Detection Limits > 0.4 mg/kg

- ▣ All PAH Compounds are ND with a DL > 0.4 mg/kg
- ◉ Some PAH Compounds are ND with a DL > 0.4 mg/kg
- ☐ OU-1 Boundary
- ☐ OU-3 Boundary

# Locations analyzed for PAHs	452
# Locations where any PAH compound was ND and the DL was > 0.4 mg/kg	25
# Locations where all PAH compounds were ND and had DL > 0.4 mg/kg	9

NOTES:
DL = Detection Limit
ND = Non-Detect

OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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DRAFTED BY: MRJ

DATE: 11/07/2012

0 800 1,600
Feet

TOTAL PAH SAMPLE LOCATIONS

LCP CHEMICAL SITE
BRUNSWICK, GA

DRAFT

Figure
E2-7

PROJECT: 02-27105A

DRAFT

Appendix F
Fish and Shellfish Tissue Concentration Supporting Graphics

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
ENVIRON International Corporation

Anchor QEA, LLC

Date:
March 29, 2013

Appendix F: Fish and Shellfish Tissue Concentration Supporting Graphics

The information in this appendix is provided in support of the Feasibility Study of OU-1. The information is used to inform Remedy Alternative decisions, and to evaluate long-term monitoring trends for the LCP Site estuary. This appendix provides a graphical summary of the 2011 fish tissue data collection effort. These data already have been reported to U.S. Environmental Protection Agency, the Georgia Environmental Protection Division, and the Georgia Department of Natural Resources (GA DNR) in tabular form by Environmental Planning Specialists, Inc. in 2011. These data were used by GA DNR to set fish consumption advisories for Turtle River/Brunswick Estuary (TRBE) in 2012.

This appendix is includes the following sections:

Section F-1:	Excerpt from GA DNR Fish Consumption Advisory Threshold Memorandum Describes dietary thresholds used by the GA DNR to set fish consumption advisories
Section F-2:	Collection Locations for Fish and Shellfish within the Turtle River/Brunswick Estuary Presents a map of fish and shellfish sample locations, or zones, in the TRBE
Section F-3:	Available Fish and Shellfish Data (Fillet Tissues, Wet Weight) Presents a tabular and graphical depiction of available edible tissue data of fish and shellfish collected in the TRBE
Section F-4:	Available Fish and Shellfish Data (Whole Body Fish Tissues, Wet Weight) Presents a tabular and graphical depiction of available whole body data of fish and shellfish collected in the TRBE

Section F-1 Contents: Excerpt from GA DNR Fish Consumption Advisory Threshold Memorandum

This section is an excerpt from the GA DNR technical memorandum identifying the dietary thresholds used by GA DNR to establish fish consumption advisories for the TRBE. The edible fish and shellfish tissue data provided in Section F-3 are compared to these thresholds. These thresholds are not appropriate for comparing to the whole body fish tissue data provided in Section F-4 because anglers do not consume the whole body fish samples, only the edible tissues.

Georgia Department of Natural Resources (GA DNR). 2004. “Data Summary for the Turtle River.” Technical Memorandum from R.O. Manning, Environmental Toxicology Coordinator, Georgia Department of Natural Resources, Atlanta, Georgia, to J. McNamara, Georgia Environmental Protection Division, Atlanta, Georgia. February 9.

Georgia Department of Natural Resources
2 Martin Luther King, Jr. Drive, Suite 1152 East Tower, Atlanta, Georgia 30334-4100
Lonice C. Barrett, Commissioner
Carol A. Couch, Ph.D., Director
Environmental Protection Division
404/656-4713

MEMORANDUM

TO: Jim McNamara

FROM: Randall O. Manning, Ph.D., DABT
Environmental Toxicology Coordinator

DATE: February 9, 2004

RE: Data summary for the Turtle River

Samples of shellfish and/or finfish have been collected in the Turtle River near LCP in 1991, 1992, 1993, 1995, 1997, and 2002. While most of the samples have been analyzed for a large number of chemicals (> 40), my summary will deal only with total mercury and total PCBs (in this area almost exclusively Arochlor 1268) because those two chemicals have been found in sufficient quantity to contribute to fish consumption restrictions. In all instances, samples are edible composites, and numbers of composites (not individuals) are referred to as N. Composites of fish are created using fillet tissue from five individuals of the same species and size class. In rare instances composites may be created using less than five fish, but the majority of data summarized herein are for 5 fish composites. For shellfish, compositing is not based on specific numbers of organisms, but composites are created based on tissue volume (or amount) needed for laboratory analysis. All results are in mg/kg or ppm.

Since 1991, more than 700 composites of fish and shellfish have been collected in the Turtle River near LCP. About 75% of those composites (535) represent tissues from 5 individual fish. More that 2600 individual fish have been collected from the area.

The data is evaluated on a yearly basis for development of fish consumption guidelines. Those guidelines are developed using U.S. EPA's potency factors for carcinogenicity and reference doses for non-cancer toxicity, whichever is most restrictive. Inputs used in the risk calculation include a risk level of 1×10^{-4} for cancer, a 30-year exposure duration for both carcinogens and toxics, 70 kg as the body weight for an adult, and 70 years as the lifetime duration. A U.S. EPA algorithm is used, and solved for intake (gm/day). By making intake the dependant variable, the difficult issue of determining what are appropriate intake values for different subpopulations is avoided.

The intake value (which is really how much one can eat to keep theoretical lifetime cancer risk less than 1 X 10^{-4}, or to keep the daily intake below the RfD for non-cancer toxicity) is then compared to a scale equating to meals per week or month.

The scale is:

Calculated intake (gm/day)	equates to	guidance
≤ 3		do not eat
> 3 - 10		limit consumption to 1 meal/month
> 10 - 30		limit consumption to 1 meal/week
> 30		no restrictions

The scale is based on a range of meal sizes from ¼ to ½ lb. For practical purposes, the tissue concentrations for total PCBs and total mercury that bound the different consumption recommendations are shown below.

Chemical	No Restriction	One Meal/ Week	One Meal/ Month	Do Not Eat	FDA Action Level
PCBs (mg/kg)	≤ 0.10	> 0.10	> 0.30	> 1.0	2.0
mercury (mg/kg)	≤ 0.23	> 0.23	> 0.71	> 2.0	1.0

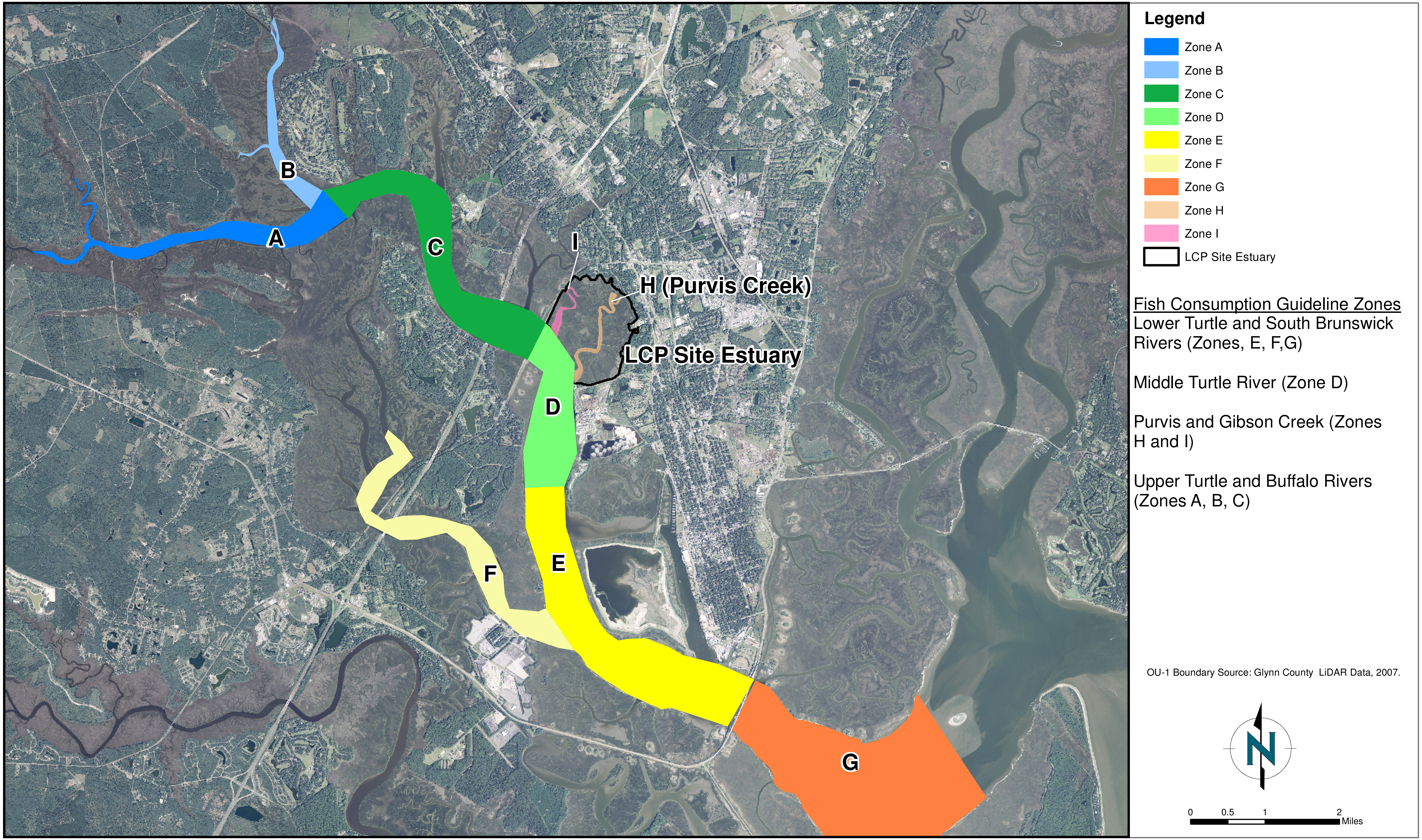
1991

In 1991 five composites of oysters and five composites of crab were collected in Purvis Creek and the Turtle River. Ranges and averages are shown below.

Sample	Contaminant	Conc. Range (ppm)	Mean Conc. (ppm)
Oysters, N=5	Mercury	0.1 to 1.2	0.4
	PCBs	0.1 to 0.4	0.2
Crab, N=5	Mercury	0.1 to 0.5	0.5
	PCBs	0.1 to 9.9	3.1

Section F-2 Contents: Collection Locations for Fish and Shellfish within the Turtle River/Brunswick Estuary

This section includes a map of fish and shellfish sample locations in the Turtle River/Brunswick Estuary. Data groupings in Sections F-3 and F-4 of this memorandum provide time trends for Zone H, with is the LCP Site estuary. In addition, Sections F-3 and F-4 provide a graphical summary of all locations sampled in the 2011 fish collection effort.



Fish Consumption Guideline Zones

Lower Turtle and South Brunswick Rivers (Zones, E, F,G)

Middle Turtle River (Zone D)

Purvis and Gibson Creek (Zones H and I)

Upper Turtle and Buffalo Rivers (Zones A, B, C)

OU-1 Boundary Source: Glynn County LiDAR Data, 2007.

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Turtle River/ Brunswick Estuary Fish Consumption Guideline Zones

LCP CHEMICAL SITE
BRUNSWICK, GA

Figure
F-2A

DRAFTED BY: ARG
DATE: 03/07/2013
DRAFT
PROJECT: 02-27105A

Section F-3 Contents: Available Fish and Shellfish Data (Edible Tissues, Wet Weight)

This section presents a tabular and graphical presentation of available edible tissue data from fish and shellfish collected in the TRBE from 1995 to 2011 for Zone H, the LCP Site estuary. In addition, this section provides a graphical summary of all locations sampled in the 2011 fish collection effort. These edible fish and shellfish tissue data are compared to dietary thresholds used by the GA DNR to set fish consumption advisories, as was described in Section F-1 for the locations identified in Section F-2.

The graphics in this portion of Appendix F show that the concentrations of mercury and Ar1268 have decreased over time. Table 3-4 of the FS summarizes the changes in fish consumption advisories over time; consumption advisories have been lifted for some species due to low concentrations and have been reduced for many other species due to lowering concentrations. However, there are still fish with some degree of exceedances of the threshold levels, which is a basis of discussion in Section 6 of the FS.

Figure F-3A provides a tabular summary of shrimp and crab edible tissues, and fish fillet sample counts by year. Each of the figures below provides the “Comparison of Fish and Crab Tissue Data for Multiple Fish Species for the Two Years with the Most Data”, as follows:

- Figure F-3B: Mercury
- Figure F-3C: Arcolor 1268

Each of the figures below provides the “Comparison of Fish and Crab Tissue Data for All Years By Location,” focused on Zone H (with all locations illustrated for the 2011 sampling event) as follows:

- Figure F-3D: Mercury in Blue Crab
- Figure F-3E: Aroclor 1268 in Blue Crab
- Figure F-3F: Mercury in Atlantic Croaker
- Figure F-3G: Aroclor 1268 in Atlantic Croaker
- Figure F-3H: Mercury in Black Drum
- Figure F-3I: Aroclor 1268 in Black Drum
- Figure F-3J: Mercury in Red Drum
- Figure F-3K: Aroclor 1268 in Red Drum
- Figure F-3L: Mercury in Sheepshead
- Figure F-3M: Aroclor 1268 in Sheepshead
- Figure F-3N: Mercury in Southern Flounder
- Figure F-3O: Aroclor 1268 in Southern Flounder
- Figure F-3P: Mercury in Southern Kingfish

DRAFT

Species Collected	Fillet Count Per Year						Grand Total
	1995	2002	2004	2005	2006	2011	
Atlantic Croaker	0	19	0	1	3	1	24
Black Drum	0	29	10	9	0	24	72
Blue Crab	14	27	14	9	0	27	91
Brown Shrimp	17	0	0	0	0	0	17
Flounder	0	0	0	2	0	0	2
Red Drum	0	15	8	1	0	23	47
Sheepshead	0	25	0	1	0	13	39
Silver Perch	0	0	14	0	0	0	14
Southern Flounder	0	27	0	0	0	12	39
Southern Kingfish	0	25	0	3	1	28	57
Spot	14	27	0	0	0	17	58
Spotted Seatrout	0	28	12	9	0	32	81
Striped Mullet	0	28	8	9	0	27	72
White Shrimp	0	27	0	0	0	27	54

Notes:
(a) Fish counts are for all zones (Zone A to Zone I).
(b) 2002 and 2011 (highlighted in yellow) have the largest sample counts and allow the most robust comparison over time.

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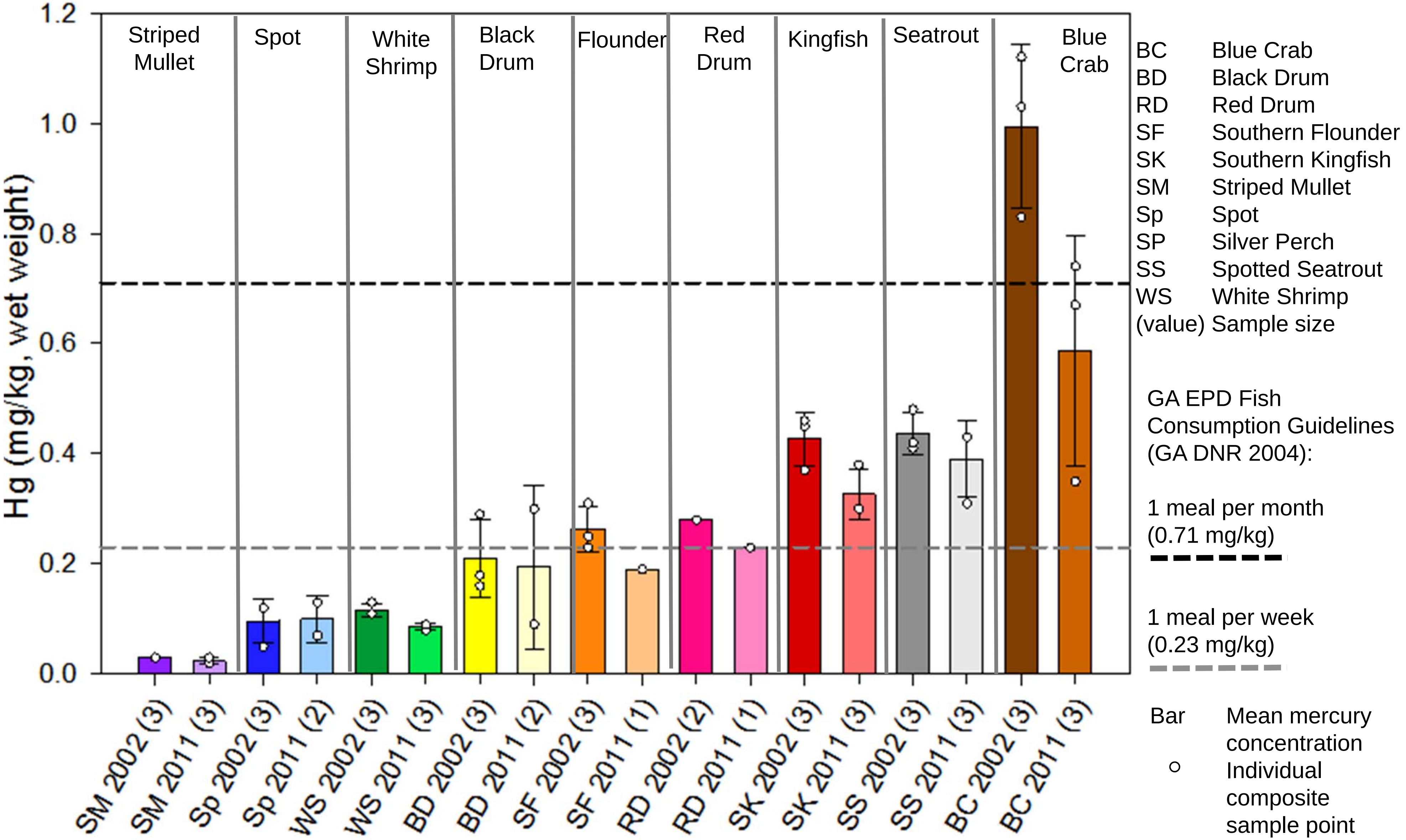
Tabular Summary of Shrimp and Crab Edible Tissues, and Fish Fillet Sample Counts By Year For All Zones

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3A

DRAFT



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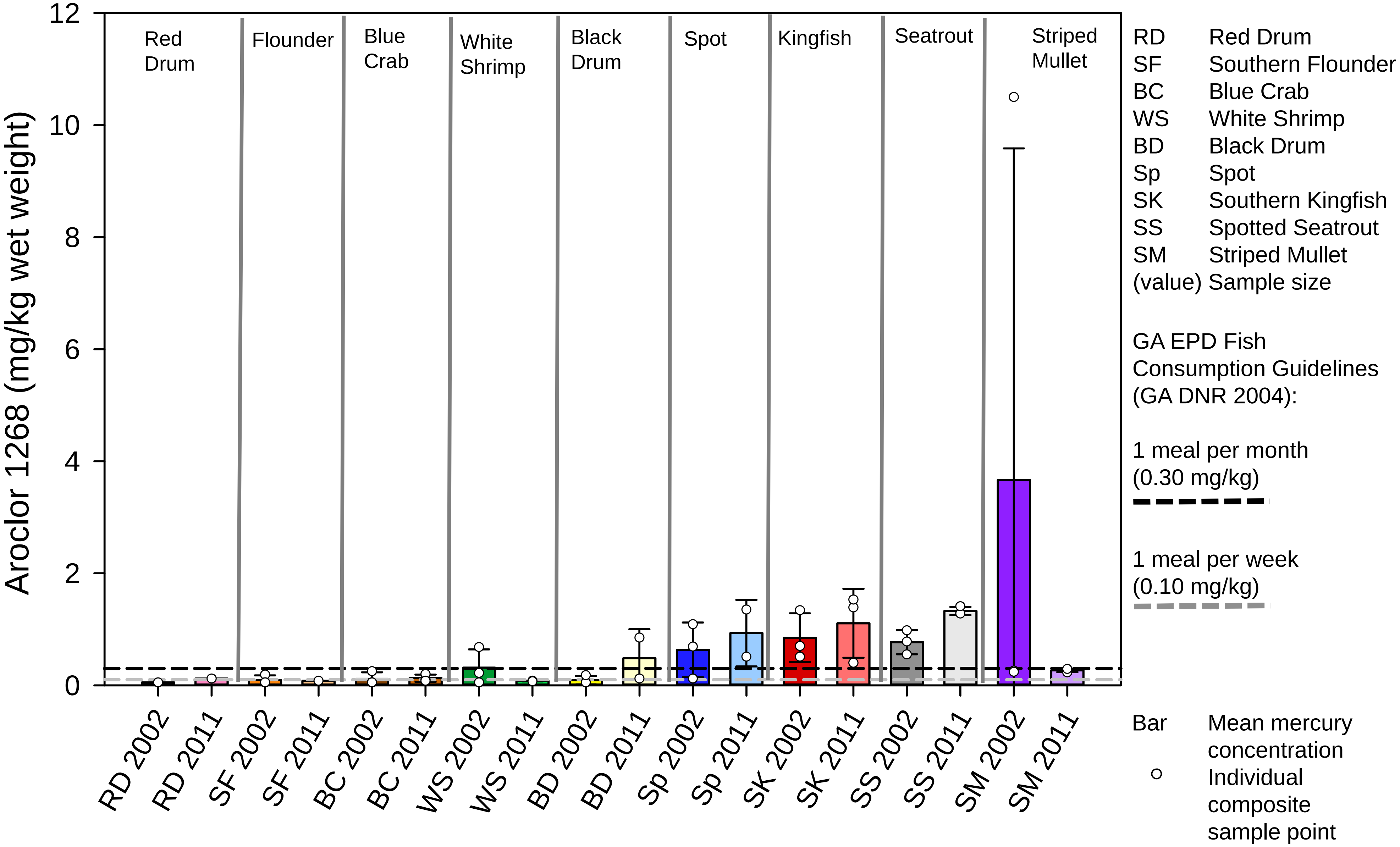
Comparison of Mercury in Shrimp, Crab, and Fish Fillet Tissue for the Two Years with the Most Data for Zone H (2002 vs. 2011, wet weight)

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3B

DRAFT



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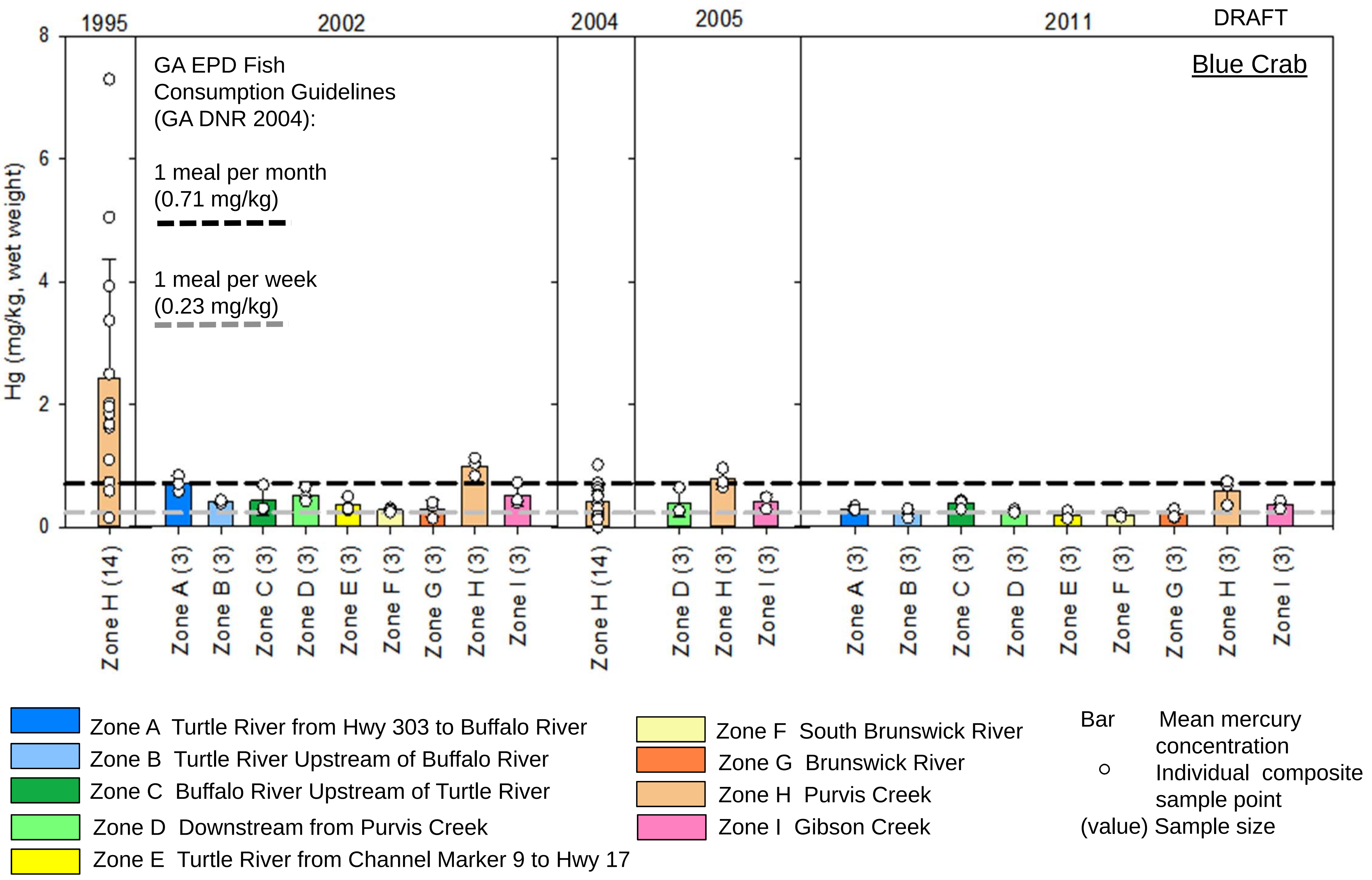
Comparison of Arcolor 1268 in Fillet Tissue for the Two Years with the Most Data for Zone H (2002 vs. 2011, wet weight)

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3C



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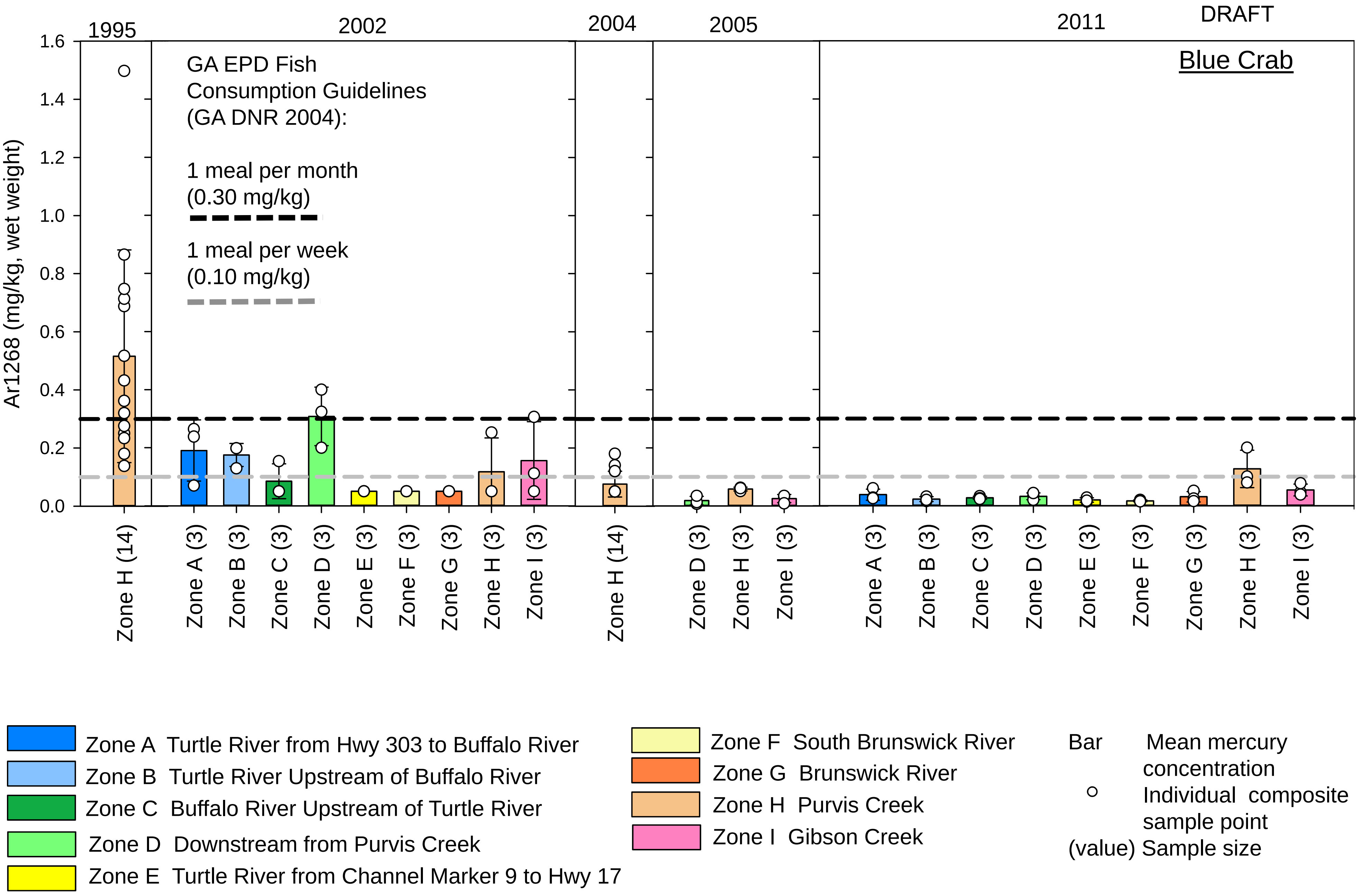
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Blue Crab

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3D



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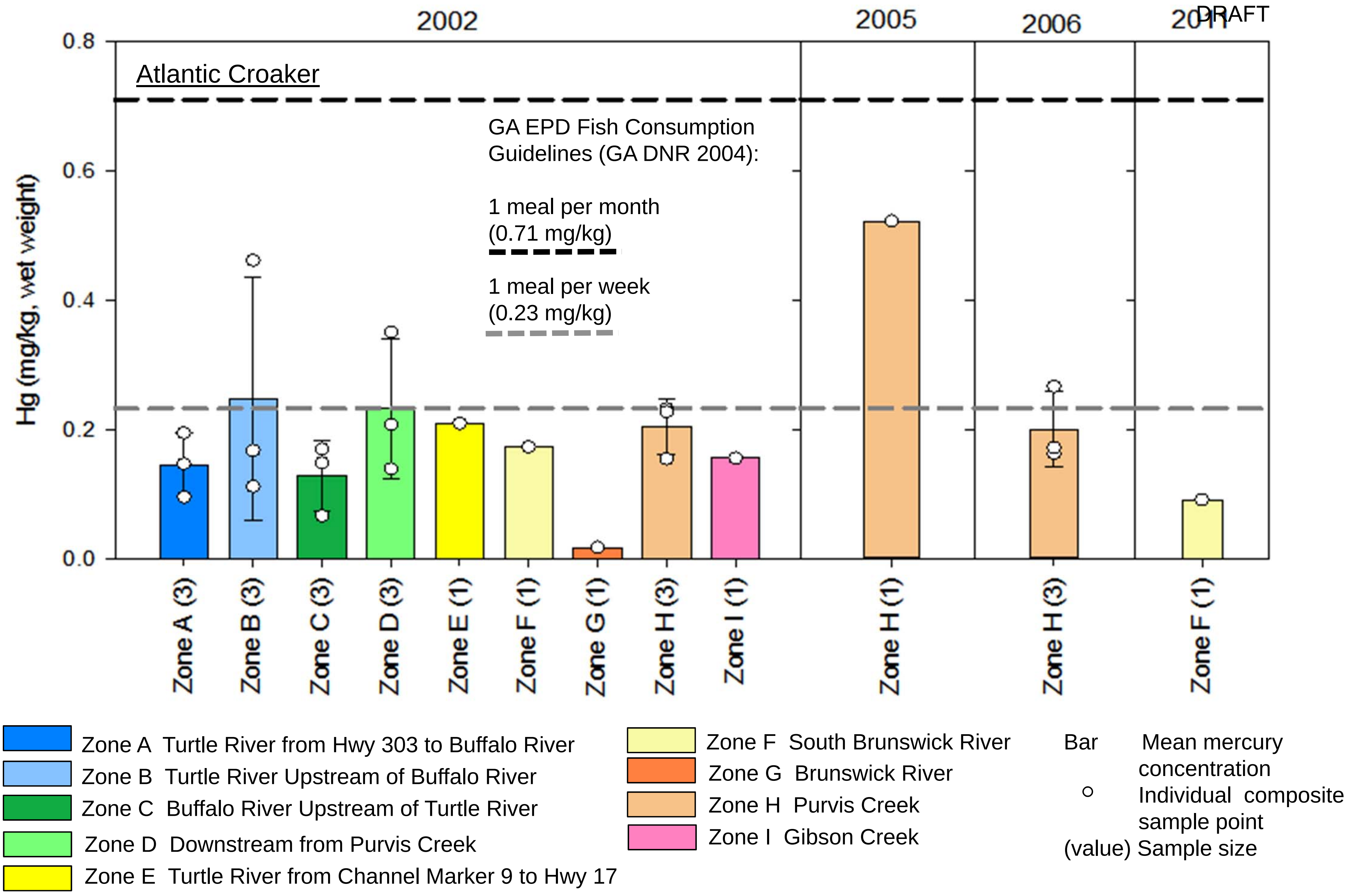
Blue Crab Aroclor 1268 (edible tissue, wet weight)
All Zones Over Time

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3E

DRAFT



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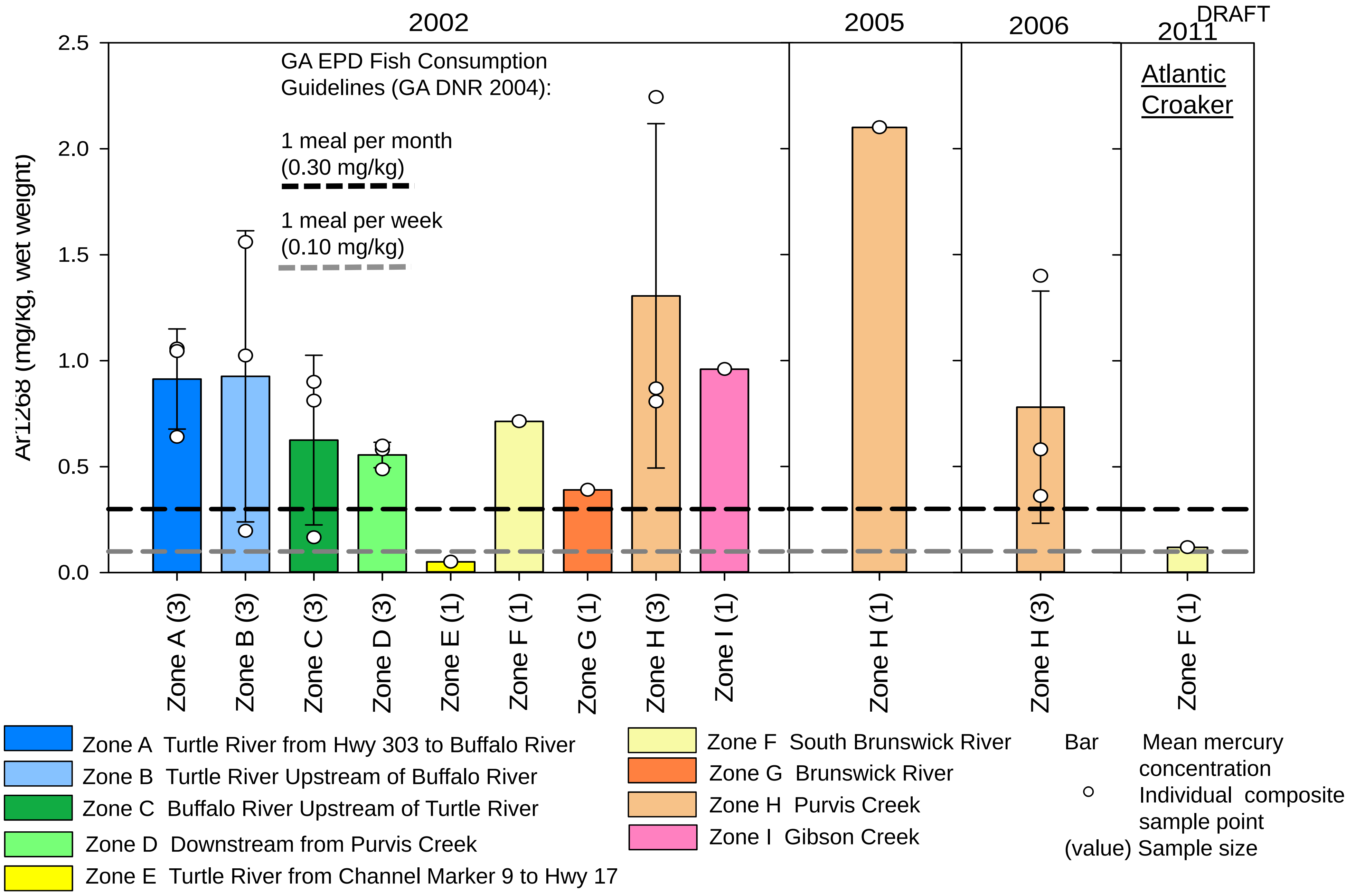
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Atlantic Croaker

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3F

DRAFT



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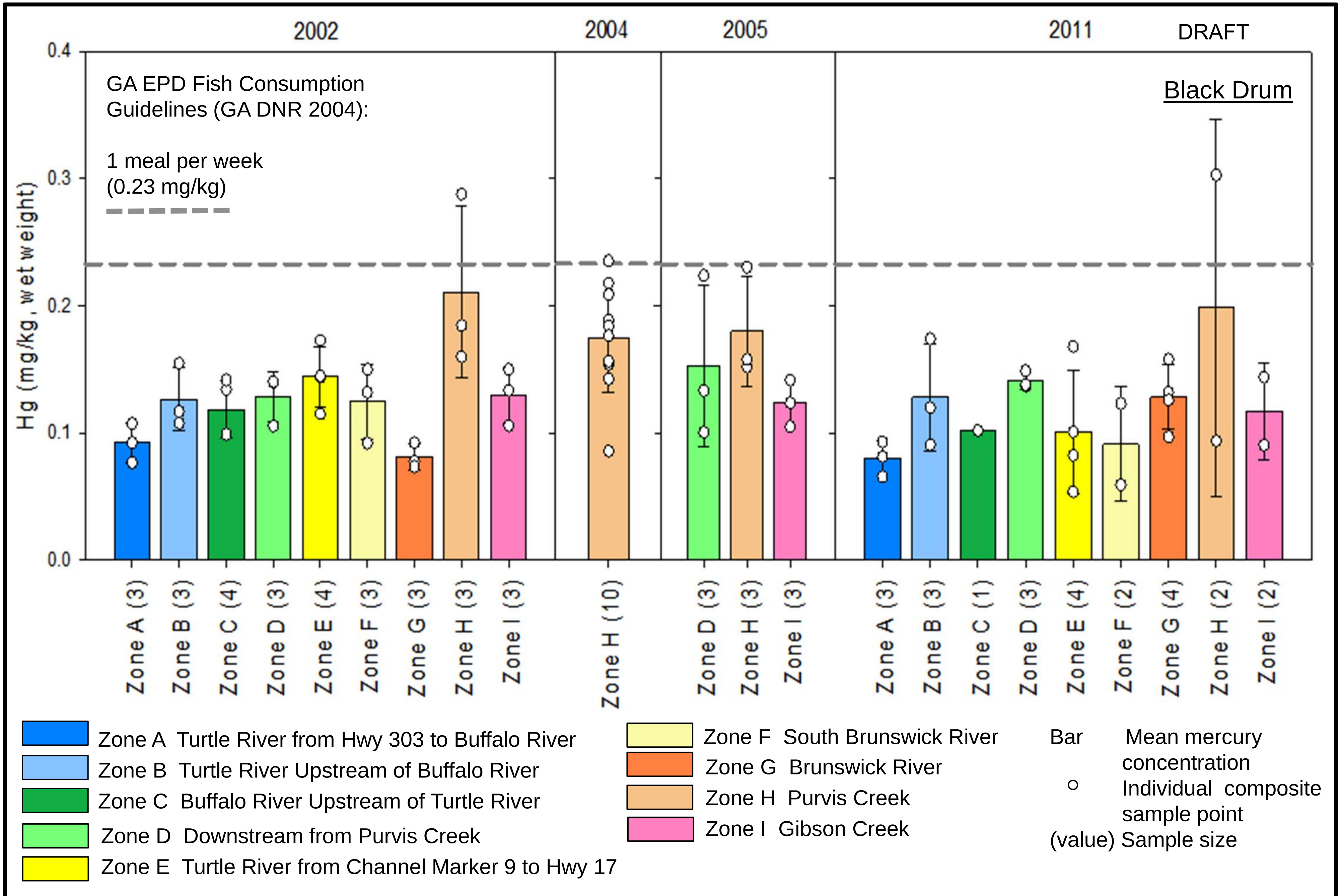
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Atlantic Croaker

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3G



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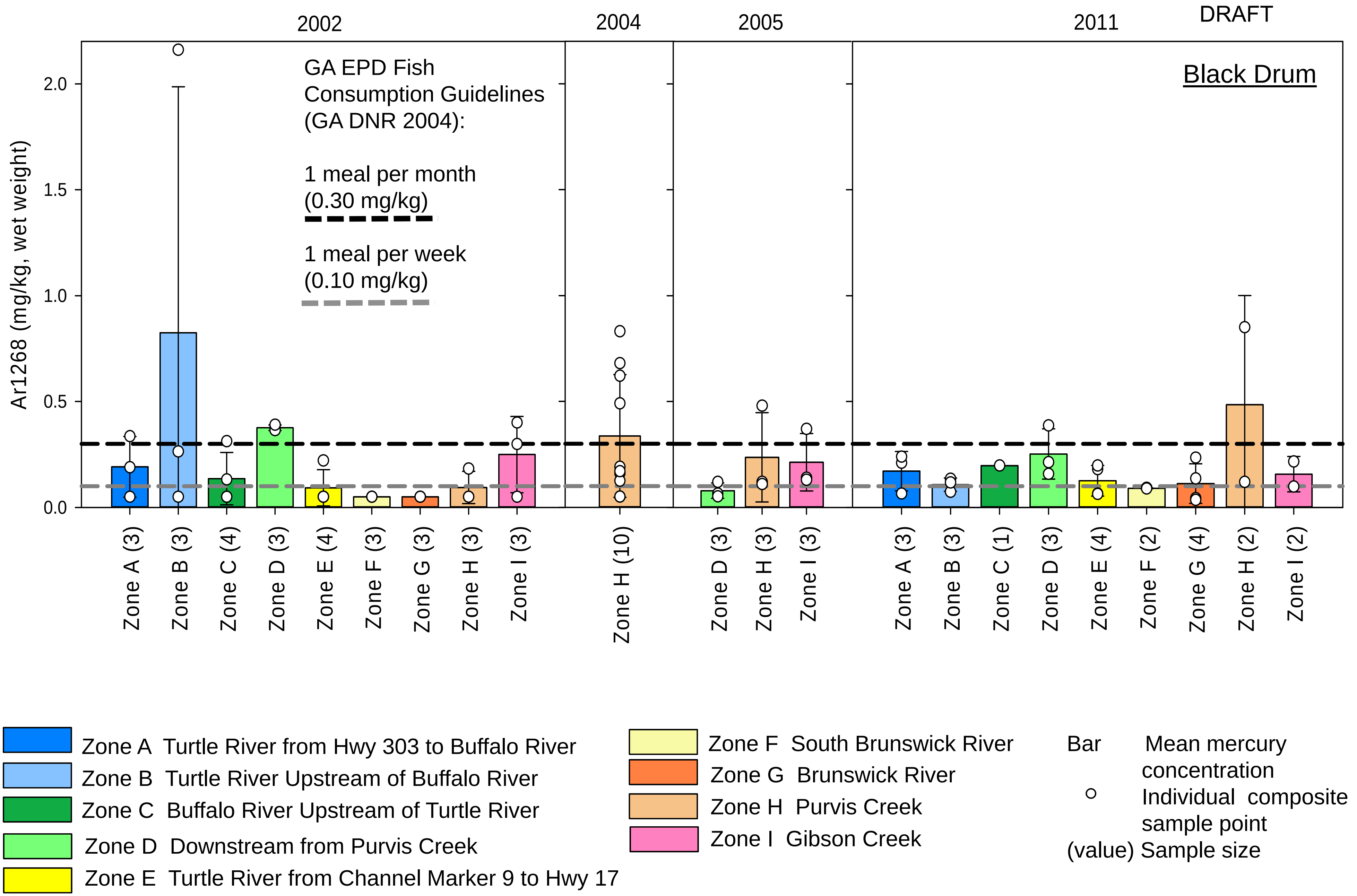
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Black Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3H



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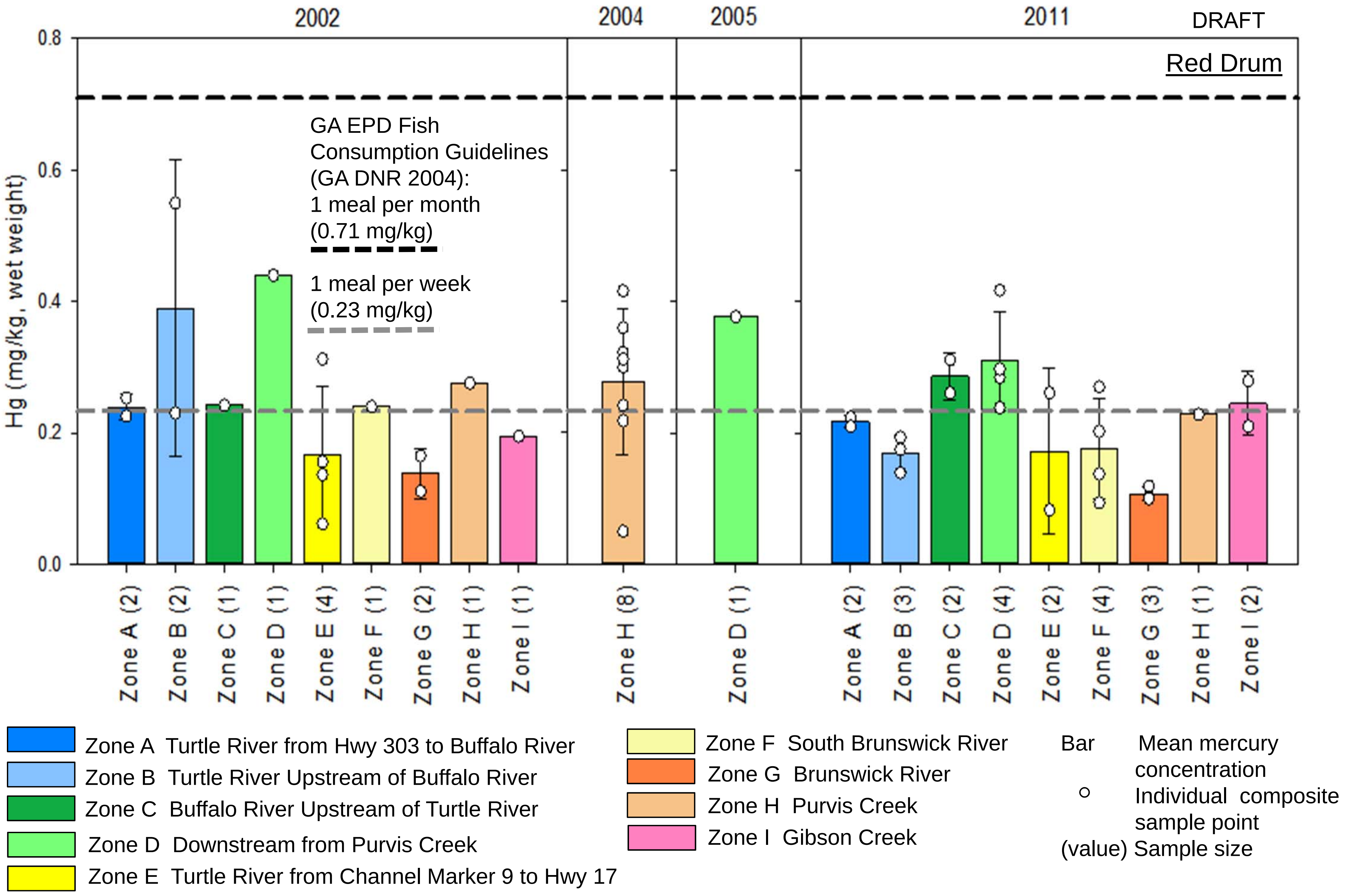
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Black Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3I



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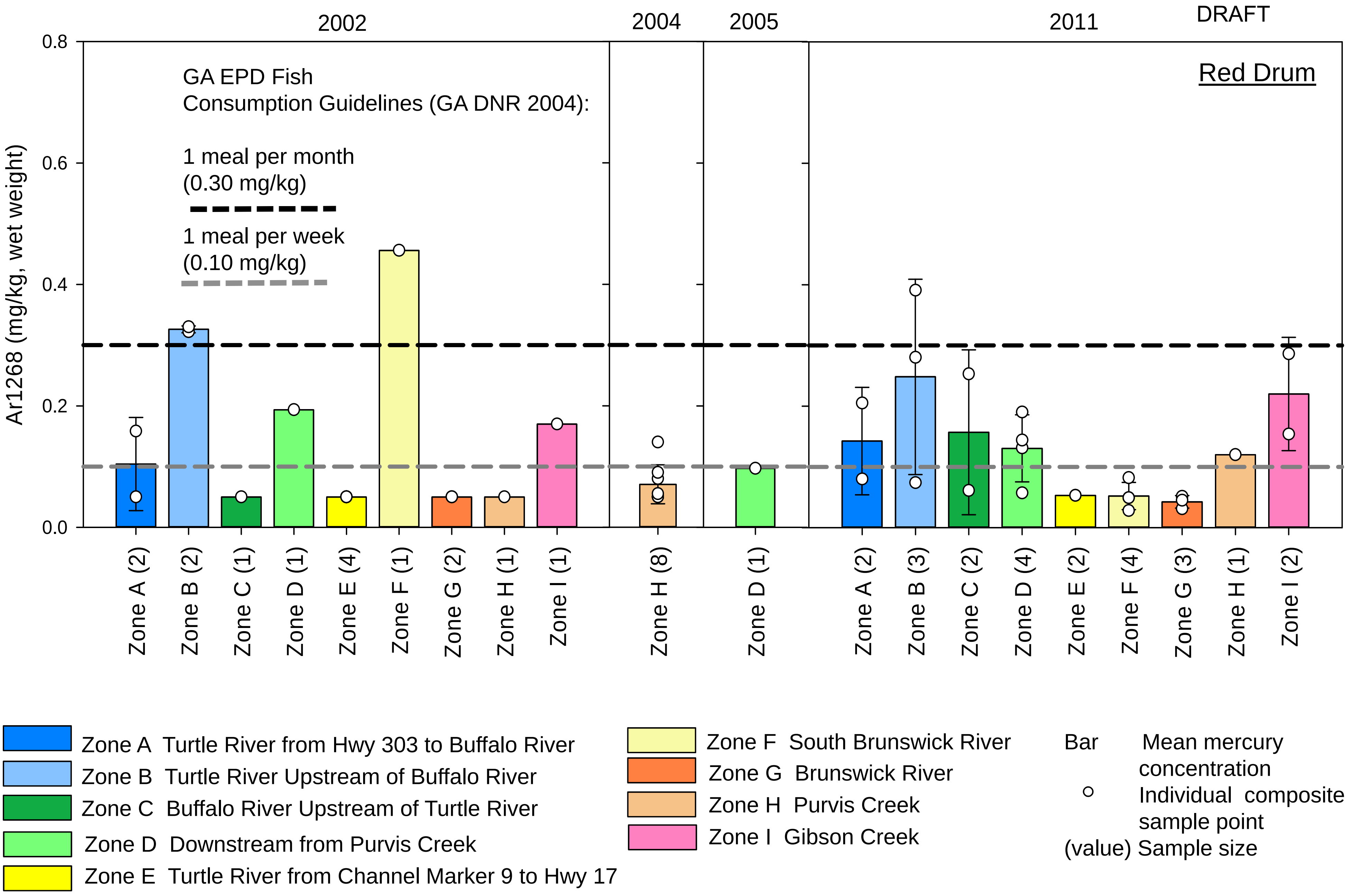
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Red Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3J

DRAFT



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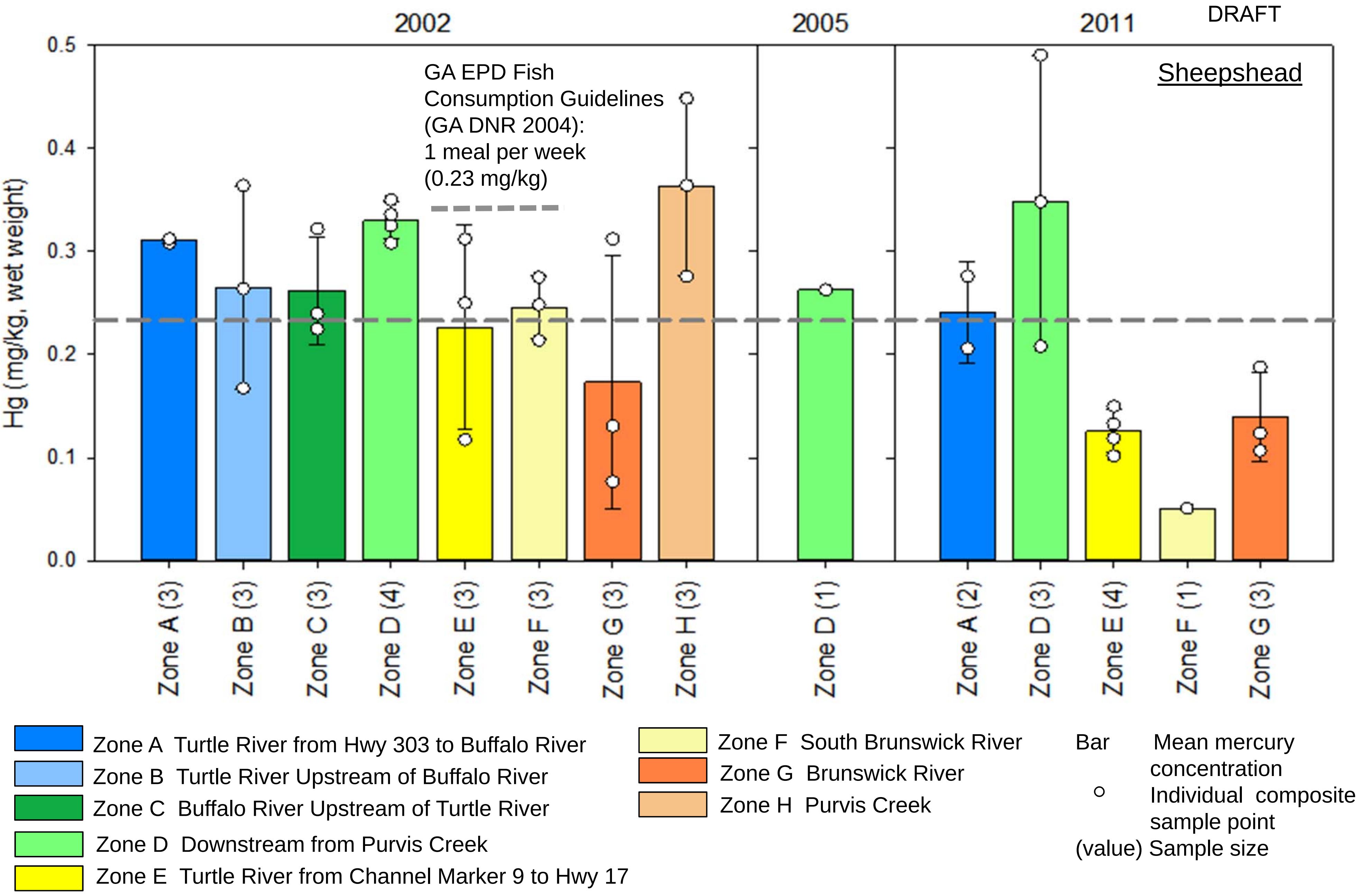
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Red Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3K

DRAFT



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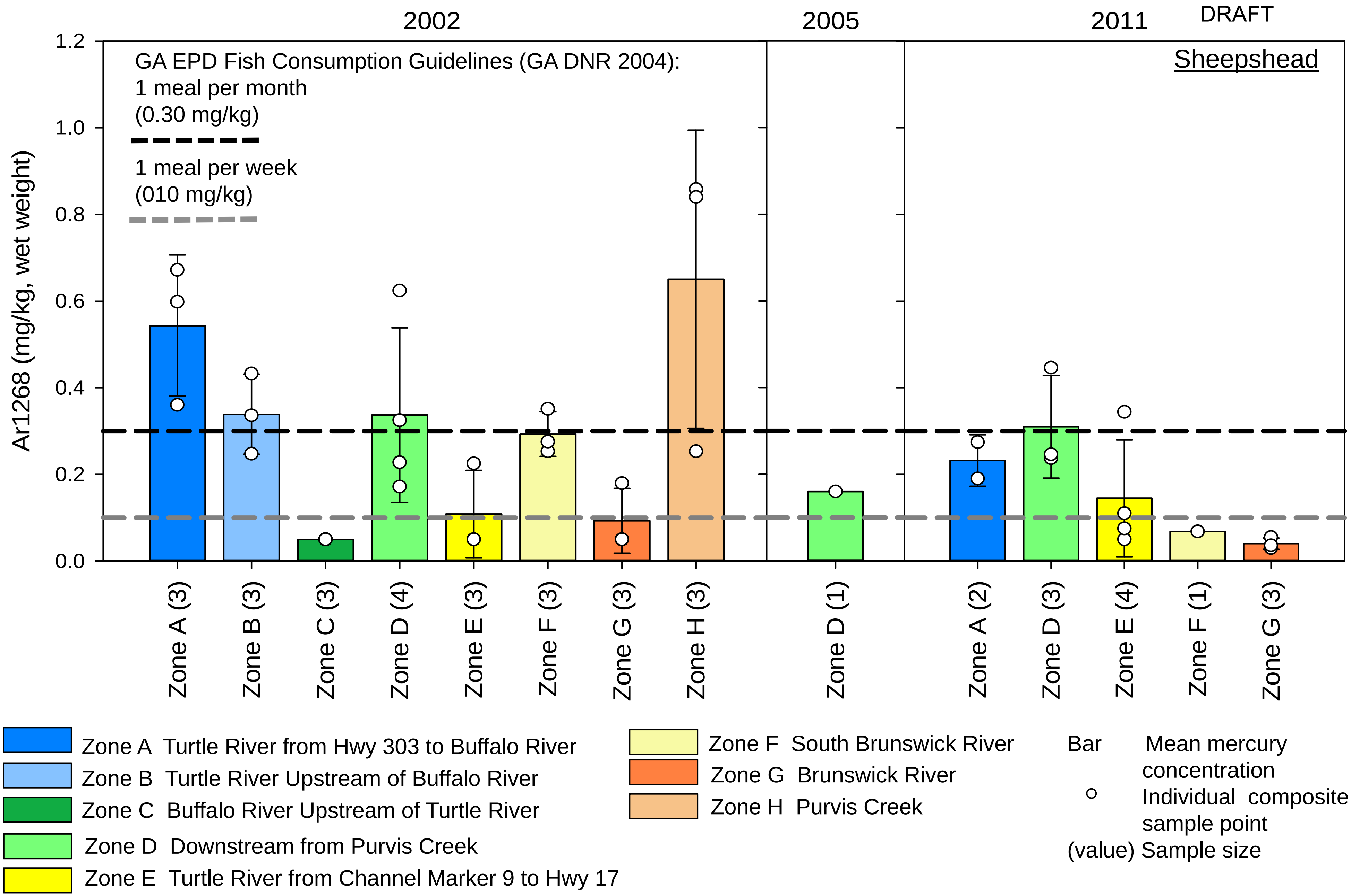
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Sheepshead

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3L



ENVIRON
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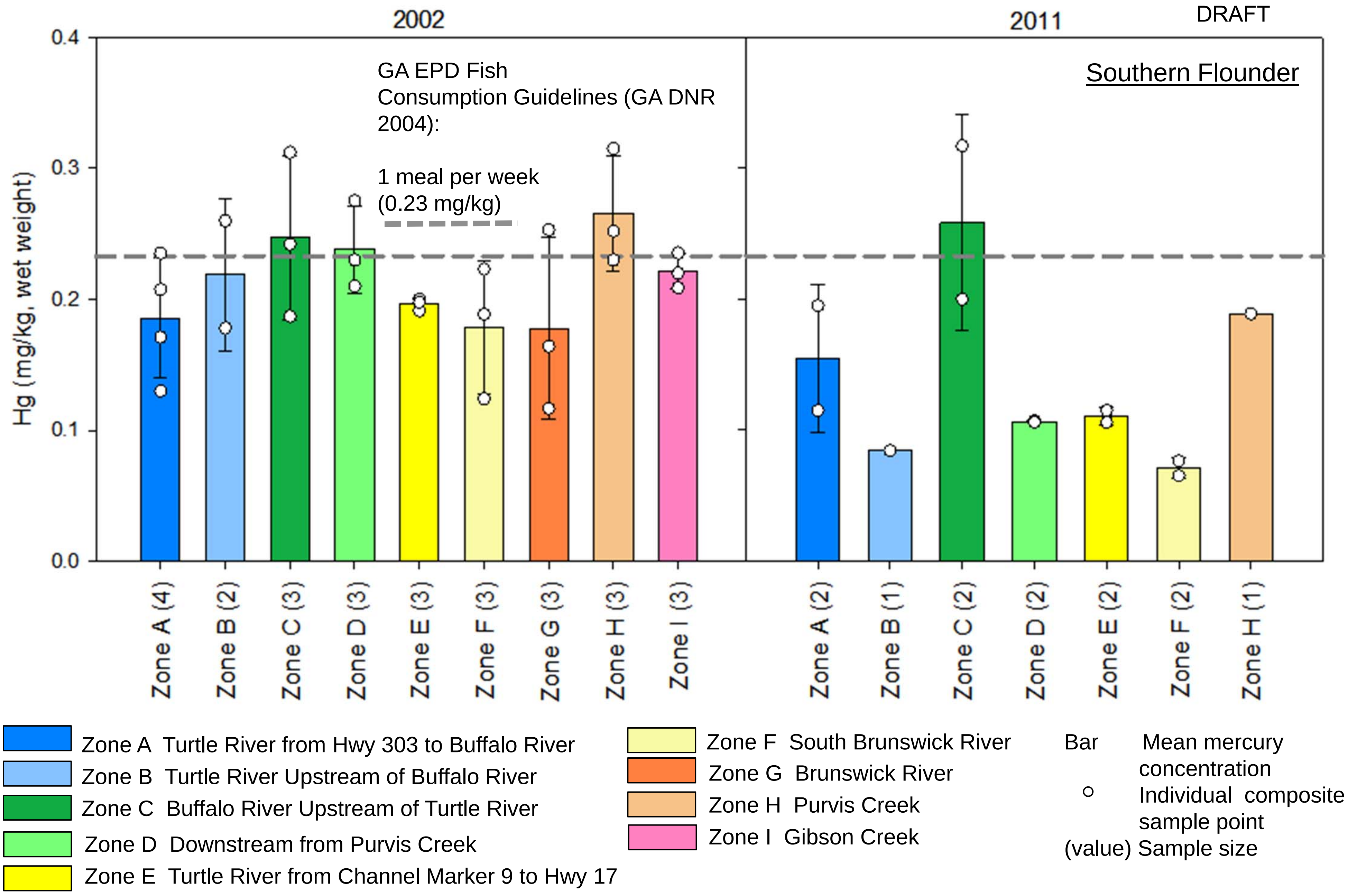
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Sheepshead

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3M

DRAFT



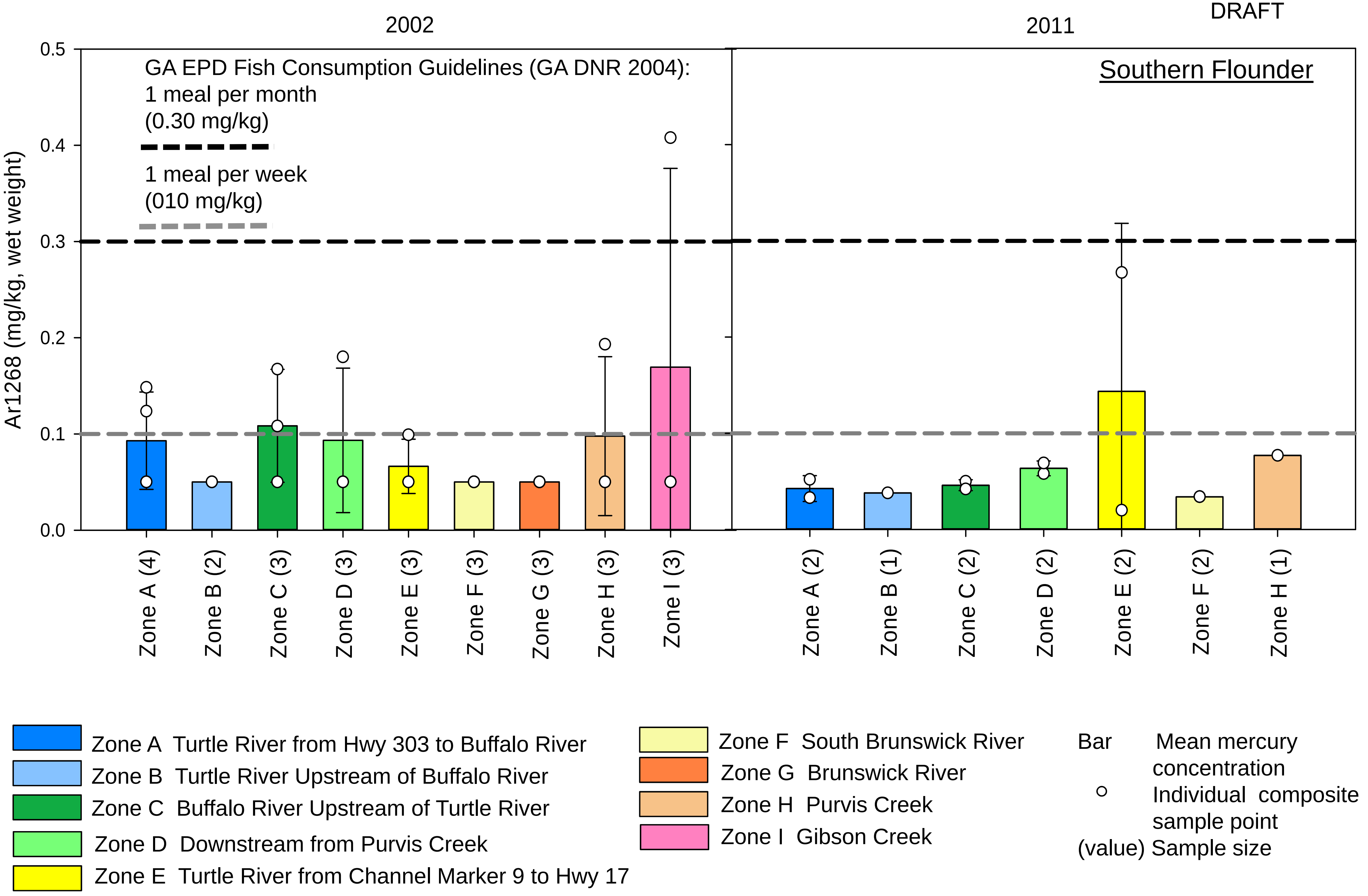
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Southern Flounder

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3N

DRAFT



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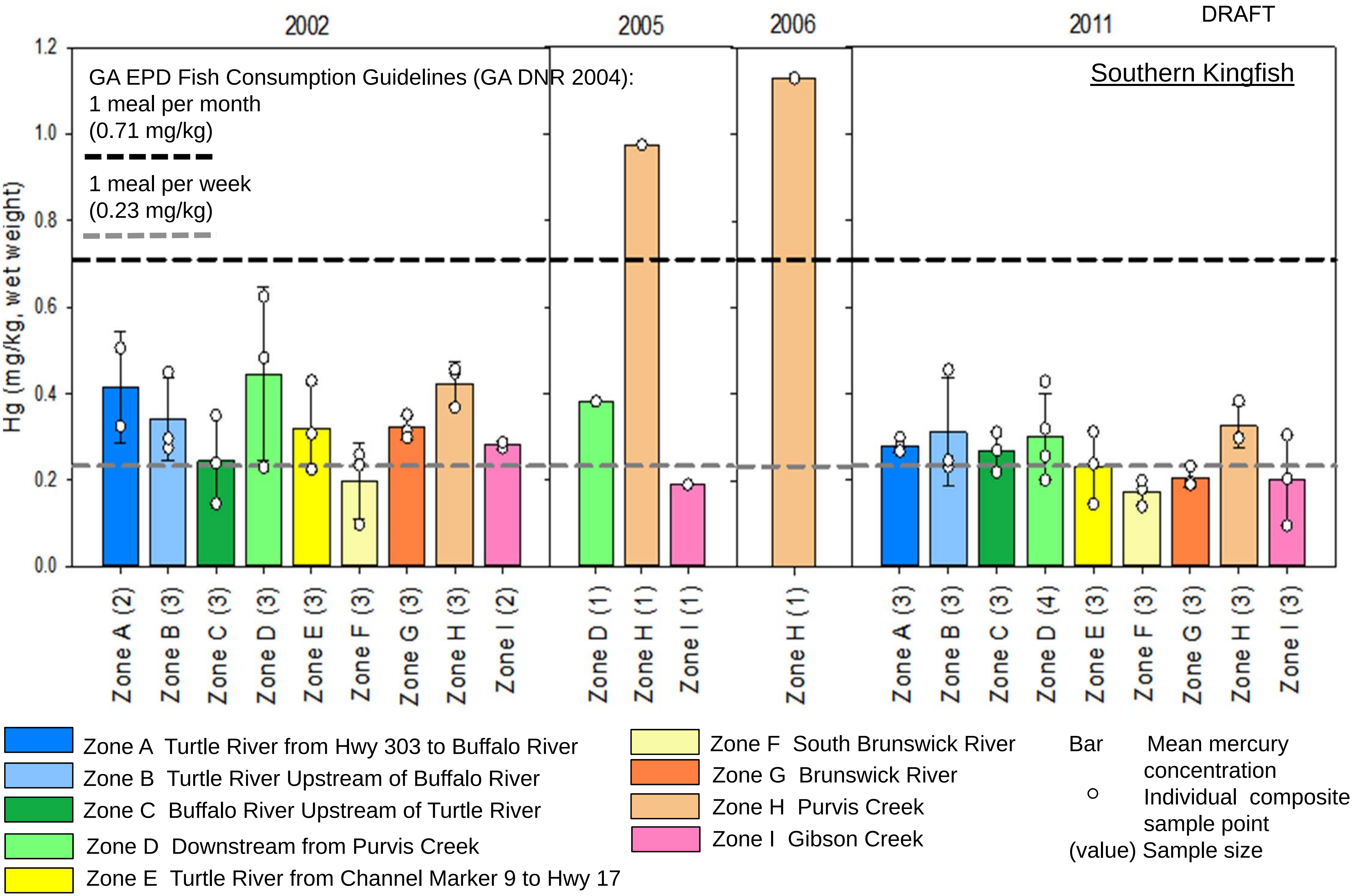
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Southern Flounder

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3O

DRAFT



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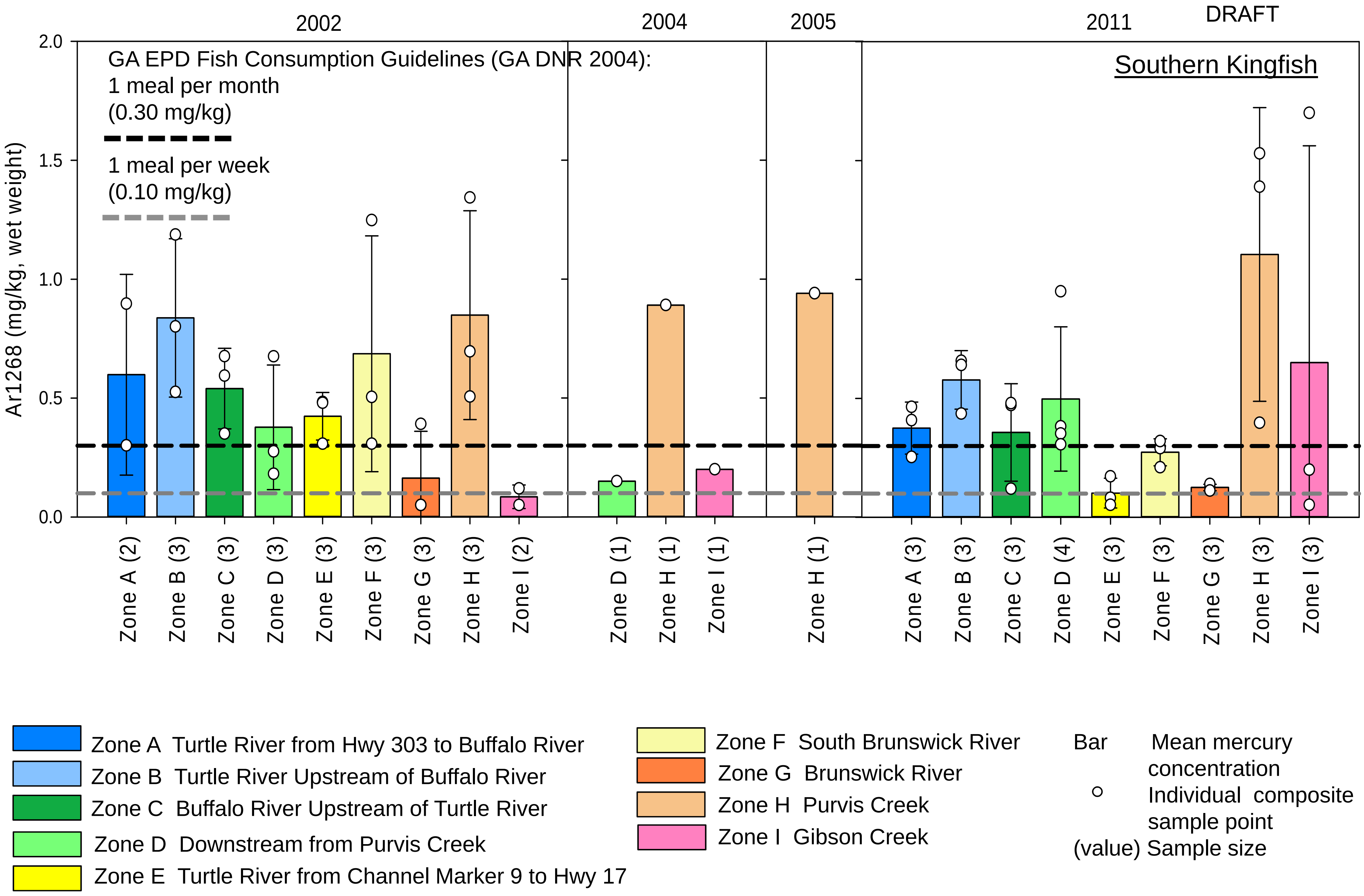
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Southern Kingfish

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3P



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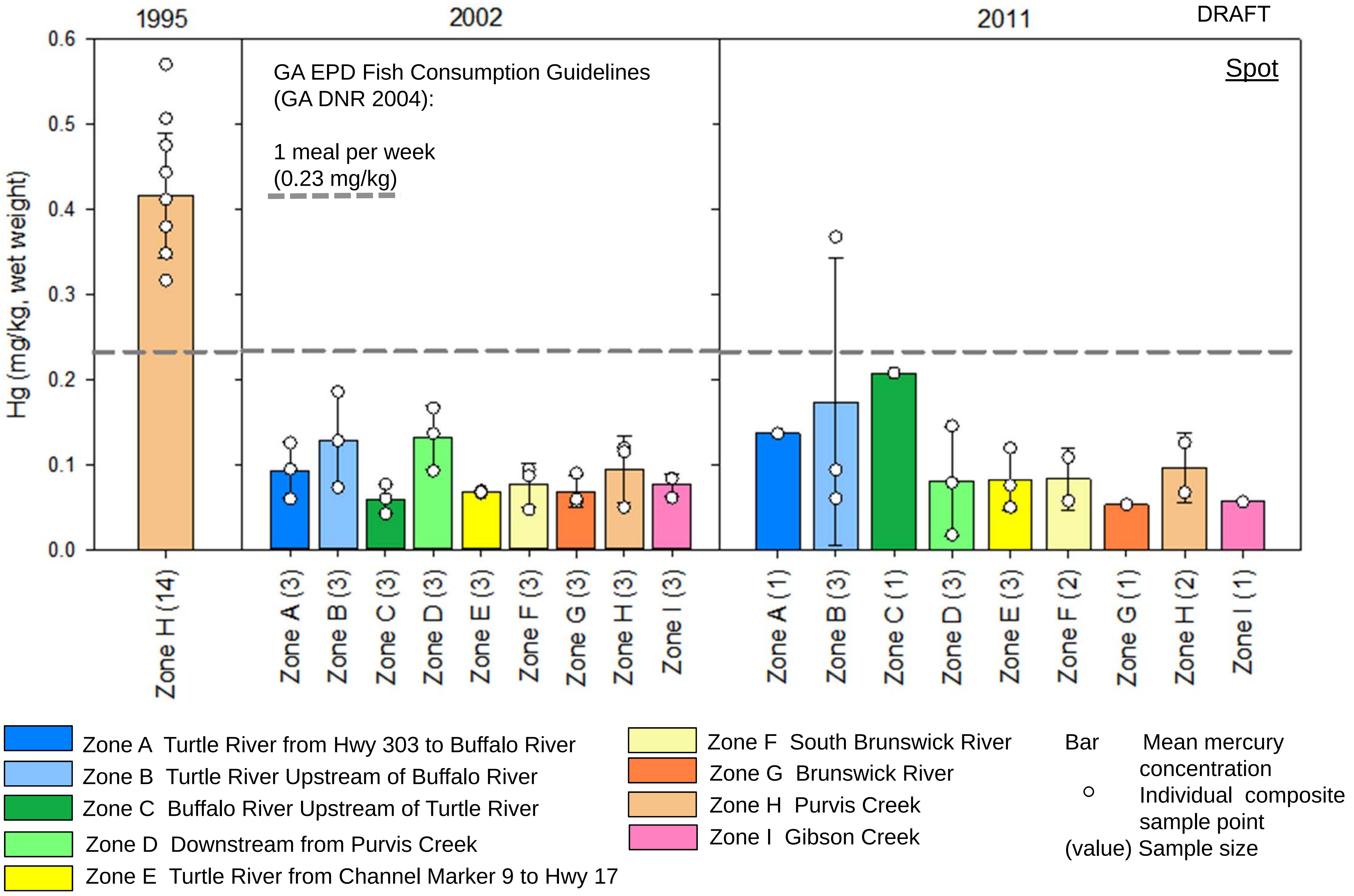
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Southern Kingfish

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3Q



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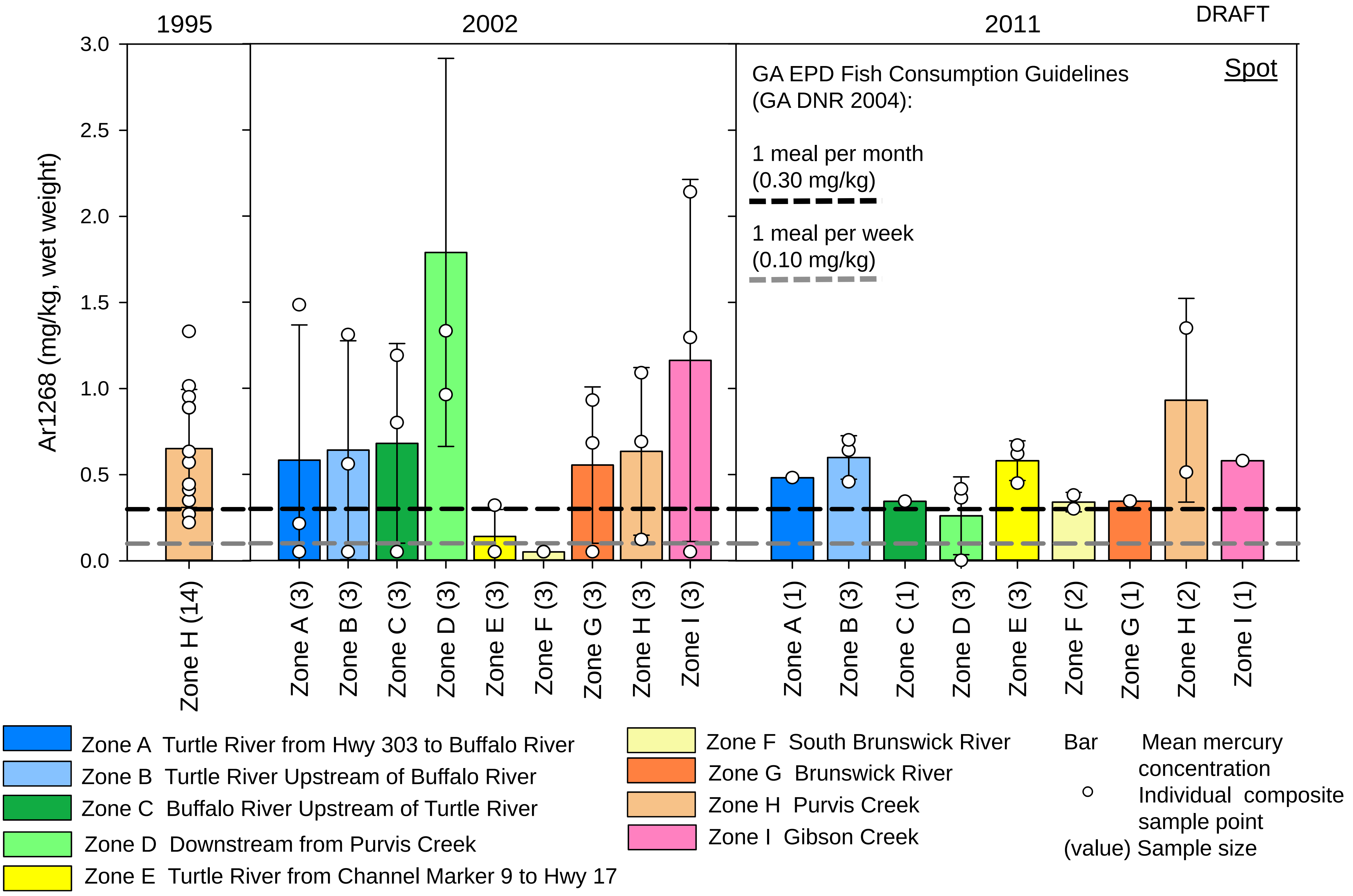
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Spot

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3R



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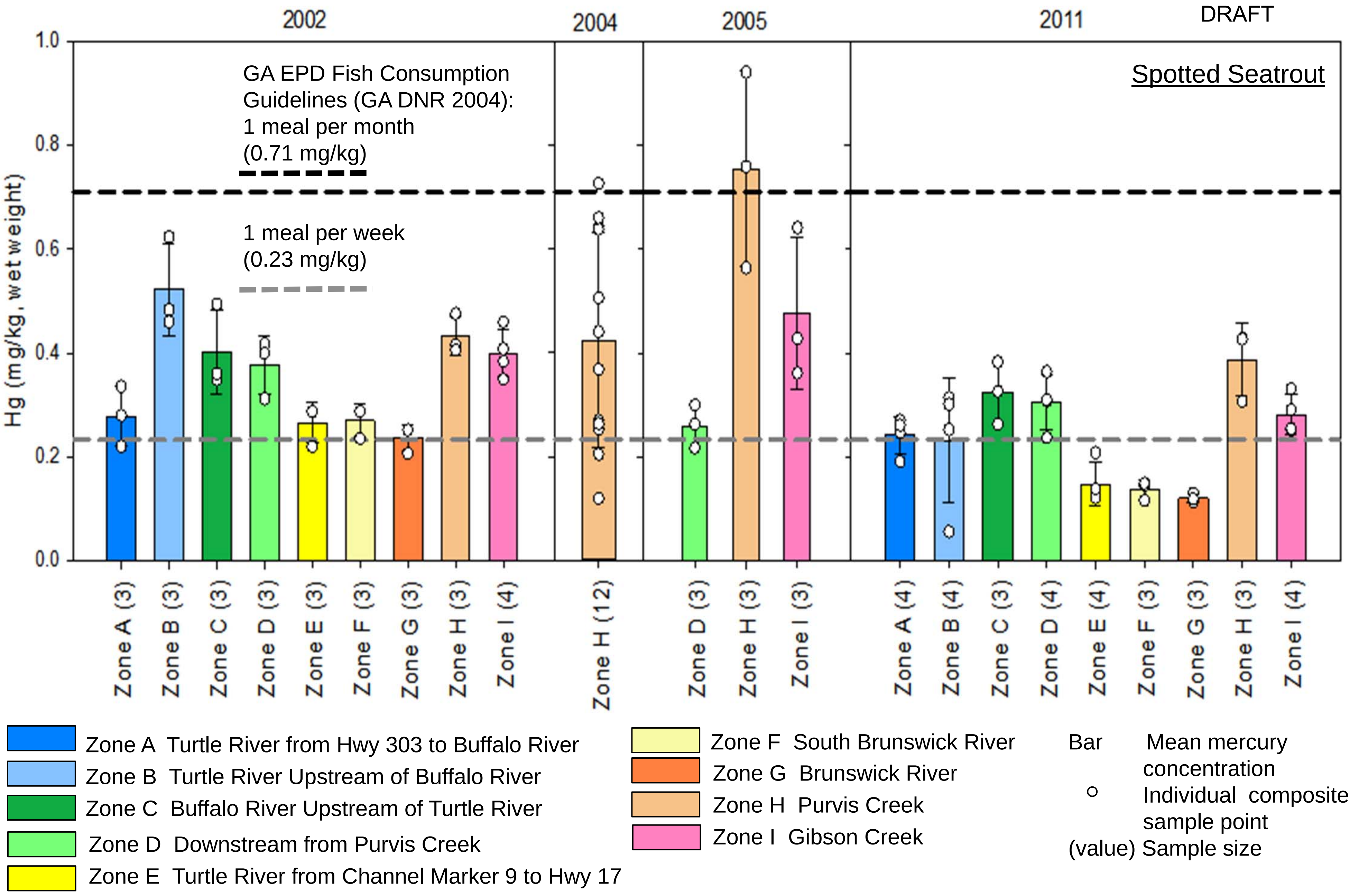
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Spot

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3S

DRAFT

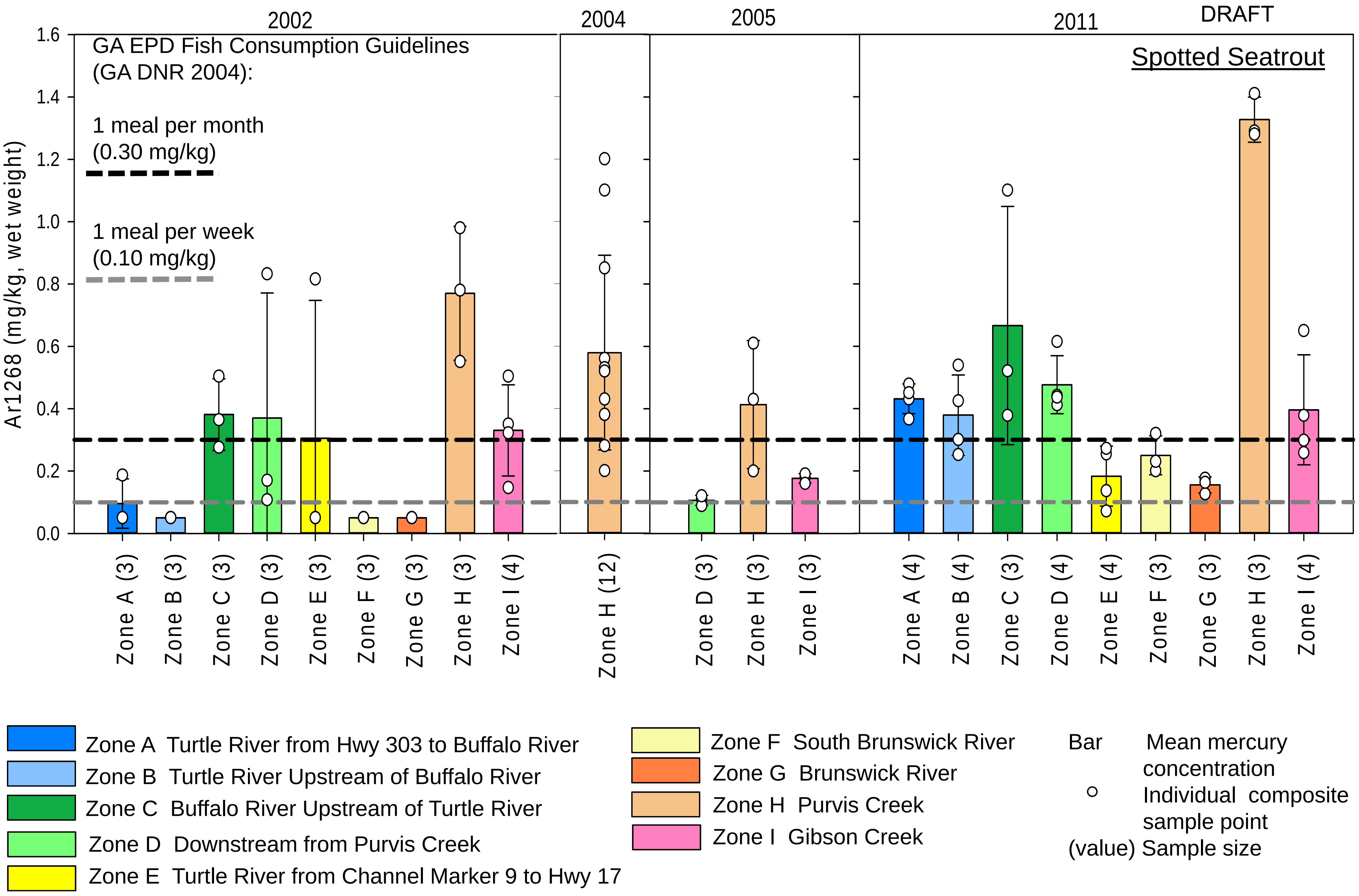


Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Spotted Seatrout

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3T



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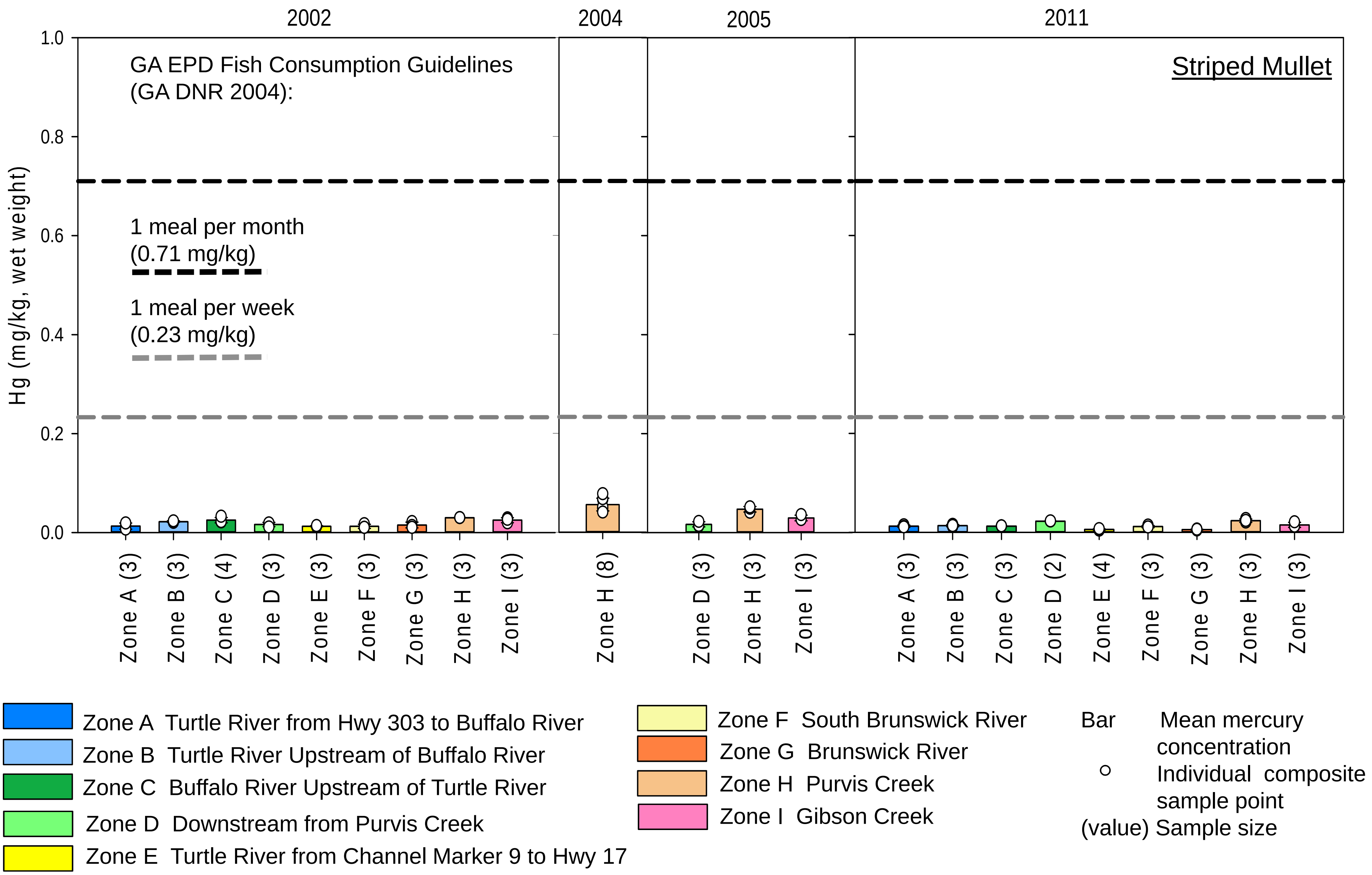
Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Spotted Seatrout

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3U

DRAFT



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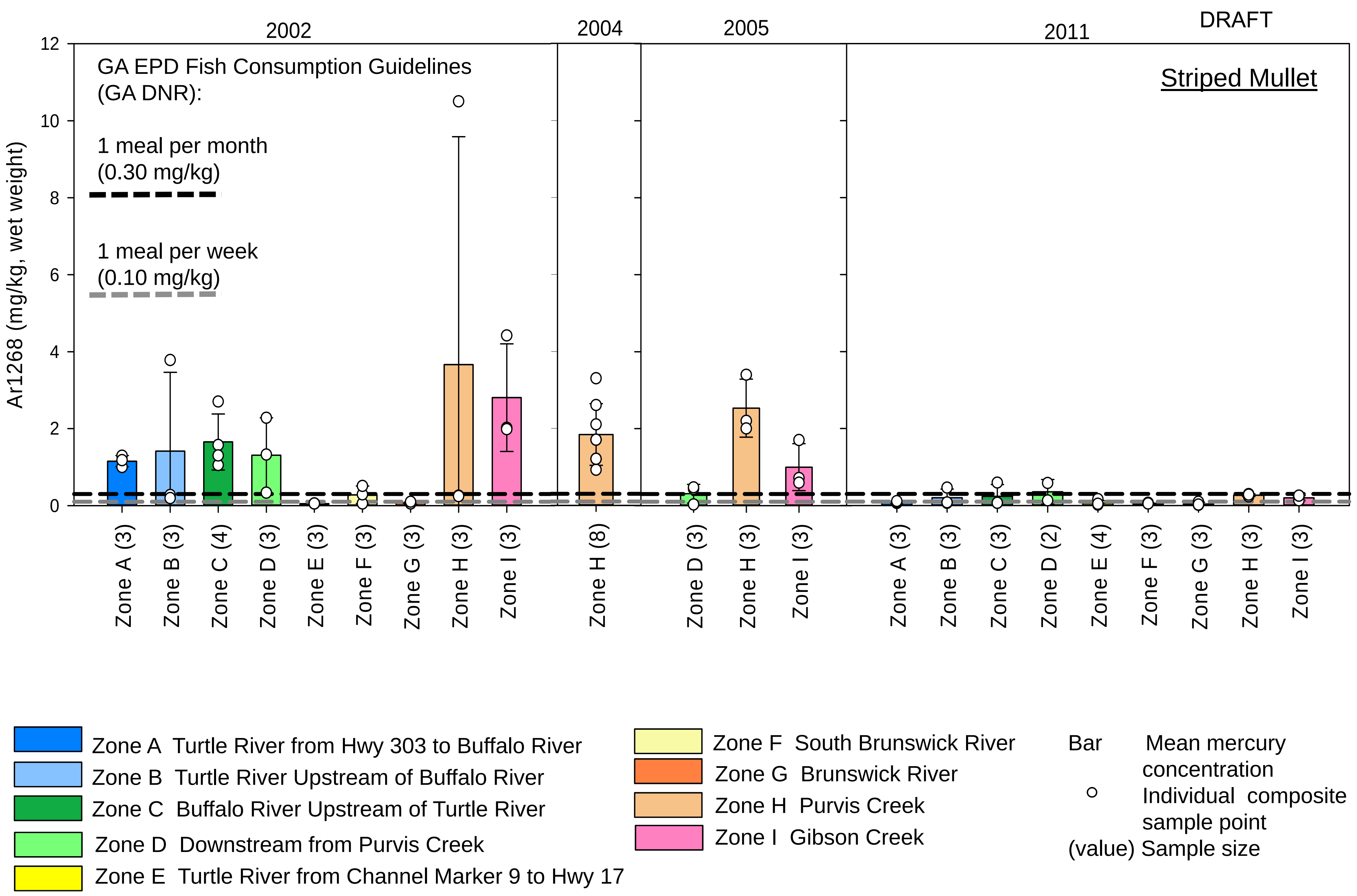
Comparison of Mercury Fillet Tissue Data for All Years By Location (Wet Weight) for Striped Mullet

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3V



Comparison of Aroclor 1268 Fillet Tissue Data for All Years By Location (Wet Weight) for Striped Mullet

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-3W

Section F-4 Contents: Available Fish and Shellfish Data (Whole Body Tissues, Wet Weight)

This section presents a tabular and graphical presentation of available whole body tissue data from fish and shellfish collected in the TRBE from 1995 to 2011 for Zone H, the LCP Site estuary. In addition, this section provides a graphical summary of all locations sampled in the 2011 fish collection effort. Note that Section 6 and Appendix E2 of the FS provide additional considerations related to whole body fish tissues and the anticipated remedial effectiveness anticipated for whole body fish tissues.

Figure F-4A provides a tabular summary of whole body shrimp, crab, and fish sample counts by year. Each of the figures below provides the "Comparison of Fish and Crab Tissue Data for Multiple Fish Species for the Two Years with the Most Data," as follows:

- Figure F-4B: Mercury
- Figure F-4C: Arcolor 1268

Each of the figures below provides the "Comparison of Fish and Crab Tissue Data for All Years By Location," as follows:

- Figure F-4D: Mercury in Blue Crab
- Figure F-4E: Aroclor 1268 in Blue Crab
- Figure F-4F: Mercury in Black Drum
- Figure F-4G: Aroclor 1268 in Black Drum
- Figure F-4H: Mercury in Red Drum
- Figure F-4I: Aroclor 1268 in Red Drum
- Figure F-4J: Mercury in Spotted Seatrout
- Figure F-4K: Aroclor 1268 in Spotted Seatrout
- Figure F-4L: Mercury in Silver Perch
- Figure F-4M: Aroclor 1268 in Silver Perch
- Figure F-4N: Mercury in Striped Mullet
- Figure F-4O: Aroclor 1268 in Striped Mullet

DRAFT

Species Collected	Fish Count Per Year										Grand Total
	1995	1997	2000	2002	2003	2004	2005	2006	2007	2011	
Black Drum	0	0	2	8	8	0	8	8	8	10	52
Blue Crab	0	0	14	14	14	0	14	14	7	33	110
Brown Shrimp	7	0	0	0	0	0	0	0	0	0	7
Flounder	0	0	0	0	0	0	5	0	0	0	5
Mummichog	0	9	0	0	0	0	0	0	0	0	9
Red Drum	0	0	0	1	8	0	14	3	4	11	41
Sheepshead	0	0	0	0	0	0	6	0	0	0	6
Silver Perch	0	0	8	8	8	0	8	8	8	32	80
Southern Kingfish	0	0	0	0	0	0	4	0	0	0	4
Spot	0	0	1	0	0	0	2	0	0	0	3
Spotted Seatrout	0	0	1	8	8	0	8	8	8	32	73
Striped Mullet	0	0	0	0	0	0	8	8	3	21	40
White Shrimp	0	0	0	0	0	0	9	0	0	0	9

Notes:
(a) Fish counts are for all zones (Zone A to Zone I).
(b) 2005 and 2011 (highlighted in yellow) have the largest sample counts and allow the most robust comparison over time.

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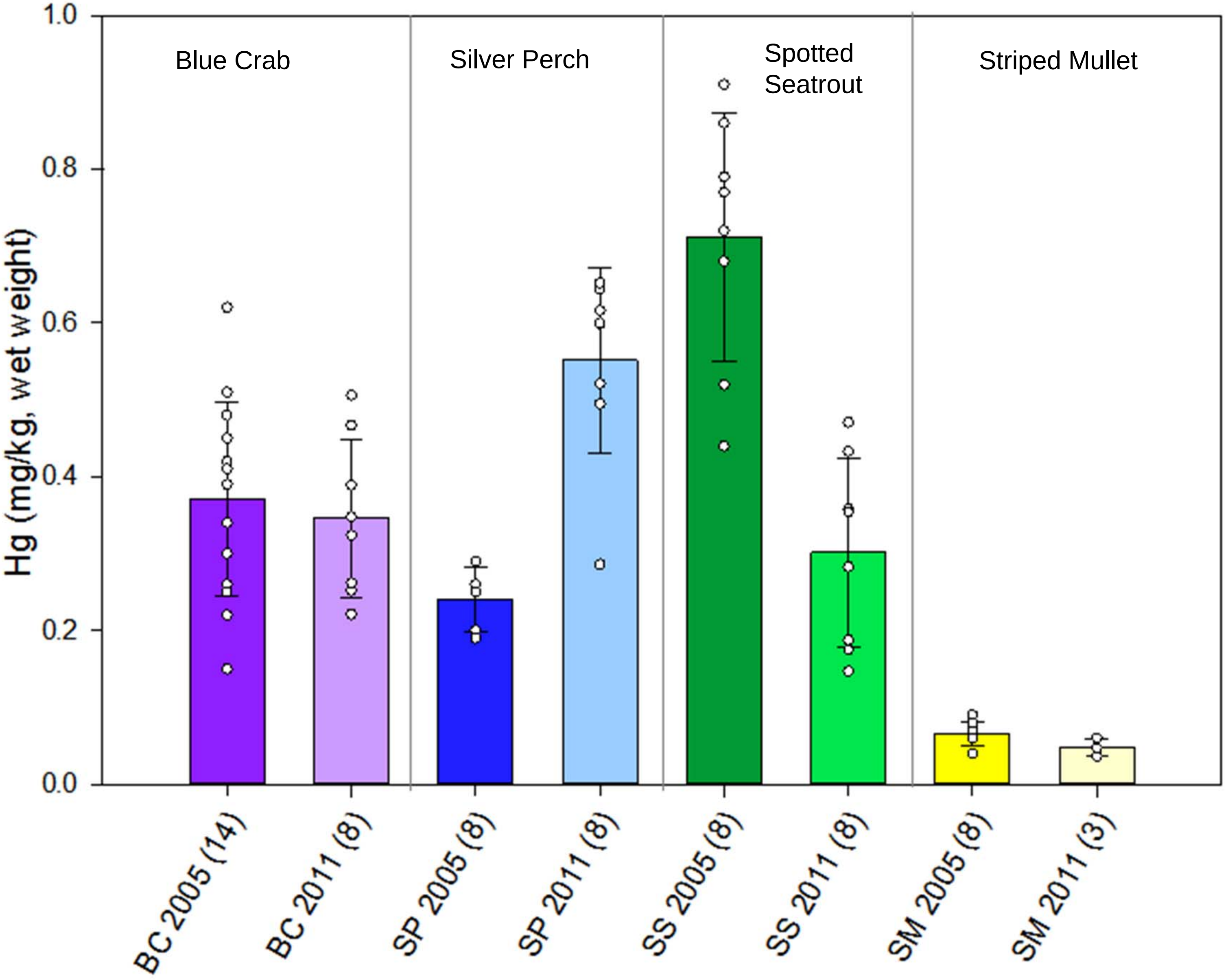
Tabular Summary Of Whole Body Shrimp, Crab, and Fish Sample Counts By Year For All Zones

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4A

DRAFT



BC	Blue Crab
SM	Striped Mullet
SP	Silver Perch
SS	Spotted Seatrout
(value)	Sample size

Red drum and black drum were available in 2005, but neither were captured in 2011.

Bar	Mean mercury concentration
○	Individual composite sample point

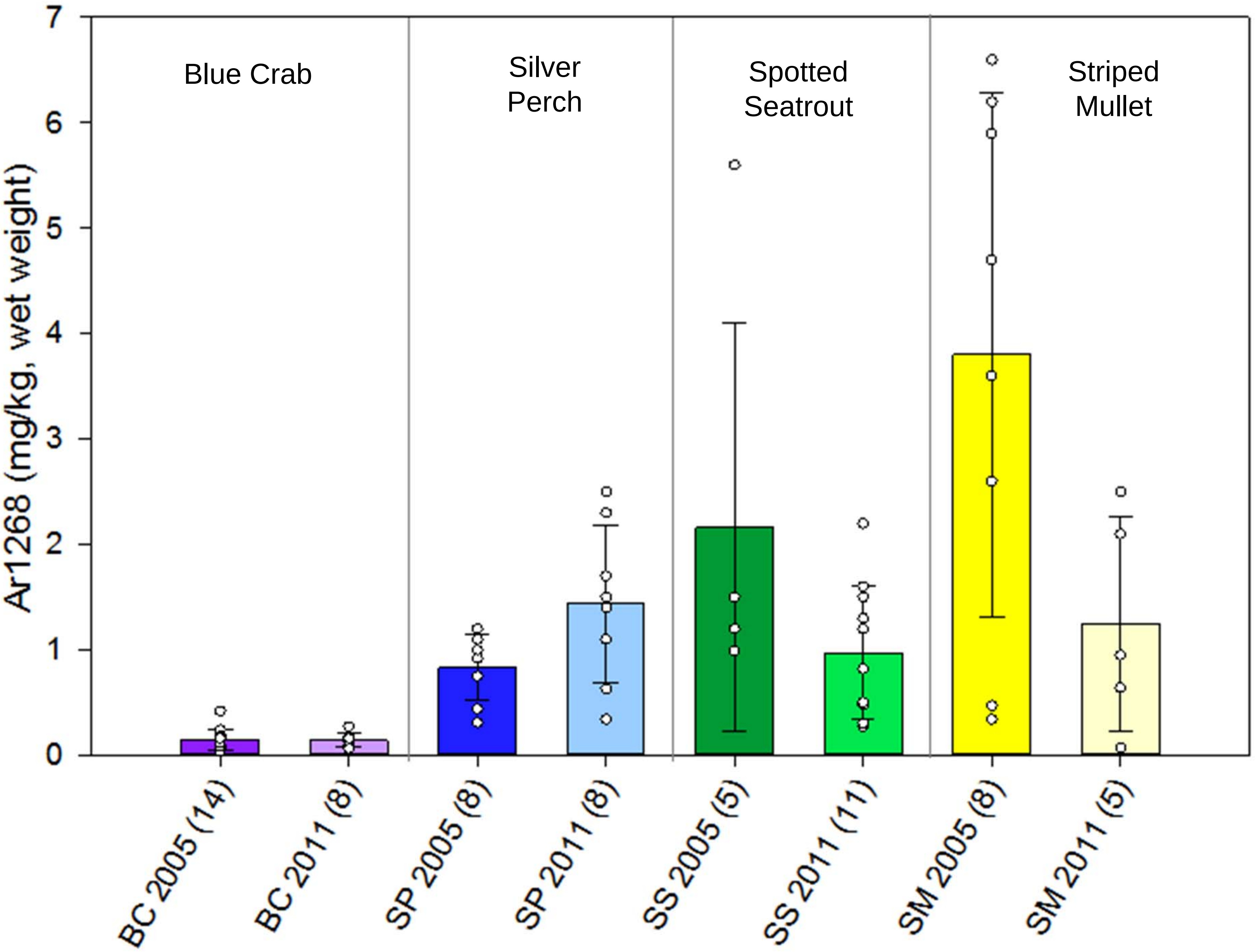
Comparison of Mercury for Multiple Fish Species in Whole Body Crab and Fish Tissues for the Two Years with the Most Data for Zone H (2005 vs. 2011, wet weight)

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4B

DRAFT



BC	Blue Crab
SM	Striped Mullet
SP	Silver Perch
SS	Spotted Seatrout
(value)	Sample size

Red drum and black drum were available in 2005, but neither were captured in 2011.

Bar	Mean mercury concentration
○	Individual composite sample point

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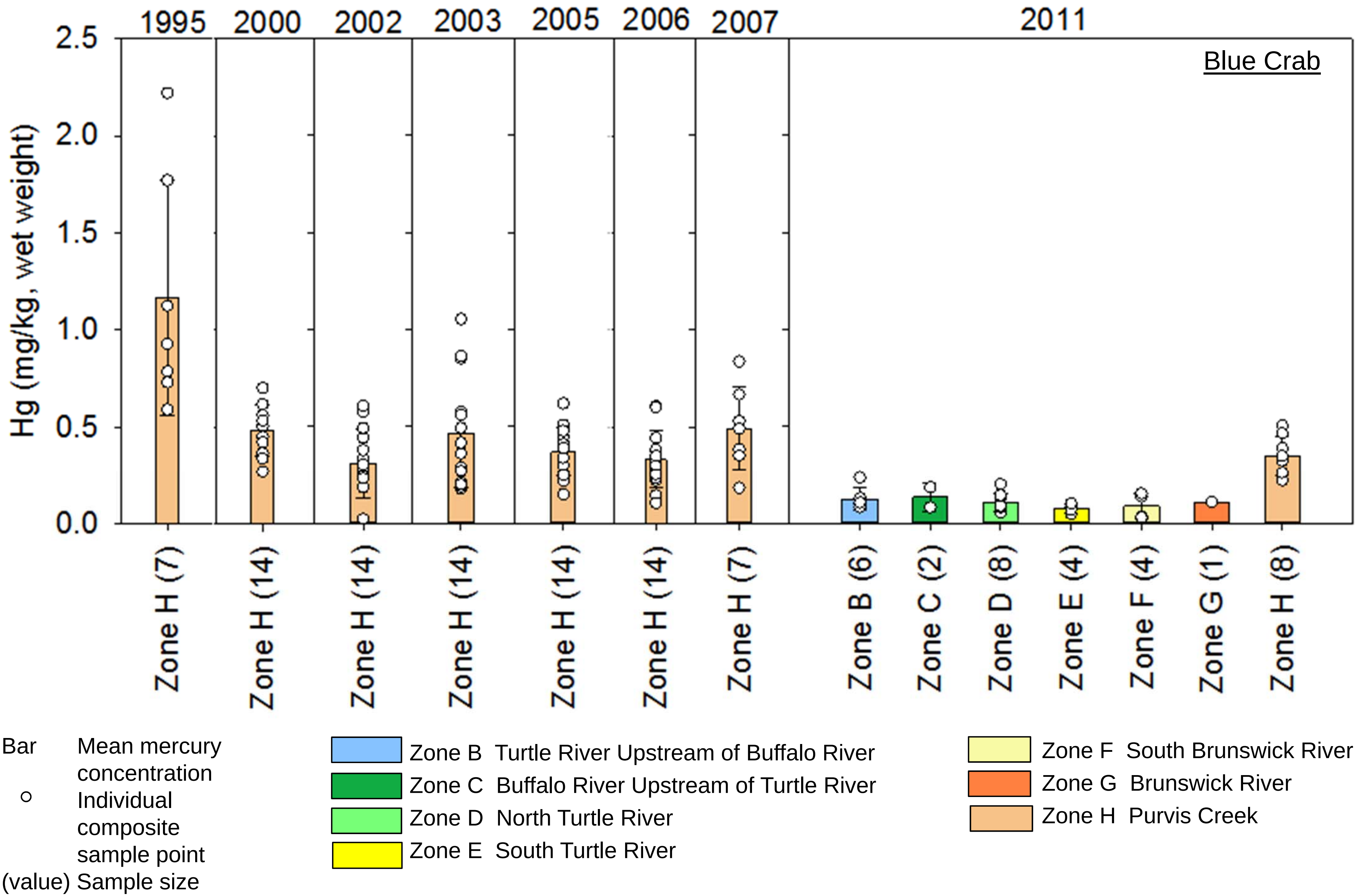
Comparison of Aroclor 1268 in Whole Body Crab and Fish Tissues for the Two Years with the Most Data for Zone H (2005 vs. 2011, wet weight)

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4C

DRAFT



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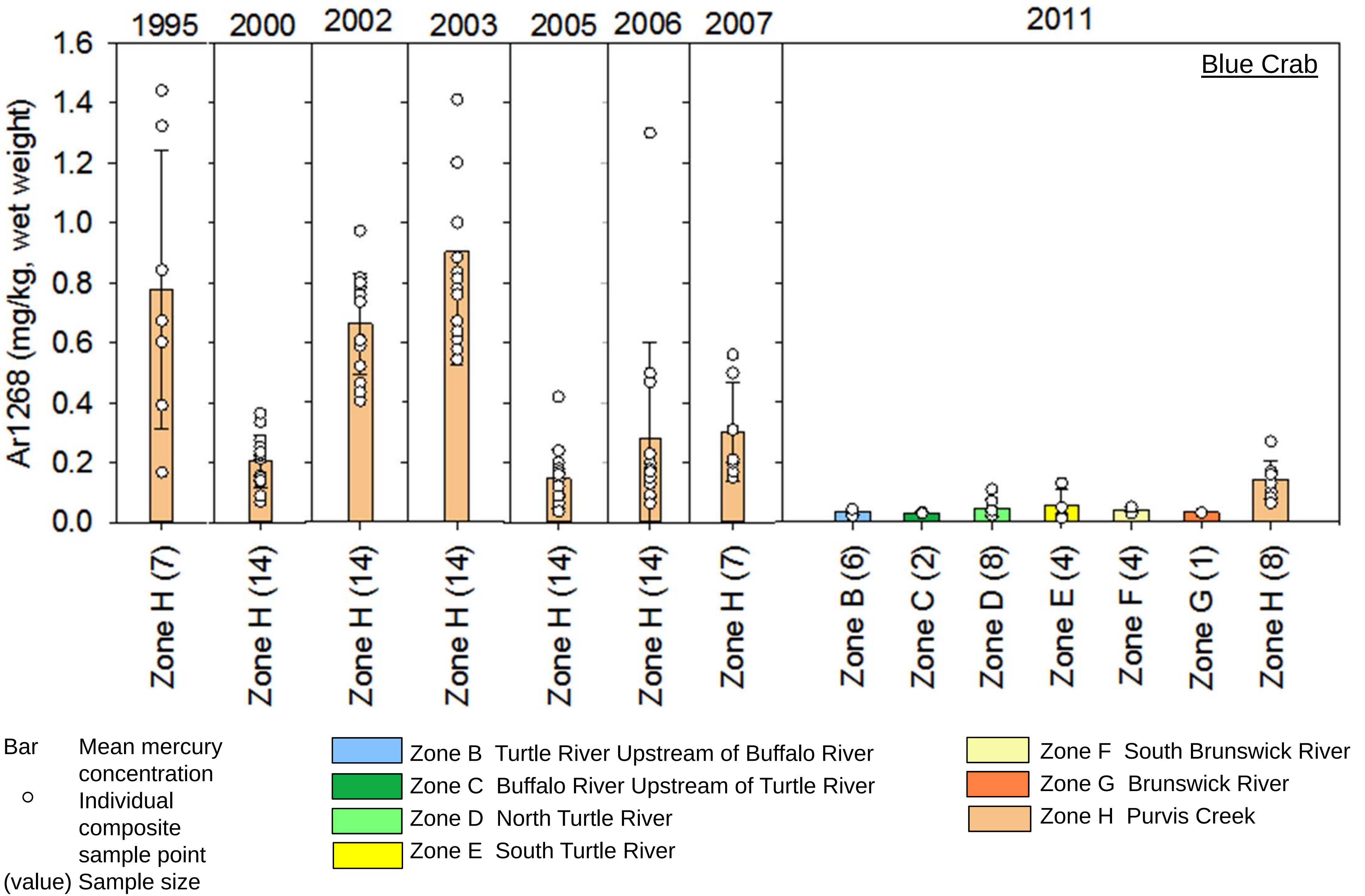
Comparison of Whole Body Mercury Crab Tissue Data for All Years By Location (Wet Weight) for Blue Crab

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4D

DRAFT



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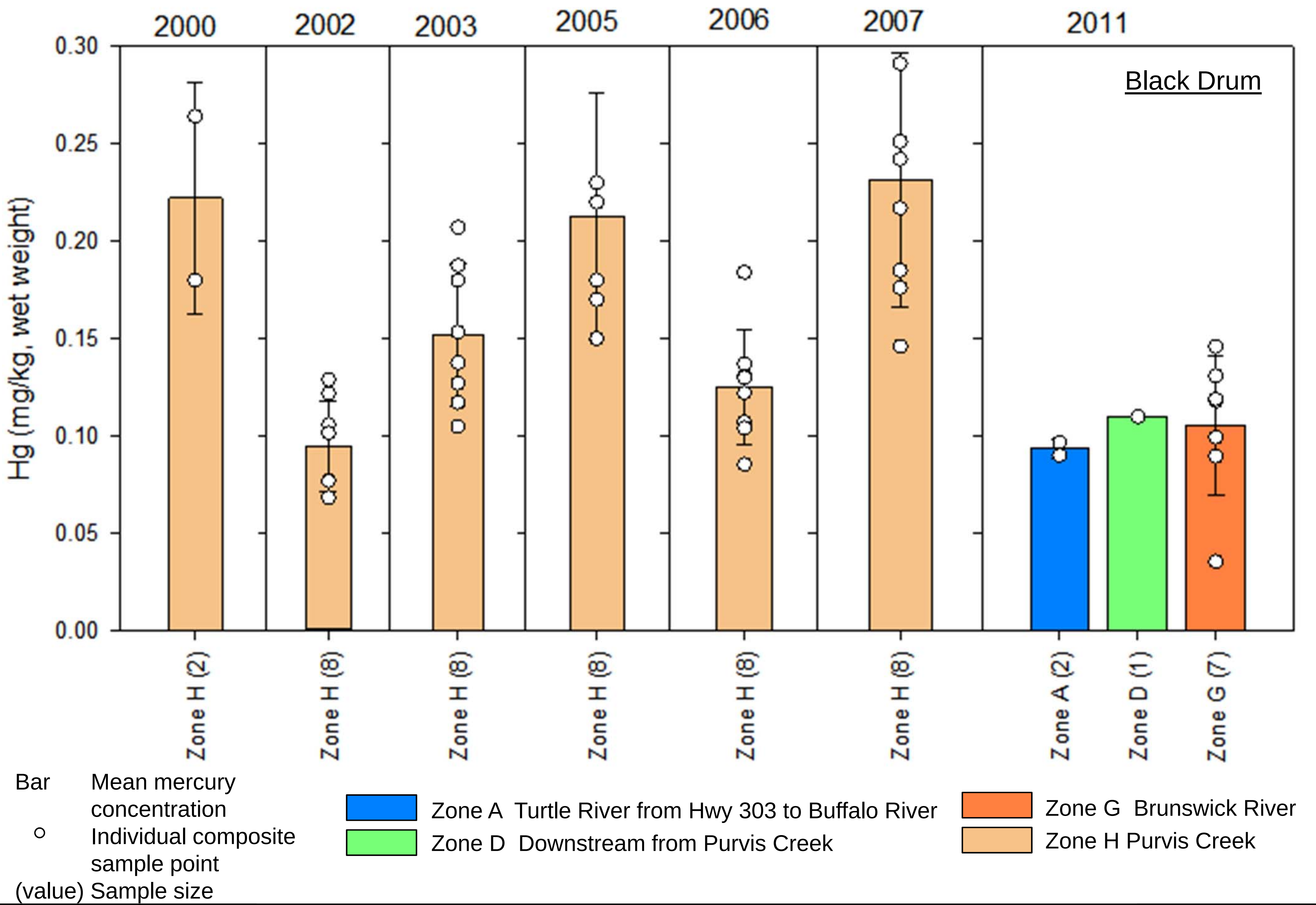
Comparison of Whole Body Aroclor 1268 Crab Tissue Data for All Years By Location (Wet Weight) for Blue Crab

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4E

DRAFT



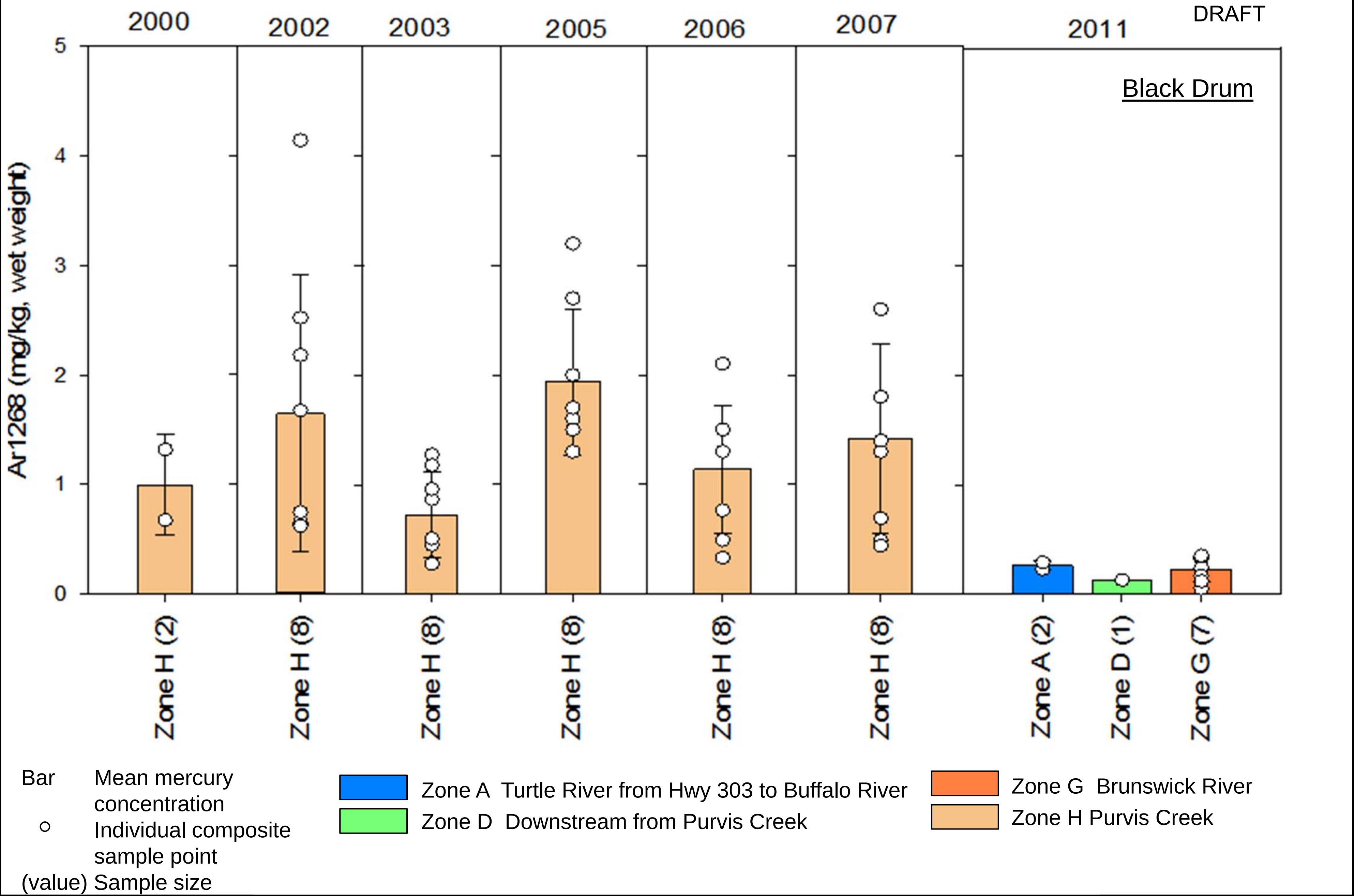
Comparison of Whole Body Mercury Fish Tissue Data for All Years By Location (Wet Weight) for Black Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4F

DRAFT



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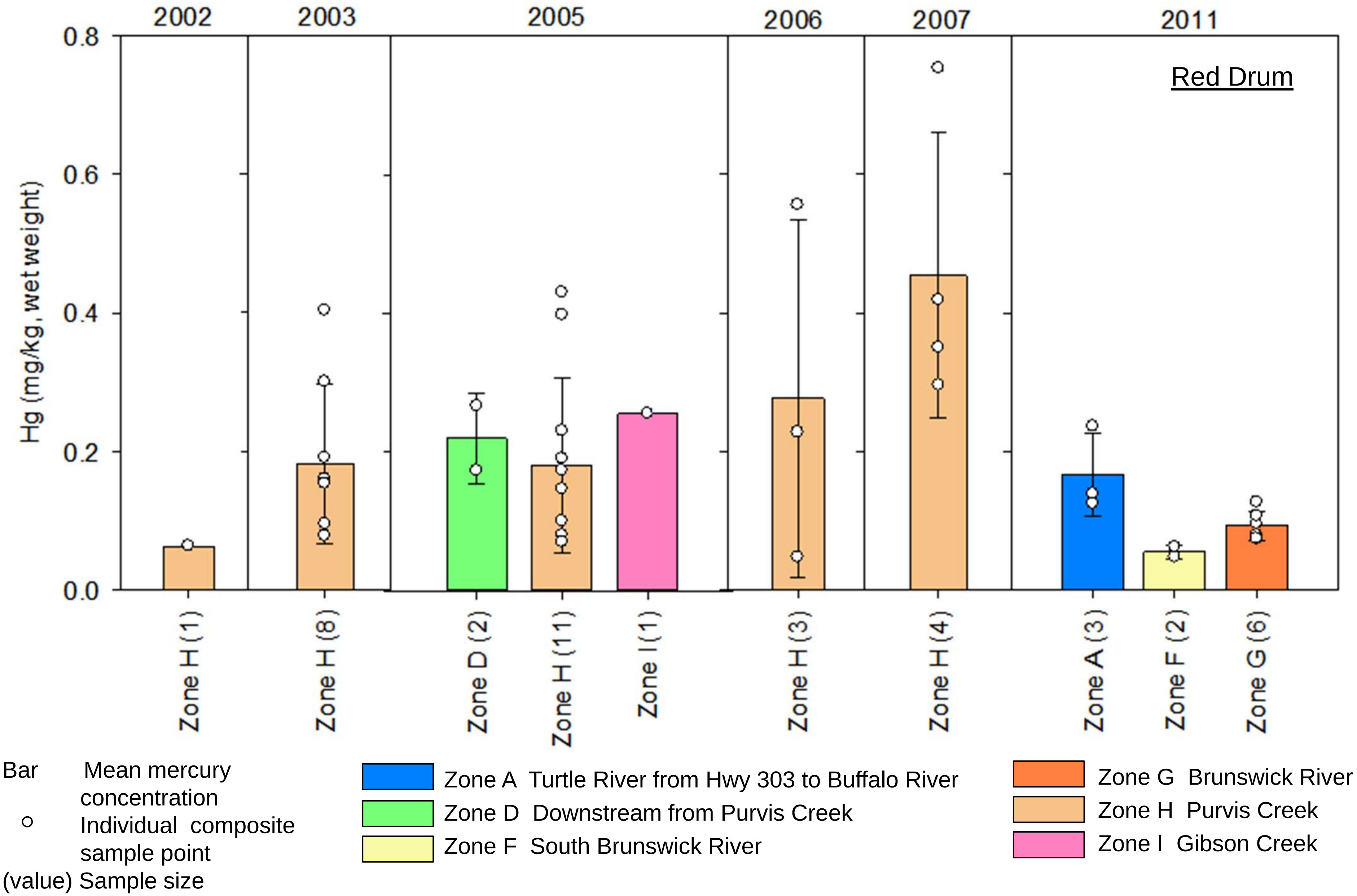
Comparison of Whole Body Aroclor 1268 Fish Tissue Data for All Years By Location (Wet Weight) for Black Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4G

DRAFT



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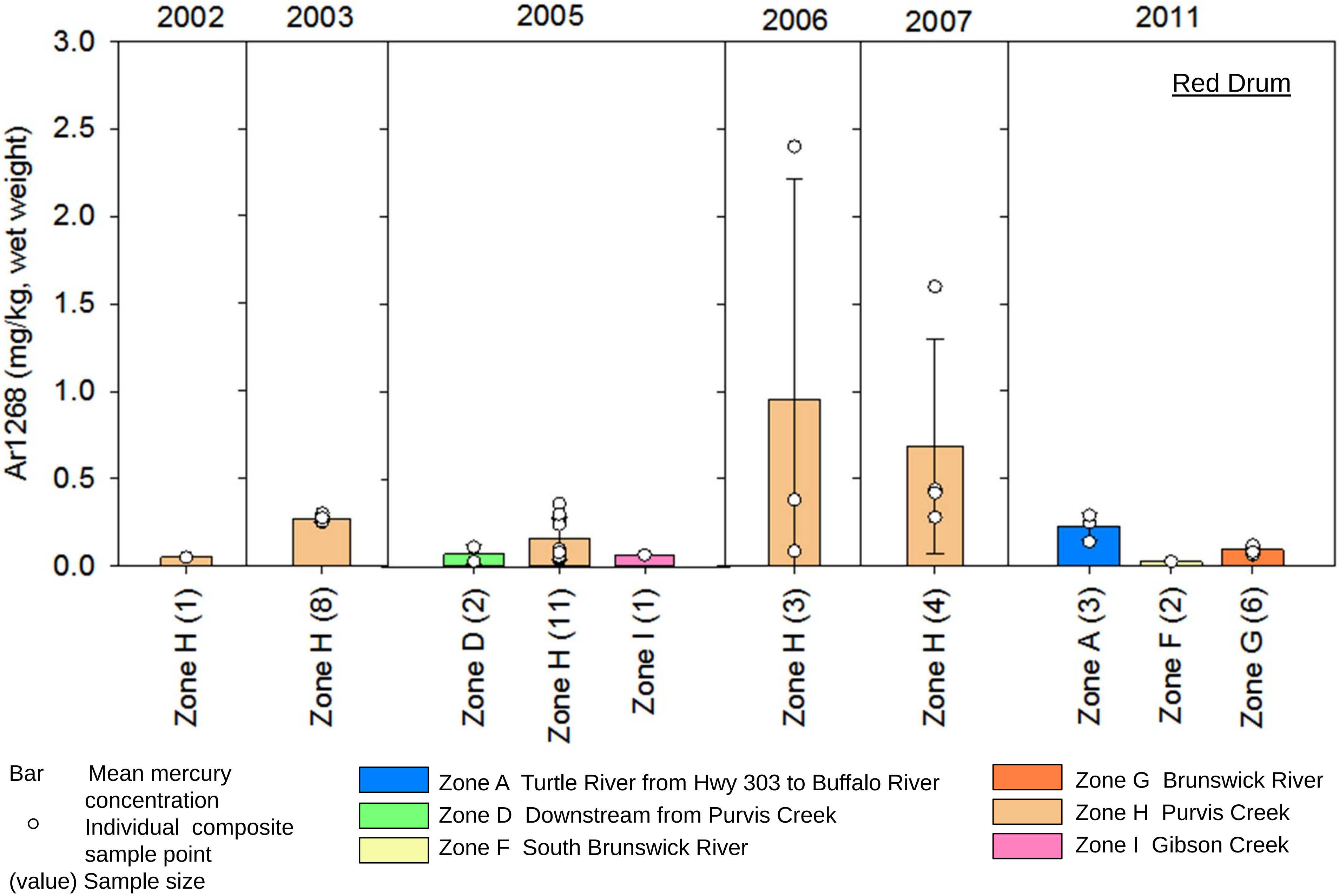
Comparison of Whole Body Mercury Fish Tissue Data for All Years By Location (Wet Weight) for Red Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4H

DRAFT



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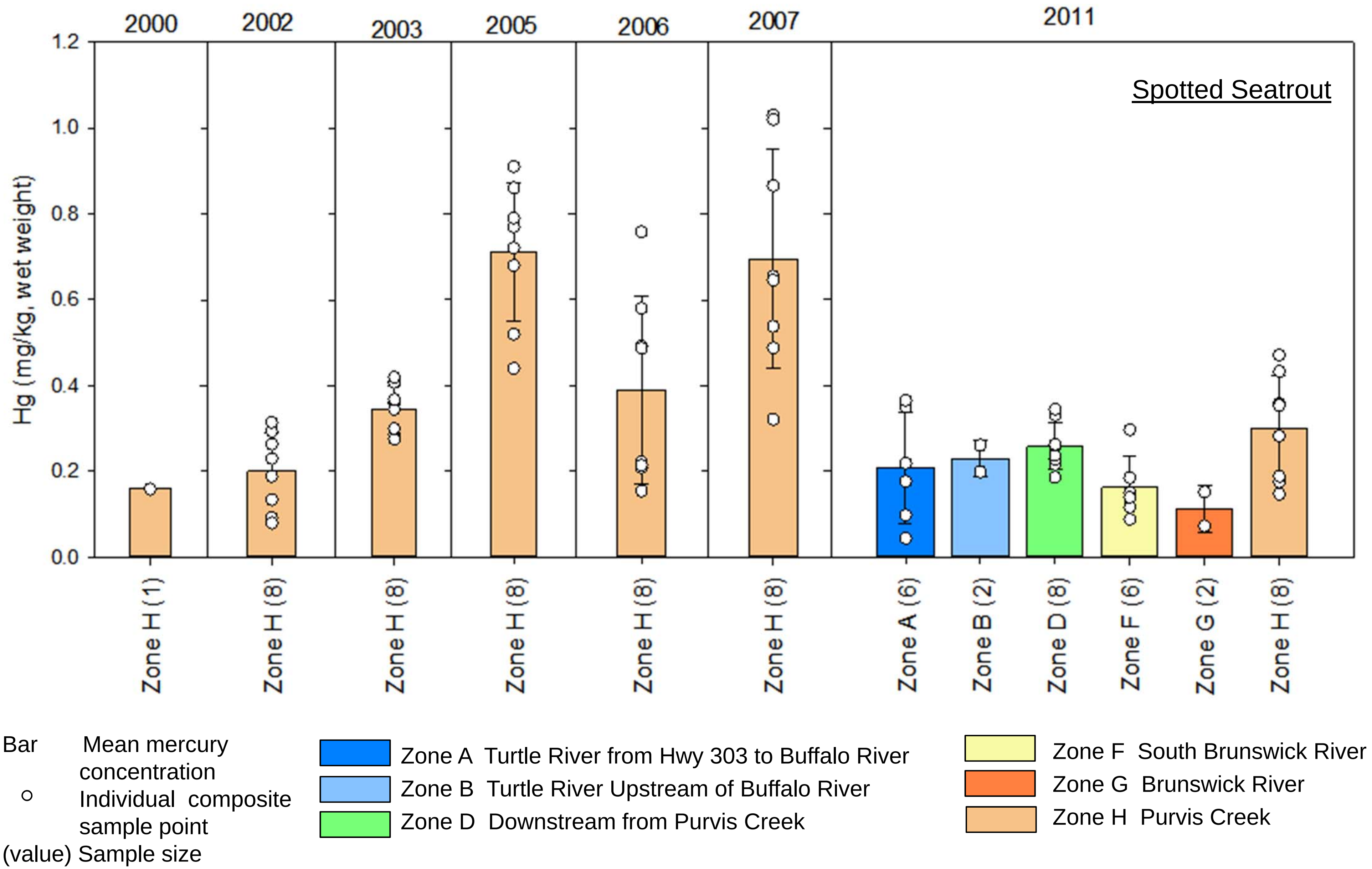
Comparison of Whole Body Aroclor 1268 Fish Tissue Data for All Years By Location (Wet Weight) for Red Drum

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4I

DRAFT



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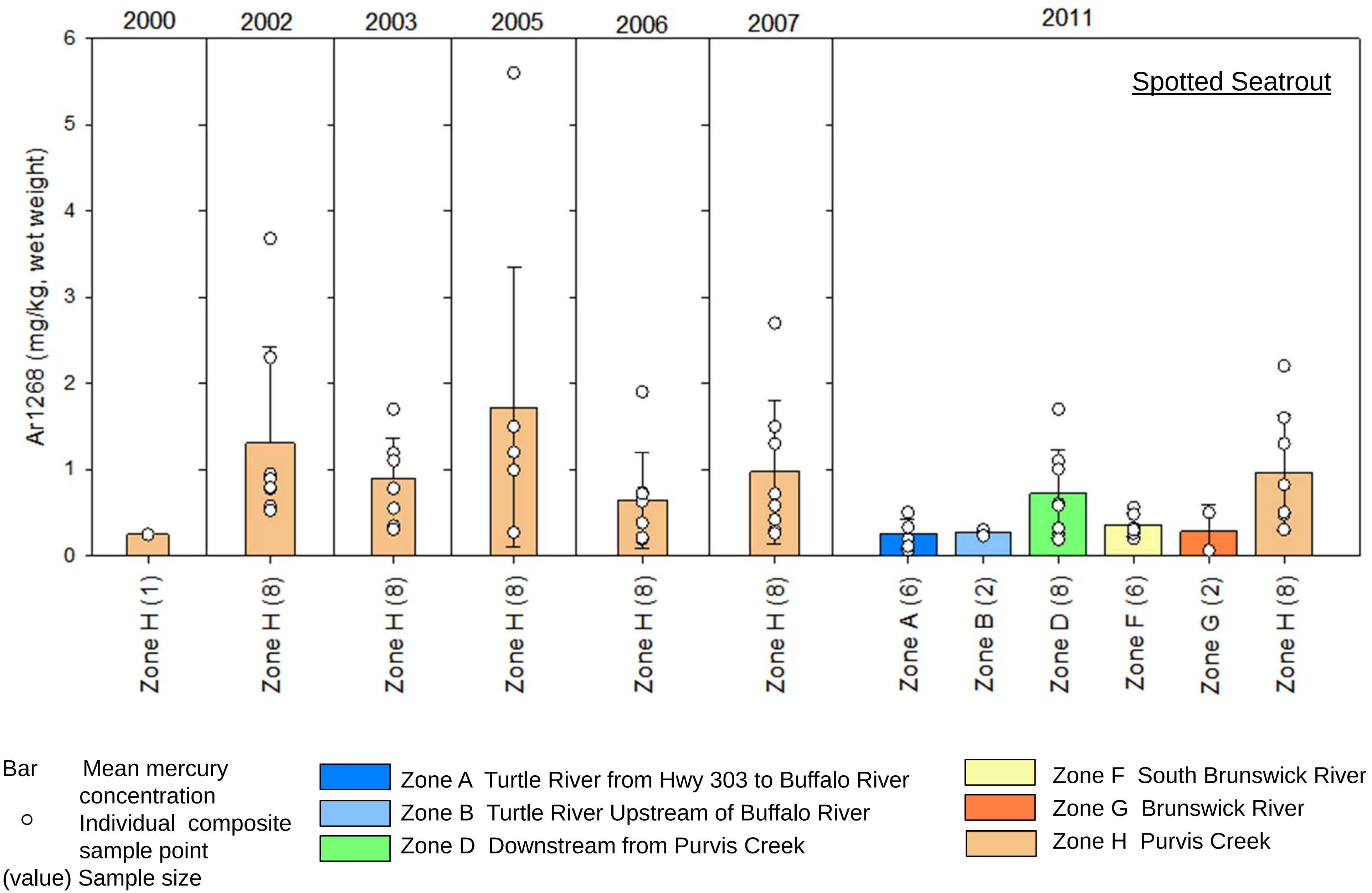
Comparison of Whole Body Mercury Fish Tissue Data
for All Years By Location (Wet Weight) for Spotted Seatrout

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4J

DRAFT



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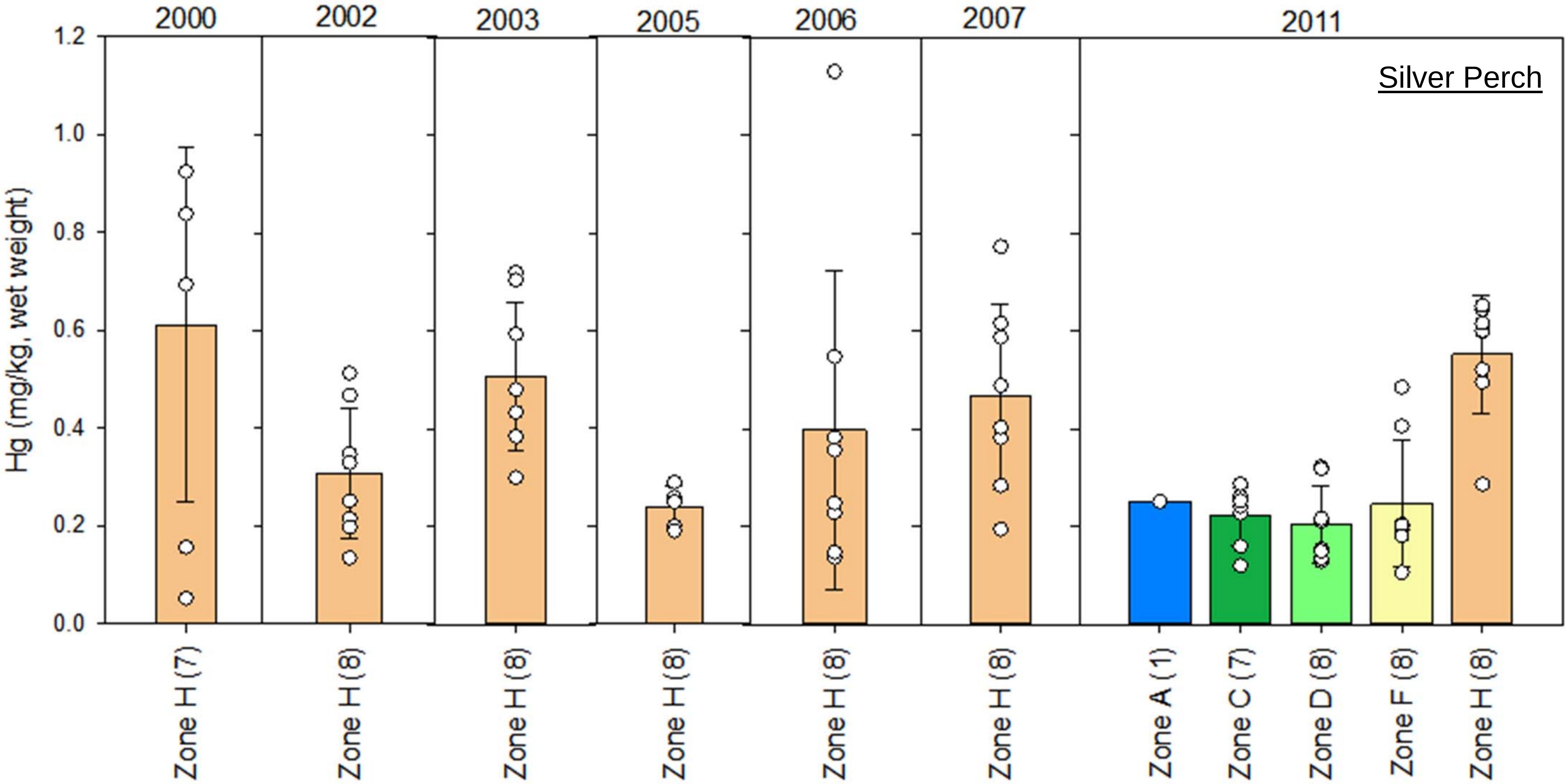
Comparison of Whole Body Aroclor 1268 Fish Tissue Data for All Years By Location (Wet Weight) for Spotted Seatrout

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4K

DRAFT



Bar Mean mercury concentration

○ Individual composite sample point

(value) Sample size

🟦 Zone A Turtle River from Hwy 303 to Buffalo River

🟩 Zone C Buffalo River Upstream of Turtle River

🟩 Zone D Downstream from Purvis Creek

🟨 Zone F South Brunswick River

🟧 Zone H Purvis Creek

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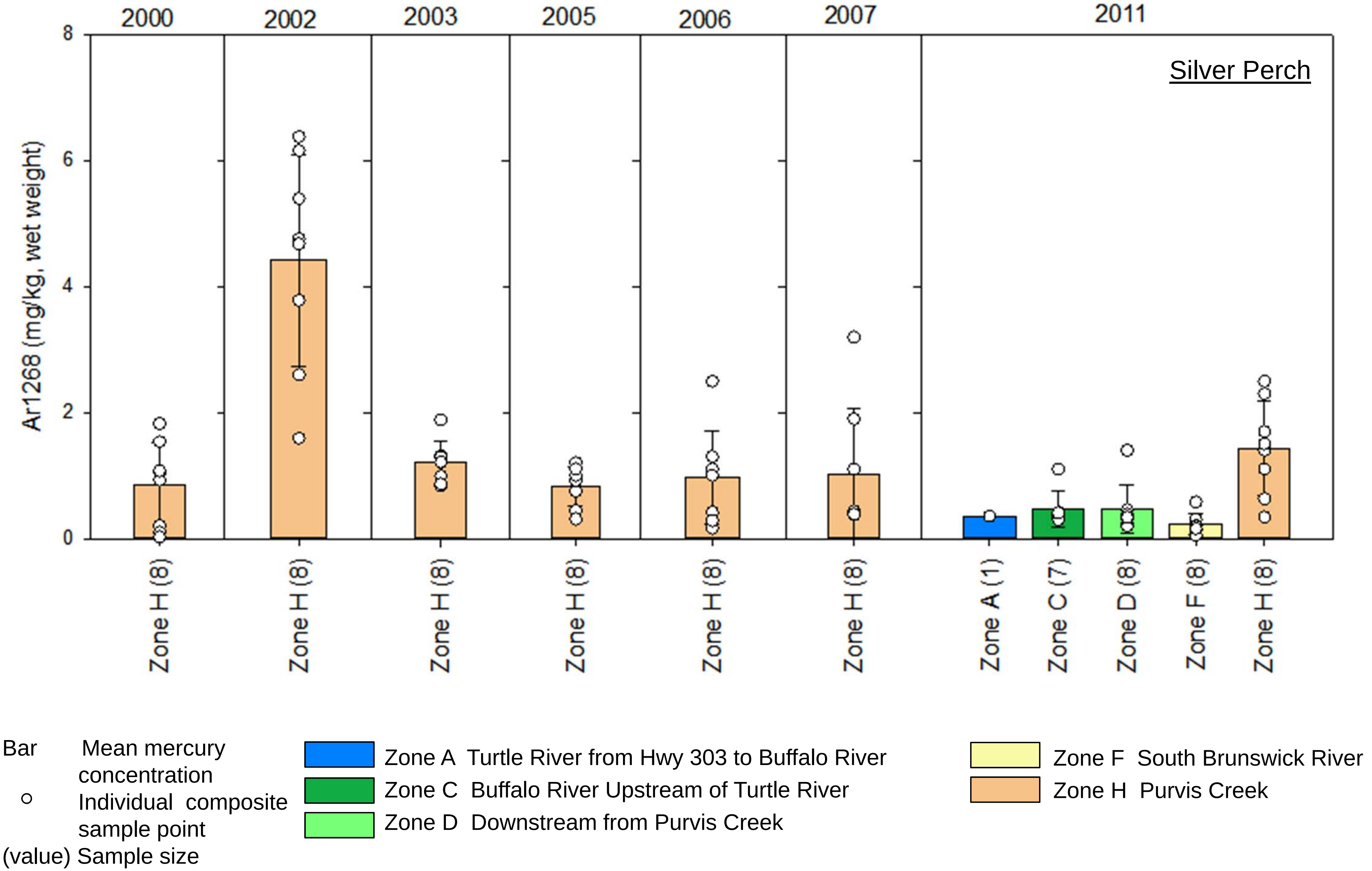
Comparison of Whole Body Mercury Fish Tissue Data for All Years By Location (Wet Weight) for Silver Perch

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4L

DRAFT



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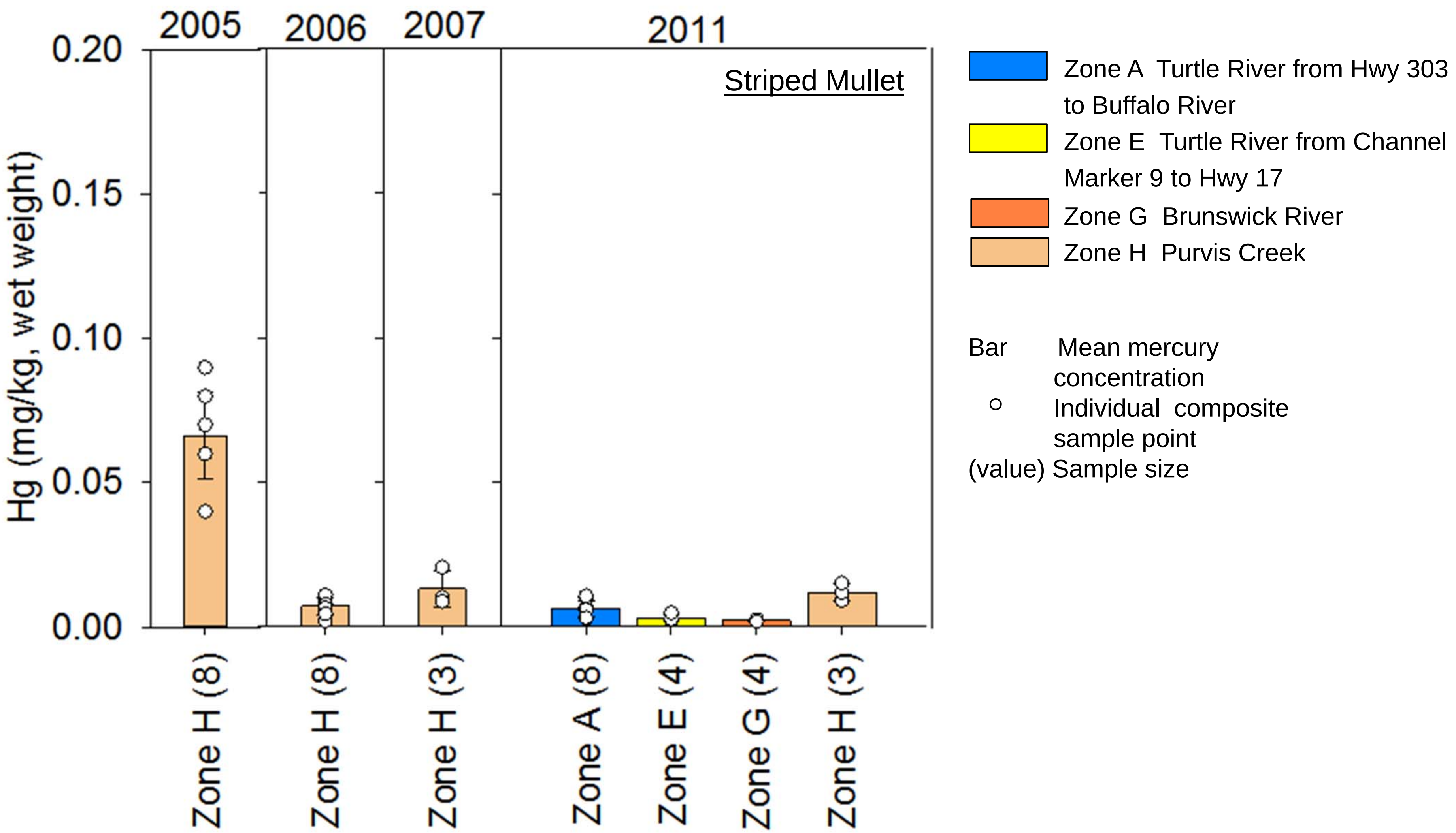
Comparison of Whole Body Aroclor 1268 Fish Tissue Data for All Years By Location (Wet Weight) for Silver Perch

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4M

DRAFT



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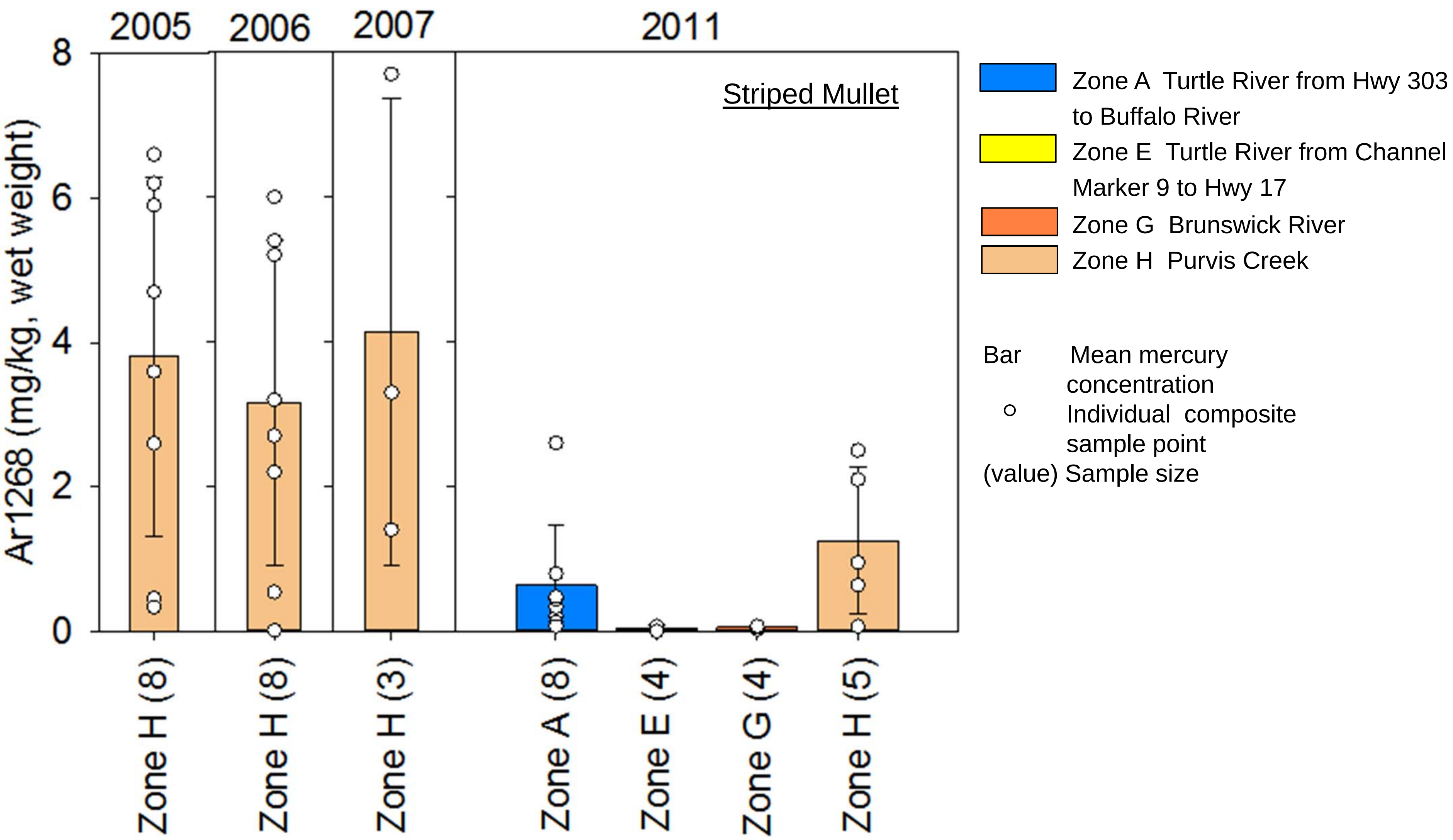
Comparison of Whole Body Mercury Fish Tissue Data for All Years By Location (Wet Weight) for Striped Mullet

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4N

DRAFT



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Comparison of Whole Body Aroclor 1268 Fish Tissue Data for All Years By Location (Wet Weight) for Striped Mullet

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

Figure

F-4O

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Appendix G
Basis for Estimated Costs

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
Anchor QEA, LLC

ENVIRON International Corporation

Date:
March 29, 2013

Contents

List of Tables

Acronyms and Abbreviations

CM	construction management
CQA	construction quality assurance
CY	cubic yard
FS	feasibility study
GAC	granular activated carbon
gpm	gallons per minute
LTM	long term monitoring
TSCA	Toxic Substances Control Act

1 Introduction

This appendix provides the basis for the cost estimate presented in Section 6 of the *Feasibility Study - LCP Chemical Superfund Site, Operable Unit No. 1 (Estuary), Brunswick, GA* (FS) Report. Six sediment remedial alternatives were evaluated, including:

- Alternative 1: No action
- Alternative 2: Sediment Removal in SMA-1
- Alternative 3: Sediment Removal, Capping, and Thin Cover in SMA-1
- Alternative 4: Sediment Removal in SMA-2
- Alternative 5: Sediment Removal, Capping, and Thin Cover in SMA-2
- Alternative 6: Sediment Removal, Capping and Thin Cover in SMA-3

The six alternatives include, in some combination, the following items:

- Removal of 1.5 feet of sediment with placement of 1 foot of clean backfill material
- Placement of cap material consisting of a 6-inch sand isolation layer and a 6-inch erosion protection layer
- Thin-cover placement involving application of a thin layer of 6 inches of clean material over existing vegetated marsh areas

Table G1 summarizes dredge volumes and remediation areas associated with each of the remedy components included in each alternative. Some of the key factors incorporated in the development of estimated cost for each alternative include the following items:

- Large tidal variations, ranging from 7 to 9 feet
- Narrow creeks (less than 10 ft wide) with shallow draft (less than 2 ft) restrictions
- Daily inundation of offshore work areas
- Limited land access to offshore remediation areas
- Low strength marsh environment, limiting equipment productivity/effectiveness

The cost estimate includes indirect (non-construction and overhead) costs, direct (construction) costs and reoccurring costs (annual operation and maintenance). All estimated costs are provided in 2013 dollars.

The following sections describe the basis of the cost estimate. **Section 2** summarizes the indirect costs associated with each of the alternatives. **Section 3** describes the direct construction costs associated with each of the remedial technologies that make up the sediment remedial alternatives. **Section 4** outlines reoccurring costs associated with the remedy, and **Section 5** provides a summary overview of the estimated costs by remedy alternative.

In order to arrive at a reasonable, FS-level cost estimate, various assumptions were made regarding the predicted means and methods of construction. Many of these assumptions may change during the design and contractor bidding processes. Thus, they are intended only to establish a basis for costs and are not intended to direct the means and methods of construction.

2 Indirect Costs

Indirect costs include non-construction and overhead-related costs. For the FS, indirect costs include costs associated with the implementation of institutional controls, studies, design (engineering, plans and specifications), project management, and construction management.

2.1 Institutional Control

Institutional control costs are included as a single lump-sum cost item for each alternative; costs are assumed to be consistent between alternatives and are not expected to vary significantly based on remedy footprint or construction methodology.

2.2 Predesign investigation and Reporting

The pre-design investigations and reporting are included in all alternatives as a single lump-sum cost item; costs are assumed to be consistent between alternatives and are not expected to vary significantly based on remedy footprint or construction methodology. This cost is representative of the anticipated costs to collect and analyze pertinent information (e.g., bench scale sediment dewatering, stabilization, debris and topographic surveys) prior to final design of the selected alternative.

2.3 Remedial Design

The remedial design costs are estimated as 8% of the total direct construction costs of each alternative. This determination was based on past experience with design effort and agency interaction on projects of similar scope.

2.4 Construction Management

The construction management (CM) costs have been estimated in this analysis as 8% of the total direct construction costs of each alternative. This determination was based on past experience with CM and construction quality assurance (CQA) efforts on projects of similar site conditions.

3 Direct Construction Costs

Direct construction costs were developed using estimated material quantities and anticipated labor crew, construction equipment, and production rate estimates. Direct construction tasks include mobilization and site preparation, dredging operations, capping operations, thin cover placement operations, marsh restoration, and demobilization and staging-area restoration.

The construction schedule varies for each sediment remedial alternative based on dredging quantity, capping area, and expected production rates throughout the various conditions of the LCP Site, Operable Unit 1 (OU1). The construction season is not restricted, and remedial activities are expected to occur year round. Costs assume a 12 hours per day, 5 days per week schedule.

3.1 Mobilization and Site Preparation

Mobilization and site preparation cost elements include the following costs associated with materials, equipment, and labor:

- Mobilization of general construction support material and equipment to the site
- Establishing necessary temporary facilities at the site
- Construction of the staging areas (for regulated and non-regulated material)
- Installation of soil erosion and sediment controls
- Construction of access roads to the remediation areas

The majority of the cost elements in this section are presented on a lump-sum basis to represent the cost of completing each element, and it is assumed that minimal additional costs for maintenance/repair during construction are required. Mobilization of equipment, access roads and associated costs are proportional to the scope and extent of each remedial footprint of each alternative (**Table G2**).

3.2 Dredging

Sediment removal cost elements include bathymetric and topographic surveys, debris removal, sediment removal, turbidity controls and water quality monitoring, sediment dewatering/stabilization, transport and disposal of removed sediments, shoreline stabilization along creek boundaries, and backfill testing and placement operations.

Sediment removal costs were developed separately for different areas of OU1 to differentiate costs associated with deep-water removal (North and South Purvis Creek), shallow-water/marsh removal (LCP Ditch, Eastern Creek, Western Creek Complex, Domain 3 Creek, Dillon Duck, Domain 1A Marsh, Domain 2 Marsh & Domain 3 Marsh), and removal of regulated or non-regulated material.

Equipment and labor assumed for deep-water removal includes excavators operating on flexi-float platforms and performing sediment removal using a hydraulically operated environmental bucket. Sediment would be removed and placed into small scows and transported to a temporary mooring facility. Material would be offloaded mechanically and transported by truck to the on-site staging area for dewatering/stabilization.

The anticipated equipment and labor assumed for shallow water/marsh removal includes excavators operating from landside using mats and/or the constructed access road for access to the remedy areas. Removal would be performed using a hydraulically operated environmental bucket. Sediment would be removed and placed into trucks and transported to the on-site staging area for dewatering and/or stabilization.

Approximately 1 foot of clean material will be backfilled over the areas where sediment was removed utilizing the same equipment used for sediment removal operations. Material is expected to be placed in a manner to minimize compaction and to promote re-establishment of benthic or marsh habitat.

Excavated material is expected to dewater on a constructed slack drying pad prior to stabilization. Material transported via truck will be end dumped onto the pad and managed to promote drying of the sediments. Once free water has been removed, material will be stabilized for transportation and disposal using Portland cement or other pozzolanic materials, assumed for this estimate to be blended in at a 15% by weight ratio. Blending is assumed to be accomplished using a hydraulic excavator used to turn over sediment and mix in reagent prior to load out. Water generated during the dewatering and handling process will be managed through an on-site water treatment plant.

Once the material is sufficiently dewatered and stabilized, it will be transported to an approved disposal facility. Costs currently assume regulated material will be transported to and disposed at a Toxic Substances Control Act (TSCA) facility—assumed to be the facility in Emmelle, Alabama for the purpose of this cost estimate. Non-regulated materials are assumed to be disposed at the Camden County, Georgia landfill facility. Debris removed from within the allowable dredging limits will also be transported to the Camden County, Georgia landfill for disposal.

Costs associated with the health and safety program at the site vary throughout construction based on the duration and number of concurrent operations. Costs include time and materials for a certified industrial hygienist to be present on site.

3.2.1 Quantities

Sediment removal volumes have been calculated using a 1.5-foot removal depth over the entire remedial footprint designated for sediment removal for each alternative. A 0.5-foot overdredging allowance was added to the proposed removal depth to account for removal inefficiencies. The total removal volumes represent the combination of the deep water, shallow water and marsh removal volumes.

Dewatering operations costs assume that the full volume of sediment removed from the site will be processed at an on-site dewatering and stabilization area. Costs assume the use of a stabilization agent at a rate of 15% by weight, to aid dewatering.

Disposal volumes are calculated assuming a density of dewatered sediment at 1.35 tons per cubic yard (CY). Debris volume is calculated as 15% of the total removal.

Backfill placement volumes assume a 1.0-foot sand backfill layer will be placed over the entire dredging area following removal operations. A 0.25-foot overplacement tolerance is added to the proposed placement thickness, which adjusts the total estimated backfill placement volume to represent a 1.25-foot layer over the entire dredging footprint.

3.2.2 Unit Costs

Dredging unit rates consider labor, equipment, and materials necessary to complete operations and integrate a projected production rate to determine a cost per cubic yard of removal. These costs include costs associated with sediment removal, dewatering/stabilization, transportation and disposal, and backfilling of dredge areas. Production rates are calculated assuming equipment capacities and cycle times (**Table G3**). Production rates consider operational downtime due to typical maintenance, repairs, and tidal cycle impacts. Costs for removal of regulated material include decontamination at the end of operations.

Dewatering unit costs assume passive dewatering of the mechanically-dredged sediment and operation of an on-site water treatment system. For water treatment, a 300-gallon-per-minute (gpm) system with granular activated carbon (GAC), organoclay, and metals media was assumed. It was also assumed that treatment media is replaced every 3 months during dewatering operations. The costs for dewatering and water treatment vary depending on the estimated dredging duration that is controlled by the dredging volume.

Transportation costs have been developed for transport and disposal of both regulated and non-regulated material. Regulated material is transported to a disposal facility located in Emmelle, Alabama, and non-regulated material and project debris are transported to the Camden County, Georgia, landfill.

The backfill placement costs were calculated by considering labor and equipment necessary to complete operations and integrating a calculated production rate to determine a cost per CY. Costs for purchase and delivery of the backfill material are included in this line item.

3.3 Capping

Capping includes all cost associated with the purchase, transport and placement of an engineered cap in OU1. Cost elements developed in this section include purchase and placement of the isolation cap layer and the erosion protection layer.

The equipment and labor for deep-water and shallow-water/marsh capping operations are similar to the equipment assumed for sediment removal operations. Placement uses hydraulic excavators operating from flexi-float platforms, or from constructed haul roads to remedial areas. Material is placed using hydraulically-operated environmental clamshell buckets. Production rates are comparable to backfilling operations for dredging.

Health and safety costs depend on the remedy duration and types of equipment associated with the remediation. Costs include time and materials for a certified industrial hygienist based on the duration of capping operations.

3.3.1 Quantities

The proposed cap includes both an isolation layer and erosion protection layer, consisting of sand placed directly over the existing sediments for isolation followed by an armor stone layer for erosion protection. The sand layer is 0.5-foot thick plus 0.25-foot over-placement tolerance for a total layer thickness of up to 0.75 feet. Similarly, the armor stone layer is 0.5-foot thick plus 0.25-foot over-placement tolerance for a total layer thickness of up to 0.75 feet.

3.3.2 Unit Costs

Capping unit rates consider labor and equipment necessary to complete operations and integrate a calculated production rate to determine a cost per cubic yard. Production rates are calculated assuming equipment capacities and cycle times (**Table G4**). When calculating production rates, consideration is given to operational downtime due to typical maintenance, repairs, and tidal cycle impacts.

3.4 Thin Layer Cover Placement

The thin layer cover placement includes costs associated with the purchase, transport and placement of a thin layer cover at designated areas of the marsh. Locations receiving thin layer cover vary depending on the proposed alternative. This cost estimate assumes that thin layer covers will be placed hydraulically, with sand materials slurried for transport and placement in designated areas.

Health and safety costs depend on the duration and types of equipment associated with remediation. Costs include time and materials for a certified industrial hygienist based on the duration of thin layer cover operations.

3.4.1 Quantities

The proposed thin layer cover consists of a sand layer placed directly over the existing sediments. For estimating cost purposes, the thin layer cover was assumed to consist of 0.5-foot thick plus 0.25-foot over-placement tolerance for a total layer thickness of up to 0.75 feet.

3.4.2 Unit Costs

Thin layer cover unit rates considered labor and equipment required to operate the pipeline transport and placement system. Costs are integrated into an estimated production rate. The estimated production rate considers the distance of the proposed thin layer cover areas from the assumed material loading area, percent solids, and equipment capacities (**Table G5**). When calculating production rates, consideration is given to operational downtime due to typical maintenance, repairs, and tidal cycle impacts.

3.5 Marsh Restoration

The marsh restoration includes repairs to areas of the marsh impacted by construction, including access roads. Marsh restoration includes restoring impacted areas with appropriate plantings on 2-foot centers, except for the thin-cover placement areas which do not require plantings to promote recovery. The footprint for marsh restoration varies for each alternative depending on the access road layout necessary to reach the proposed remedial areas.

3.6 Demobilization/Site Restoration

Demobilization and site restoration costs include operations required to restore OU1 to conditions similar to those prior to the start of construction. This includes labor, equipment, and disposal costs to dismantle and dispose of the gravel and asphalt paving used to construct the on-site regulated material staging area, non-regulated material staging area, and site access roads. Costs to breakdown and remove temporary facilities are based on previous project experience.

3.7 Construction Cost Contingency

The costs presented in this appendix are developed at the FS level and are provided for the purposes of comparison of the level of effort, schedule, and technical elements among the proposed sediment remedial alternatives. Actual costs may be higher or lower than the costs presented in the report—within a range typical of an FS level alternatives analysis (e.g., +50%/ -30%)—due to varying pre-remedy, remedy-implementation, and post-remedy activities, subcontractor costs, and equipment for each alternative (USEPA 2000).

A construction cost contingency of 15% of the sum of direct construction costs is employed. This contingency is lower than the upper end of the recommended contingency by EPA (2000), due to the fact that two independent construction estimates from reputable national contractors were used to validate and confirm cost assumptions and estimates. The two contractors conducted independent site visits, met with the FS team, and relied on their experience on similar site environments, prior to developing their own independent estimates.

4 Recurring Costs

Recurring costs include O&M and monitoring costs, applied after remedy implementation. Depending on the alternative, long-term monitoring (LTM) of cap areas, LTM of thin layer cover areas, and of marsh restoration components of the remedy may be specified.

The cost for the LTM program has been estimated in this analysis as 15% of the total direct cost of each of the operations (cap, thin layer cover and/or marsh restoration) of the alternative.

Conceptually, the LTM program would consist of:

- Physical monitoring of the capped areas at seven scheduled events (years 1, 3, 5, 10, 15, 20, 30) during the initial thirty years following construction.
- Physical monitoring of the thin layer cover areas at four scheduled events (years 1, 3, 5, 10) during the initial ten years following construction.
- Physical and biological monitoring of the marsh restoration areas at four scheduled events (years 1, 3, 5, 10) during the initial ten years following construction;
- Two monitoring events following potential storm events of a predetermined return interval.

5 Summary of Cost estimates

A summary of total costs associated with each alternative is presented in **Table G6**. The detailed FS cost sheets for Alternative 2 through Alternative 6 are presented in **Tables G7** through **G11**.

6 References

USEPA (U. S. Environmental Protection Agency). 2000. A Guidance to Developing and Documenting Cost Estimates During the Feasibility Study. Office of Emergency and Remedial Response. Washington DC. EPA 540-R-00-002/OSWER 9355.0-75.

Tables

Table G1
Summary of Remedy Alternatives
LCP Chemical, Brunswick, GA

Alternative		Remediation Area (Acres)	Dredge Volume (CY)
No Action			
ALT 1	No action	N/A	N/A
SMA-1 (48 Acres)			
ALT 2	Dredge & Backfill: all areas	47.5	142,800
ALT 3	Dredge & Backfill: LCP Ditch, Eastern Creek, and Western Creek Complex	8.2	26,800
	Cap: Domain 3 Creek, Purvis Creek North, and Purvis Creek South	16	
	Thin cover: Dillon Duck, Domain 1A, Domain 2, and Domain 3	23.3	
SMA-2 (18 Acres)			
ALT 4	Dredge & Backfill: all areas	17.6	56,690
ALT 5	Dredge & Backfill: LCP Ditch and Eastern Creek	6.5	21,620
	Cap: Domain 3 Creek	3	
	Thin cover: Dillon Duck, Domain 1A, and Domain 2	8.1	
SMA-3 (24 Acres)			
ALT 6	Dredge & Backfill: LCP Ditch and Eastern Creek	6.5	21,620
	Cap: Domain 3 Creek and Purvis Creek South	6	
	Thin cover: Domain 1A, Domain 2, and Dillon Duck	11.1	

ALT: alternative
N/A: not applicable
cy: cubic yard

Table G2
Access Road and Dewatering/Staging Area Footprint
LCP Chemical, Brunswick, GA

Alternative	Access Road and Dewatering/Staging Area Footprint (Acres)
ALT 2	21.6
ALT 3	15.6
ALT 4	13.9
ALT 5	11.3
ALT 6	12.5

Table G3
Production Rates for Mechanical Dredging
LCP Chemical, Brunswick, GA

Task	**Production Rate**	**Units**
Mechanical Dredge – Deep water	430	CY/day
Mechanical Dredge – Shallow water/marsh	350	CY/day
Mechanical placement of backfill	430	CY/day

CY/day: cubic yards per day

Table G4
Cap Production Rates
LCP Chemical, Brunswick, GA

Task	Production Rate	Units
Mechanical placement of Sand Cap – Deep water	350	CY/day
Mechanical placement of Sand Cap – Shallow water/marsh	230	CY/day
Mechanical placement of Armor Stone Cap – Deep water	280	CY/day
Mechanical placement of Armor Stone Cap – Shallow water/marsh	190	CY/day

CY/day: cubic yards per day

Table G5
Thin Layer Cover Production Rate
LCP Chemical, Brunswick, GA

Task	Production Rate	Units
Thin Layer Cover	170	CY/day

CY/day: cubic yards per day

Table G6
Summary FS Costs for Remedial Alternatives
LCP Chemical, Brunswick, GA

Alternative		Area (Acres)	Total Estimated Cost (Present Day $M)	Estimated Cost per Acre (Present Day $M/Acre)
No Action				
ALT 1	No action	N/A	N/A	N/A
SMA-1 (48 Acres)				
ALT 2	Dredge: all areas	47.5	$64.80	1.37
ALT 3	Dredge: LCP Ditch, Eastern Creek, and Western Creek Complex	8.2	$38.70	0.82
	Cap: Domain 3 Creek, Purvis Creek North, and Purvis Creek South	16		
	Thin Cover: Domain 1A, Domain 2, Domain 3, and Dillon Duck	23.3		
SMA-2 (18 Acres)				
ALT 4	Dredge: all areas	17.6	$34.10	1.94
ALT 5	Dredge: LCP Ditch and Eastern Creek	6.5	$26.00	1.48
	Cap: Domain 3 Creek	3		
	Thin Cover: Dillon Duck, Domain 1A, and Domain 2	8.1		
SMA-3 (24 Acres)				
ALT 6	Dredge: LCP Ditch and Eastern Creek	6.5	$28.60	1.21
	Cap: Domain 3 Creek & Purvis Creek South	6		
	Thin Cover: Dillon Duck, Domain 1A, and Domain 2	11.1		

$M: million of dollars
$M/acre: million of dollars per acre
N/A: not applicable

Table G7
Alternative 2 – Feasibility Study Cost Estimate
LCP Chemical, Brunswick, GA

Task		Quantity	Unit	Unit Cost	Total Cost
Indirect Costs					
1.01	Institutional Controls	1	LS	$250,000	$250,000
1.02	Pre-Design Investigations and Reporting	1	LS	$600,000	$600,000
1.03	Remedial Design		8%	$0	$3,884,320
1.04	Construction Management		8%	$0	$3,884,320
Direct Construction Costs					
2.0	Mobilization and Site Preparation	1	LS	$10,957,000	$10,957,000
3.0	Dredging	153,200	CY	$220	$34,215,000
4.0	Capping	0	CY	$0	$0
5.0	Thin Layer Cover	0	CY	$0	$0
6.0	Marsh Restoration	878,000	SF	$3	$2,564,000
7.0	Demobilization and Site Restoration	1	LS	$818,000	$818,000
Recurring Costs					
8.0	Long-term Monitoring of Capping Areas	1	LS	$0	$0
9.0	Long-term Monitoring of Thin Layer Cover Area	1	LS	$0	$0
10.0	Long-term Monitoring of Marsh Restoration Are	1	LS	$385,000	$385,000
			Contingency (15% of TDCC)		$7,283,100
			Total Alternative Cost		**$64,840,740**

CY: cubic yard
LS: lump sum
SF: square foot
TDCC: Total Direct Construction Cost

General notes and assumptions follow Table G11

Table G8
Alternative 3 – Feasibility Study Cost Estimate
LCP Chemical, Brunswick, GA

Task		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Indirect Costs					
1.01	Institutional Controls	1	LS	$250,000	$250,000
1.02	Pre-Design Investigations and Reporting	1	LS	$600,000	$600,000
1.03	Remedial Design		8%	$0	$2,229,760
1.04	Construction Management		8%	$0	$2,229,760
Direct Construction Costs					
2.0	Mobilization and Site Preparation	1	LS	$8,318,000	$8,318,000
3.0	Dredging	26,800	CY	$360	$9,660,000
4.0	Capping	34,850	CY	$120	$4,193,000
5.0	Thin Layer Cover	28,040	CY	$120	$3,233,000
6.0	Marsh Restoration	594,000	SF	$3	$1,734,000
7.0	Demobilization and Site Restoration	1	LS	$734,000	$734,000
Recurring Costs					
8.0	Long-term Monitoring of Capping Areas	1	LS	$629,000	$629,000
9.0	Long-term Monitoring of Thin Layer Cover Area	1	LS	$485,000	$485,000
10.0	Long-term Monitoring of Marsh Restoration Are	1	LS	$260,000	$260,000
				Contingency (15% of TDCC)	$4,180,800
				Total Alternative Cost	**$38,736,320**

CY: cubic yard
LS: lump sum
SF: square foot
TDCC: Total Direct Construction Cost

General notes and assumptions follow Table G11

Table G9
Alternative 4 – Feasibility Study Cost Estimate
LCP Chemical, Brunswick, GA

Task		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Indirect Costs					
1.01	Institutional Controls	1	LS	$250,000	$250,000
1.02	Pre-Design Investigations and Reporting	1	LS	$600,000	$600,000
1.03	Remedial Design		8%	$0	$2,014,800
1.04	Construction Management		8%	$0	$2,014,800
Direct Construction Costs					
2.0	Mobilization and Site Preparation	1	LS	$7,233,000	$7,233,000
3.0	Dredging	56,700	CY	$270	$15,527,000
4.0	Capping	0	CY	$0	$0
5.0	Thin Layer Cover	0	CY	$0	$0
6.0	Marsh Restoration	571,000	SF	$3	$1,713,000
7.0	Demobilization and Site Restoration	1	LS	$712,000	$712,000
Recurring Costs					
8.0	Long-term Monitoring of Capping Areas	1	LS	$0	$0
9.0	Long-term Monitoring of Thin Layer Cover Area	1	LS	$0	$0
10.0	Long-term Monitoring of Marsh Restoration Are	1	LS	$257,000	$257,000
				Contingency (15% of TDCC)	$3,777,750
				Total Alternative Cost	**$34,099,350**

CY: cubic yard
LS: lump sum
SF: square foot
TDCC: Total Direct Construction Cost

General notes and assumptions follow Table G11

Table G10
Alternative 5 – Feasibility Study Cost Estimate
LCP Chemical, Brunswick, GA

Task	Quantity	Unit	Unit Cost	Total Cost
Indirect Costs				
1.01 Institutional Controls	1	LS	$250,000	$250,000
1.02 Pre-Design Investigations and Reporting	1	LS	$600,000	$600,000
1.03 Remedial Design		8%	$0	$1,508,640
1.04 Construction Management		8%	$0	$1,508,640
Direct Construction Costs				
2.0 Mobilization and Site Preparation	1	LS	$6,345,000	$6,345,000
3.0 Dredging	21,600	CY	$400	$8,670,000
4.0 Capping	7,260	CY	$0	$772,000
5.0 Thin Layer Cover	9,520	CY	$0	$1,128,000
6.0 Marsh Restoration	421,260	SF	$3	$1,264,000
7.0 Demobilization and Site Restoration	1	LS	$679,000	$679,000
Recurring Costs				
8.0 Long-term Monitoring of Capping Areas	1	LS	$116,000	$116,000
9.0 Long-term Monitoring of Thin Layer Cover Areas	1	LS	$169,000	$169,000
10.0 Long-term Monitoring of Marsh Restoration Areas	1	LS	$190,000	$190,000
			Contingency (15% of TDCC)	$2,828,700
			Total Alternative Cost	**$26,028,980**

CY: cubic yard
LS: lump sum
SF: square foot
TDCC: Total Direct Construction Cost

General notes and assumptions follow Table G11

Table G11
Alternative 6 – Feasibility Study Cost Estimate
LCP Chemical, Brunswick, GA

Task		**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
Indirect Costs					
1.01	Institutional Controls	1	LS	$250,000	$250,000
1.02	Pre-Design Investigations and Reporting	1	LS	$600,000	$600,000
1.03	Remedial Design		8%	$0	$1,653,280
1.04	Construction Management		8%	$0	$1,653,280
Direct Construction Costs					
2.0	Mobilization and Site Preparation	1	LS	$6,888,000	$6,888,000
3.0	Dredging	21,600	CY	$400	$8,604,000
4.0	Capping	13,790	CY	$0	$1,570,000
5.0	Thin Layer Cover	13,190	CY	$0	$1,505,000
6.0	Marsh Restoration	471,000	SF	$3	$1,408,000
7.0	Demobilization and Site Restoration	1	LS	$691,000	$691,000
Recurring Costs					
8.0	Long-term Monitoring of Capping Areas	1	LS	$236,000	$236,000
9.0	Long-term Monitoring of Thin Layer Cover Areas	1	LS	$226,000	$226,000
10.0	Long-term Monitoring of Marsh Restoration Area	1	LS	$211,000	$211,000
				Contingency (15% of TDCC)	$3,099,900
				Total Alternative Cost	**$28,595,460**

CY: cubic yard
LS: lump sum
SF: square foot
TDCC: Total Direct Construction Cost

General notes and assumptions follow Table G11

Feasibility Study Cost Estimate Assumptions
LCP Chemical, Brunswick, GA

General Notes

- All costs are provided in present day dollars and all cost expenditures are assumed to occur at the start of construction.
- Work is to be conducted 5 days per week, 12 hours per day. Work is to be conducted year round with no planned interruptions in operations.
- Costs do not include property costs (where applicable), access costs, legal fees, Agency oversight, or public relations efforts.
- These costs have been developed using currently available information regarding site characteristics, such as site bathymetry, potential debris, and physical properties of the existing sediment at the site. As information regarding these site characteristics changes or new information becomes available, these costs will be subject to change.
- These estimates are developed using current and generally accepted engineering cost estimation methods. Note that these estimates are based on assumptions concerning future events and actual costs may be affected by known and unknown risks including, but not limited to, changes in general economic and business conditions, site conditions that were unknown to Anchor QEA, LLC at the time the estimates were performed, future changes in site conditions, regulatory or enforcement policy changes, and delays in performance. Actual costs may vary from these estimates and such variations may be material. Anchor QEA, LLC is not licensed as accountants, or securities attorneys, and, therefore, make no representations that these costs form an appropriate basis for complying with financial reporting requirements for such costs.

Assumptions:

1.01 Institutional controls include deed restrictions, navigational controls and signage installation as deemed necessary.

1.02 Pre-design investigation includes all sampling, analysis and design work to be conducted prior to construction.

1.03 Remedial design work includes all plans, specifications and reporting necessary for construction to be implemented at the site. This has been preliminarily estimated as 8% of the direct construction costs based on best engineering judgment and previous experience at similar sites.

1.04 Construction management costs include necessary monitoring and oversight throughout construction. This includes only elevation verification after excavation, surface WQ measurement during dredging, and post backfill verification that the surface layer is clean. This cost has been preliminarily estimated as 8% of the direct construction costs based on best engineering judgment and previous experience at similar sites.

2.0 Mobilization and site preparation includes all pre-construction submittals and bonds. Also includes construction of temporary facilities, access roads, staging areas, mooring facilities and installation of soil erosion and sediment controls. Includes all costs necessary to mobilize construction equipment and general construction support materials necessary to complete the work.

3.0 Dredging costs include all equipment, labor, and materials necessary to perform the sediment removal operations at the site. Variations in dredging costs have been developed to account for adjustments in sediment disposal characterization, removal methodology due to site conditions and limited working times due to tidal cycles. Costs for sediment dewatering and disposal are also included in this task and vary depending on material characterization. This task also includes costs associated with turbidity controls, turbidity monitoring, health and safety oversight, and site surveying.

4.0 Capping costs include all equipment, labor, and materials necessary to perform the capping operations. Costs for delivery and placement of the cap components are included and placement cost variations have been developed to account for variable site conditions which impact production of this task. Also includes costs associated with turbidity monitoring and health and safety oversight.

5.0 Thin layer cover costs include all equipment, labor and materials necessary to perform the thin cover placement operations. Costs for delivery and placement of the cover material is included. It is assumed that thin cover placement will be conducted utilizing a pipeline transport system to delivery the slurried cover materials. Also includes costs associated with turbidity monitoring and health and safety oversight.

6.0 Marsh restoration costs include all equipment, labor and materials necessary to perform the restoration activities over the area impacted by the construction of access roads. Assumes that general plantings will be spaced on 2-foot centers over the restoration area.

7.0 Demobilization and site restoration involves removing equipment, materials, and labor from the site and restoring all disturbed areas to conditions similar to those existing prior to the start of construction. Disturbed areas include, at a minimum the two constructed staging areas, access roads, temporary site facilities, and temporary mooring facilities. It is assumed that only the top 2 inches of gravel on the access roads will be transported off site for disposal and that all remaining road fill material will be utilized in the remedy to the extent possible.

8.0 The cost for cap monitoringhas been estimated in this analysis as 15% of the total direct capping cost of the alternative.

9.0 The cost for thin layer cover monitoring has been estimated in this analysis as 15% of the total direct thin layer cover cost of the alternative.

10.0 The cost for marsh restoration monitoring has been estimated in this analysis as 15% of the total direct marsh restoration cost of the alternative.

Appendix H
Preliminary Chemical Isolation Modeling

LCP Chemical Superfund Site,
Operable Unit No. 1 (Estuary)
Brunswick, Georgia

Responsible Parties:
Honeywell

Atlantic Richfield Company

Georgia Power Company

Prepared by:
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ENVIRON International Corporation

Date:

March 29, 2013

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List of Acronyms and Abbreviations

f_{OC}	fraction organic carbon
FS	Feasibility Study
K_d	equilibrium partitioning coefficient
K_{OC}	organic carbon partitioning coefficient
L/kg	liters per kilogram
mg/kg	milligrams per kilogram
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
RGO	Remedial Goal Option
Site	LPC Site located in Brunswick, Georgia
SWAC	surface weighted average concentration
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency

1 Executive Summary

Model simulations were performed to evaluate the effectiveness of capping as a remedy to address the contaminated sediments at Operable Unit 1 of the LCP Site located in Brunswick, Georgia. These simulations were performed in accordance with the U.S. Environmental Protection Agency (USEPA) and U.S. Army Corps of Engineers (USACE) guidance for designing subaqueous caps for aquatic systems (Palermo et al. 1998). A one-dimensional model of chemical transport within sediment caps was used in this analysis. The model was developed by Dr. Danny Reible at the University of Texas (Reible 2012, Lampert and Reible 2009, Go et al. 2009) and has been used on numerous capping sites across the United States.

The modeling described in this appendix provides an appropriate screening-level evaluation of the effectiveness of caps in potential remedial areas. The following conservative assumptions were employed in this screening-level analysis:

- The erosion protection layer was assumed to not contribute to chemical isolation.
- An infinite mass of contaminant is present immediately beneath the cap.
- Maximum-gradient groundwater seepage flux estimates were used to estimate flow conditions through the cap.
- Sediment deposition was ignored.
- Contaminant degradation was ignored.

Under these conservative assumptions, the model predicts that the average concentrations within the biologically active zone of a 6-inch cap, placed with nominal (0.1 percent) total organic carbon (TOC), will remain below the proposed Remedial Goal Options (RGOs) criteria for more than 100 years.

2 Introduction

Preliminary chemical transport modeling was conducted to evaluate the long-term performance of the chemical isolation caps being considered as a component of the various remedial options to address contaminated sediments for Operable Unit 1 of the LCP Site (Site) located in Brunswick, Georgia. Modeling was performed consistent with U.S. Environmental Protection Agency (USEPA) and U.S. Army Corps of Engineers (USACE) guidance for designing subaqueous caps for aquatic systems (Palermo et al. 1998).

The chemical isolation layer is being designed to prevent the long-term transport of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and metals (mercury and lead) into the bioavailable layer at the cap surface (as well as into the overlying water column). Capping as a remedial option is being evaluated for the following four representative areas at the Site representative of the proposed 48-acre remedy (**Figure H1**):

- Purvis Creek
- Western Creek Complex
- Eastern Creek
- Domain 3 Creek

These areas were evaluated separately based on spatial differences in groundwater flow and chemical concentrations. Though areas to be capped may be modified as more data are evaluated, these areas are considered representative of areas that could be capped under the final remedy. This appendix does not presume to delineate sediment management areas, nor is it intended to define whether or not capping will be employed for each of the areas evaluated. Instead, the intent is to evaluate whether chemical migration through a cap could potentially undermine the use of sediment capping for remediation in the areas identified for this study, and whether design modifications are needed to improve cap effectiveness; minor variations to the extent of these areas should not affect the modeling results presented herein. Thus, the primary goal of modeling was to simulate the transport of chemicals of interest at the Site (i.e., PAHs, PCBs, mercury, and lead) within the chemical isolation component of a cap and to use the model to evaluate the long-term effectiveness of a cap to manage the potential for chemical migration through the cap.

3 Methodology

3.1 Model Framework

The one-dimensional model of chemical transport within sediment caps developed by Dr. Danny Reible at the University of Texas was used for this evaluation (Reible 2012, Lampert and Reible 2009, Go et al. 2009). This model simulates the time-variable fate and transport of chemicals (dissolved and sorbed phases) under the processes of advection, diffusion/dispersion, biodegradation, bioturbation/bioirrigation, and exchange with the overlying surface water. This model has been used to support the evaluation and design of sediment caps at numerous sites around the United States. Details on the model structure and underlying theory and equations are provided in Lampert and Reible (2009), Go et al. (2009), and the USEPA/USACE capping guidance (Palermo et al. 1998).

3.2 Model Setup and Inputs

3.2.1 Model Domain and Layers

A schematic of the sediment and cap profile represented in the model is shown on **Figure H2**.

The conceptual cap design consists of an erosion protection layer (6 inches of fine to coarse gravel) overlying a base layer (6 inches of sand) that will be placed over the native sediment. The uppermost layer is intended to armor the cap so it can resist erosive forces and stresses resulting from flow and tidal current velocities. The erosion protection layer often has some sorptive capacity and provides added separation distance between the contaminated sediments and the cap surface; however, for the chemical isolation modeling performed in this evaluation, the erosion protection layer was conservatively assumed not to contribute to chemical isolation (see **Section 3.3**). Therefore, the cap profile simulated in the model consisted of only 6 inches of base material overlying the contaminated sediments.

The upper portion of a cap comprises the bioturbation zone, which is the depth over which benthic mixing processes are anticipated to occur. For an armored cap, the bioturbation zone would likely be confined to the armored layer and, thus, would not impact the cap base layer; however, for modeling purposes, a 10-centimeter (cm) bioturbation zone within the base layer was assumed. This allows the results of the model to be extrapolated to caps that may not include armoring, including thin-cover placement. The 10-cm bioturbation zone thickness is based on literature, standard practice for cap design (e.g., Clarke et al. 2001, Reible 2012), and the analysis of bioturbation presented in Appendix E1 of this Feasibility Study (FS).

3.3 Model Input Parameters

Input parameters for the cap model were based on Site-specific data, such as sediment concentrations, total organic carbon (TOC) measurements, and groundwater parameters from previous evaluations at the Site, as well as information derived from literature and experience with cap design at other sites. Several conservative assumptions were incorporated into the model for the purposes of this screening-level analysis. If results indicate that the cap is sufficiently protective despite the use of the following conservative assumptions, then no further adjustment of the model is needed. Alternatively, if results indicate insufficient protection of surface sediment and surface water, then one or more of the following conservative assumptions may be challenged so the model better represents the actual conditions at the Site:

- The armor layer was assumed to not contribute to chemical isolation, when in reality it would provide added separation distance between contaminated sediments and the cap surface, which would enhance cap performance by decreasing diffusive flux.
- A 10-cm bioturbation layer was assumed, regardless of whether the 6 inches of armoring would limit or prevent bioturbation into the base layer.
- No further deposition of sediment was assumed to occur following cap placement. Deposition would further limit chemical transport into the bioavailable surface layer by adding new sediment to the cap surface; however, this is not an overly conservative assumption because deposition at the Site is relatively slow.
- Chemical and biological degradation of PAHs and PCBs within the cap was ignored. Some level of chemical or biodegradation is to be expected in these systems, particularly for methylmercury, which is unstable under oxidized conditions and for the lower-molecular-weight PAH compounds that are more likely to migrate into a cap and are relatively biodegradable.
- Groundwater seepage flux estimates were based on values that reflect low-tide conditions when the gradient towards the surface water is largest. These conditions represent the highest groundwater gradient and, thus, the greatest groundwater flow potential through the cap. In reality, groundwater seepage flux at the Site would be much less due to tide ranges. In fact, during high tide, when tide elevations are above groundwater elevations, flow is reversed (i.e., flow moves in a downward direction), which results in a reduced average groundwater gradient.
- An infinite mass of chemical immediately beneath the cap was assumed for the model. In reality, the mass of chemicals is finite and will reduce over time.

A description of the approach used to develop the key model input parameters is provided in the following subsections.

3.3.1.1 Diffusion and Partitioning Coefficients

The molecular diffusivity of each compound is a required model input parameter. To obtain values for the 21 chemicals modeled, the correlation identified from Schwarzenbach et al. (1993) relating diffusivity to a compound’s molecular weight was used. The model calculates an effective diffusion coefficient using the chemical-specific input value for the molecular diffusivity and an empirical equation based on the material porosity using the approach developed by Millington and Quirk (1961). Diffusivity values for each chemical are presented in **Table H1**.

Partitioning of chemicals between the dissolved and sorbed (i.e., native and cap material) phases is described in the model by the chemical-specific equilibrium partitioning coefficient (K_d). For PAHs and PCBs, the partitioning coefficient is calculated in the model based on the customary $K_d = f_{OC}*K_{OC}$ approach (e.g., Karickhoff 1984), where K_{OC} is the compound’s organic carbon partitioning coefficient and f_{OC} is the organic carbon fraction of the solid phase (i.e., cap material). K_{OC} was set to literature-based values for each compound (USEPA 2012), and K_d was calculated by the model, as previously described based on the K_{OC} and the cap material f_{OC} (see below). For mercury and lead, the f_{OC} was not considered in the partition coefficient, because organic carbon is not the dominant sorbent within sediments for metals. For mercury, a log K_d value near the low end of the range of literature values (i.e., 3.8 to 6.0 liters per kilogram [L/kg]; Lyon et al. 1997, Hintelmann and Harris 2004, Allison and Allison 2005) was conservatively used in the model to allow for greater contaminant mobility in the cap. The literature provides an even wider range of log K_d values for lead (e.g., 2.0 to 7.0 L/kg; Allison and Allison 2005); given that the literature range is large, it seemed more appropriate to use a value in the model that is in the middle of that range for lead. The partitioning coefficients used in the model are listed in **Table H1**.

3.3.1.2 Initial Porewater Concentrations

The initial porewater concentration defines the source term in the model and represents the concentration of each chemical of interest in the porewater of the native sediment beneath the cap. Porewater concentrations in sediment were calculated based on partitioning theory, using bulk sediment concentrations (organic carbon normalized for PAHs and PCBs) measured in the areas evaluated for capping and an estimate of the partitioning coefficient for each chemical. To simplify this analysis, the cap modeling evaluation was performed for a representative remedial footprint that includes Purvis Creek, Domain 3 Creek, Eastern Creek, and Western Creek Complex (**Figure H1**). Concentrations from samples within this remedial footprint were used in this evaluation.

Within each of the four areas evaluated, average and maximum porewater concentrations for mercury and PCBs (measured as Aroclor 1268) were computed and used in the model. Use of an average concentration is consistent with the proposed Site-specific cleanup criteria for these two chemicals that are expressed as a surface weighted average concentration (SWAC), whereas use of a maximum concentration is consistent with the secondary proposed Site-specific cleanup criteria for these two chemicals that are expressed on a point-by-point basis for the benthic community Remedial Goal Option (RGO). For lead and PAHs, maximum calculated porewater concentrations for each of the four areas evaluated were used in the model, because the proposed Site-specific cleanup criteria for these two chemicals are expressed on a point-by-point basis. Because of the wide range of properties associated with individual PAHs, total PAHs were evaluated in the model by simulating 18 individual PAH compounds and summing the results. This approach is considered appropriate because the intent of these evaluations is to perform a preliminary evaluation of capping as an effective remedial alternative.

Table H2 lists the porewater concentrations used as the model input for the 21 chemicals (i.e., Aroclor 1268 PCBs, mercury, 18 individual PAHs, and lead) in each of the four areas evaluated. These inputs were developed using the concentrations from samples collected within the capping footprint evaluated.

3.3.1.3 Groundwater Seepage Velocity

There are no direct measurements of groundwater seepage flux through the sediments at the Site; therefore, estimates were developed based on available information on groundwater conditions at the Site. Groundwater flux within the sediments is expected to vary with tidal conditions; the difference between low and high tide is approximately 9 feet at the Site (ENVIRON and Anchor QEA 2012). The groundwater hydraulic gradient within the sediments is upwards during low tide (i.e., potential for upward flow), and downwards during high tide (i.e., potential for downward flow).

Groundwater flux was estimated under low-tide conditions using Darcy's Law, applying a range of Site-specific hydraulic gradients (between 0.1 and 0.6), which were based on measurement of sediment thickness (EPS and ENVIRON 2012), head in sediments (EPS 2007, WMH 2006), and a hydraulic conductivity ranging from 1.8E-08 to 1.3E-07 centimeters per second.The hydraulic conductivity values are based on Site-specific values derived from marsh clay laboratory permeability results (Geosyntec 1997). The most conservative groundwater seepage fluxes resulting from the range of Darcy velocities calculated from the range of hydraulic conductivities and hydraulic gradients were used in the cap model for each respective area modeled, as listed in **Table H3**. These values are also conservative because they do not account for the fact that during high tide the gradient is reversed, producing a long-term average groundwater flux that would be less than the low tide estimate.

Groundwater transport within the sediments and within a cap is expected to be influenced by tidal action, which results in daily reversals in hydraulic gradient. In the cap model, the hydrodynamic dispersivity was set to 20 percent of the model domain length (i.e., 20 percent of the 6-inch cap thickness) to represent the gradient reversals as a dispersion process, which is a common approach used for representing tidal effects in the groundwater-surface water transition zone (Cooper et al. 1964). Typically, in the absence of flow reversals, when modeling flow through porous media, dispersion is set to between 1 and 10 percent of the model domain (e.g., Gelhar et al. 1992, Neuman 1990); because the value of 20 percent used in the base case modeling to represent tidal action is uncertain, sensitivity to this parameter was assessed.

3.3.1.4 Organic Carbon

The f_{OC} of the bioturbation zone used in the model was based on the assumption that sediments with an organic content similar to the current surface sediments would settle on the surface of the cap and be mixed into its surficial layer over time; therefore, the f_{OC} in the bioturbation zone was set to the average of the Site-specific TOC measurements from sediments collected within each area evaluated for capping. The f_{OC} of the cap's chemical isolation layer is dependent on the material evaluated. For sand isolation material, the f_{OC} was set to a nominal value of 0.1 percent based on experience from other projects.

3.3.1.5 Input Summary

The model input parameters previously described, as well as others, are listed in **Table H3**.

4 Model Application Approach

The chemical transport model previously described was used to predict sorbed-phase concentrations at the cap surface (expressed as a vertical average within the 10-cm bioturbation zone) over a 100-year simulation period. The model-predicted concentrations were compared to the following potential criteria to evaluate cap effectiveness:

- Mercury
  - 1 milligram per kilogram (mg/kg; SWAC RGO)
  - 4 mg/kg (Benthic Community RGO)
- PCBs, measured as Aroclor 1268
  - 2 mg/kg (SWAC RGO)
  - 6 mg/kg (Benthic Community RGO)
- Lead
  - 90 mg/kg (Benthic Community RGO)
- Total PAH
  - 4 mg/kg (Benthic Community RGO); individual PAH concentrations predicted by the model were summed to calculate total PAHs for comparison to the criterion

The values used for comparison with the model results represent the low-end of the range of RGOs employed in the FS. Higher values may be permitted, depending on the outcome of the model. Furthermore, whereas a 6-inch chemical isolation layer consisting of sand was simulated, if necessary, the TOC content in the isolation cap material and/or the cap thickness may be modified to achieve the criteria within the surface of the cap.

5 Model Results

Results of the cap modeling indicated that a 6-inch isolation layer with nominal TOC (approximately 0.1 percent) would be protective for more than 100 years (**Table H4**). Model-predicted average sorbed-phase concentrations over the bioturbation zone for lead, mercury (average and maximum scenario), and Aroclor 1268 (maximum and average scenario) were very small (essentially zero) at the end of the 100-year simulation. Average Total PAH sorbed-phase concentrations over the bioturbation zone at 100 years were 1.2 mg/kg in Eastern Creek, 3.5 mg/kg in Domain 3 Creek, 0.35 mg/kg in Western Creek Complex, and 1.2 mg/kg in Purvis Creek.

Modeling runs with longer simulation times were conducted to assess breakthrough time. The results of this additional modeling effort indicated that the model-predicted concentrations would not exceed the proposed criteria after more than 500 years.

The modeling in Domain 3 Creek also was performed using a dispersivity of 50 percent of the cap thickness, rather than the 20 percent value used in the base case modeling. The Domain 3 Creek was selected for this sensitivity analysis because calculated average sorbed concentrations are highest in this remedial area and closest to the proposed target concentration of 4 mg/kg. The results of this sensitivity analysis indicated that the cap would still be protective after 100 years.

6 Summary

Consistent with USEPA and USACE guidance for designing subaqueous caps, a one-dimensional model of chemical transport within sediment caps was used to evaluate the effectiveness of potential caps in four representative areas of the Site. The model was configured to represent Site conditions based on available data, literature, and experience from other sites; several conservative assumptions were included in this evaluation. The model predicted that a 6-inch cap with nominal TOC (approximately 0.1 percent) would be effective in isolating the contaminants in situ. Average concentrations at the surface of the cap were predicted to remain below the lowest end of the proposed chemical-concentration range targeted for benthic receptors, for hundreds of years.

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TABLES

Table H1
Partitioning Coefficients and Diffusivity Values
LCP Chemical, Brunswick, GA

Chemical Group	Chemical	CAS Number	log K_{OC} (organics)	log K_d (metals)	Water Diffusivity
			(log L/kg)	(log L/kg)	(cm^2/s)
PAH	1-Methyl Naphthalene	90-12-0	3.4		8.00E-06
PAH	2-Methylnaphthalene	91-57-6	3.4		8.00E-06
PAH	Acenaphthene	83-32-9	3.7		7.60E-06
PAH	Acenaphthylene	208-96-8	3.7		7.60E-06
PAH	Anthracene	120-12-7	4.2		6.80E-06
PAH	Benzo(a)anthracene	56-55-3	5.2		5.70E-06
PAH	Benzo(a)pyrene	50-32-8	5.8		5.30E-06
PAH	Benzo(b)fluoranthene	205-99-2	5.8	-	5.30E-06
PAH	Benzo(g,h,i)perylene	191-24-2	6.3	-	5.00E-06
PAH	Benzo(k)fluoranthene	207-08-9	5.8	-	5.30E-06
PAH	Chrysene	218-01-9	5.3	-	5.70E-06
PAH	Dibenzo(a,h)anthracene	53-70-3	6.3	-	5.00E-06
PAH	Fluoranthene	206-44-0	4.7	-	6.20E-06
PAH	Fluorene	86-73-7	4	-	7.20E-06
PAH	Indeno(1,2,3-cd)pyrene	193-39-5	6.3	-	5.00E-06
PAH	Naphthalene	91-20-3	3.2	-	8.60E-06
PAH	Phenanthrene	85-01-8	4.2	-	6.80E-06
PAH	Pyrene	129-00-0	4.7	-	6.20E-06
Metal	Lead	007439-92-1	-	4.6	6.10E-06
Metal	Mercury	7439-97-6	-	4	6.30E-06
PCB	Aroclor 1268	11100-14-4	7.4	-	3.50E-06

CAS: Chemical Abstracts Service
cm^2/s: square centimeters per second
L/kg: liters per kilogram

Table H2
Initial Porewater Concentrations
LCP Chemical, Brunswick, GA

Chemical	Porewater Concentration (µg/L)			
	Purvis Creek	**Domain 3 Creek**	**Eastern Creek**	**Western Creek**
Aroclor 1268 (average concentration)	0.018	0.002	0.055	0.006
Aroclor 1268 (maximum concentration)	0.064	0.014	2.6	0.021
Lead (maximum concentration)	0.98	163	19	1.3
Mercury (average concentration)	0.45	0.38	2.4	0.44
Mercury (maximum concentration)	4	2	28	1.6
PAHs (from sample with maximum total PAH porewater concentration from each area)				
1-Methyl Naphthalene	0	0	0	0
2-Methylnaphthalene	17	0	14	4.2
Acenaphthene	8.2	11	7.1	2
Acenaphthylene	8.2	0.2	7.1	2
Anthracene	2.5	3.2	2.2	0.63
Benzo(a)anthracene	0.23	0.23	0.2	0.058
Benzo(a)pyrene	0.07	0.049	0.061	0.018
Benzo(b)fluoranthene	0.069	0.04	0.06	0.017
Benzo(g,h,i)perylene	0.021	0.013	0.018	0.0053
Benzo(k)fluoranthene	0.07	0.01	0.061	0.018
Chrysene	0.23	0.45	0.2	0.057
Dibenzo(a,h)anthracene	0.022	0.0029	0.019	0.0054
Fluoranthene	0.75	1.4	0.64	0.074
Fluorene	4.5	12	3.9	1.1
Indeno(1,2,3-cd)pyrene	0.021	0.0049	0.018	0.0053
Naphthalene	27	86	23	6.7
Phenanthrene	2.5	26	2.1	0.62
Pyrene	0.76	6.2	0.66	0.11
Total PAHs	72	147	62	18

µg/L: micrograms per liter

Table H3
Input Parameter Values for the Chemical Isolation Cap Model
LCP Chemical, Brunswick, GA

Model Input Parameter	**Value**	**Data Source**
Chemical-specific Properties		
Organic carbon partitioning coefficient, log K_{OC} (log L/kg)	See Table 1	Log K_{OC} values from USEPA's EPI Suite – KOCWIN MCI log K_{OC} (USEPA 2012)
Partitioning coefficient, log K_d (log L/kg)	See Table 1	Based on values reported in literature as discussed in Section 2.3.1.1 (Lyon et al. 1997, Hintelmann and Harris 2004, Allison and Allison 2005, USEPA 2012)
Water diffusivity (cm^2/s)	See Table 1	Calculated based on the molecular weight of the compound using the correlation identified from Schwarzenbach et al. (1993) as discussed in Section 2.3.1.1
Chemical biodegradation rate	0	Assumed no degradation, which is conservative for PAHs, which have been shown to degrade in sediments
Initial chemical porewater concentration (µg/L)	See Table 2	Calculated from sediment samples within the capping areas and partitioning theory
Cap Properties		
Total Cap thickness (cm)	15.24	Design parameter; started with 6 inches of sand; refined as necessary based on results
Particle density (g/cm^3)	2.6	Typical value for inorganic particles (e.g., Domenico and Schwartz 1990)
Porosity	0.4	Typical value for sand (e.g., Domenico and Schwartz 1990)
Fraction organic carbon of cap material (%)	Variable	Started with nominal value (0.1%); refined as necessary based on results
Fraction organic carbon of bioturbation zone (%)	Domain 3 Creek: 5.1%	Based on the current surface sediment averages
	Eastern Creek: 4.3%	
	Western Creek Complex: 5.2%	
	Purvis Creek: 3.8%	

Table H3
Input Parameter Values for the Chemical Isolation Cap Model
LCP Chemical, Brunswick, GA

Model Input Parameter	Value	Data Source
Mass Transport Properties		
Boundary layer mass transfer coefficient (cm/hr)	0.75	Typical value used for capping design (e.g., Reible 2012); consistent with range of values measured in other systems (e.g., Thibodeaux et al. 2001)
Groundwater seepage Darcy velocity (cm/yr)	Domain 3 Creek: 2.3	Calculated based on Darcy’s Law estimates using low-tide hydraulic gradients based on sediment thicknesses (EPS and ENVIRON May 2012), head in sediments (EPS 2007, WMH 2006), and hydraulic conductivities from previous groundwater evaluations (Geosyntec 1997)
	Eastern Creek, Purvis Creek, and Western Creek Complex: 0.6	
Depositional velocity (cm/yr)	0	Conservatively assumed no sedimentation
Dispersion Length (cm)	3	Calculated based on model domain length (cap thickness); assumed 20% of cap thickness, which is a relatively high value, but was judged appropriate given that gradient reversals associated with tides is approximated as a dispersion process
Bioturbation zone thickness (cm)	10	Typical value for cap design (e.g., Clarke et al. 2001, Reible 2012)
Porewater biodiffusion coefficient (cm^2/yr)	100	Parameter represents bioturbation rate applied to dissolved phase; typical value used for capping design (e.g., Reible 2012, Anchor 2006)
Particle biodiffusion coefficient (cm^2/yr)	1	Parameter represents bioturbation rate applies to particulate phase; typical value used for capping design (e.g., Reible 2012, Anchor 2006)

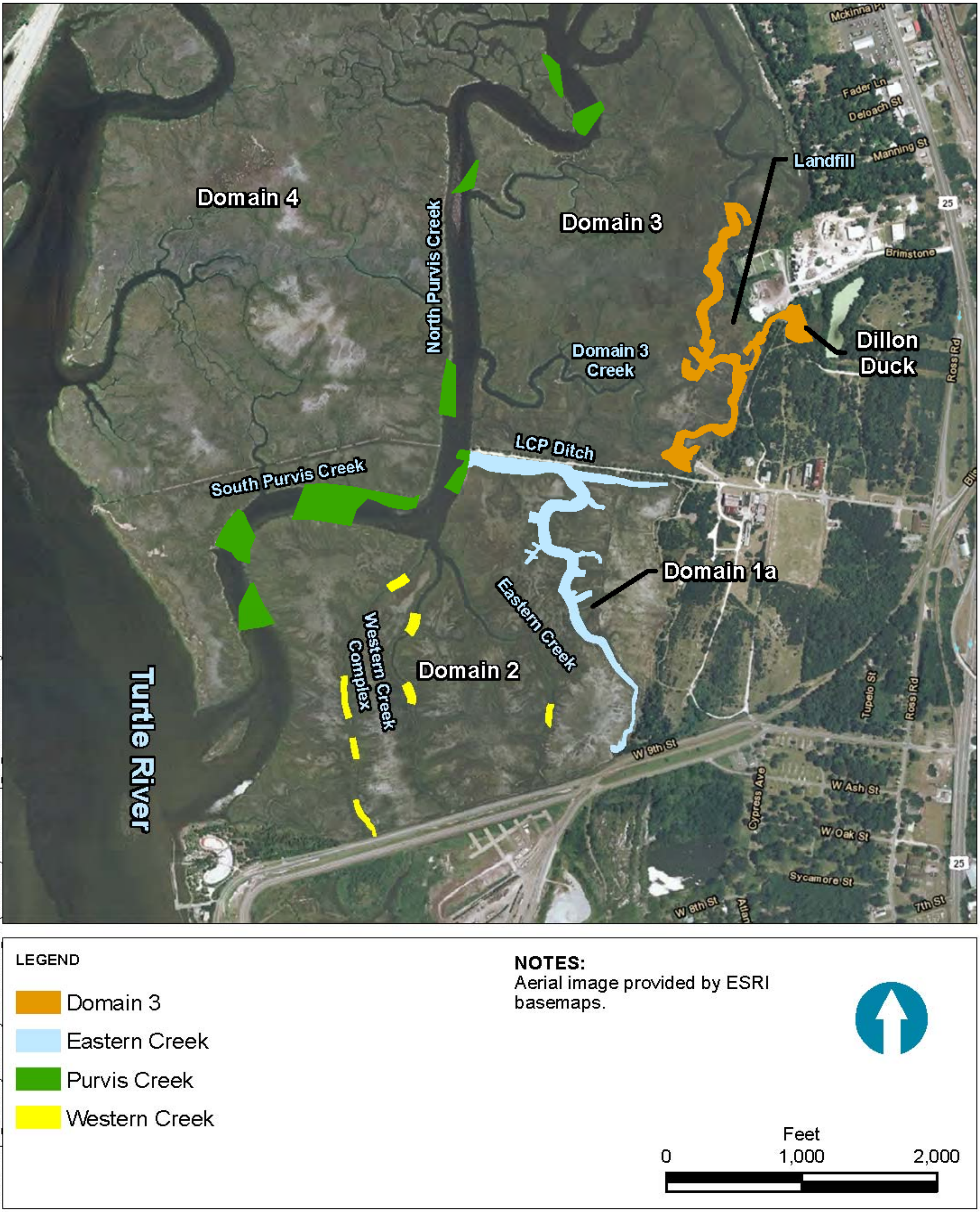
µg/L: micrograms per liter
cm: centimeters
cm/hr: centimeters per hour
cm/yr: centimeters per year
cm^2/s: square centimeters per second
cm^2/yr: square centimeters per year
EPI: Estimation Program Interface
g/cm^3: grams per cubic centimeter
L/kg: liters per kilogram

Table H4
Average Sorbed-phase Concentrations within the Bioturbation Zone at 100 Years
LCP Chemical, Brunswick, GA

Chemical	**Proposed Criteria**	**Average Sorbed-phase Concentrations (mg/kg)**			
		Domain 3 Creek	**Eastern Creek**	**Purvis Creek**	**Western Creek Complex**
1-Methylnaphthalene	-	0	0	0	0
2-Methylnaphthalene	-	0	0.24	0.24	0.074
Acenaphthene	-	0.31	0.17	0.18	0.051
Acenaphthylene	-	5.80E-03	0.17	0.18	0.051
Anthracene	-	0.12	0.069	0.076	0.02
Benz(a)anthracene	-	9.70E-03	6.80E-03	7.70E-03	2.00E-03
Benzo(a)pyrene	-	1.20E-03	1.10E-03	1.20E-03	3.10E-04
Benzo(b)fluoranthene	-	9.30E-04	1.00E-03	1.20E-03	3.00E-04
Benzo(g,h,i)perylene	-	1.60E-05	1.20E-05	1.40E-05	3.50E-06
Benzo(k)fluoranthene	-	2.30E-04	1.10E-03	1.20E-03	3.10E-04
Chrysene	-	0.019	0.0067	0.0075	2.00E-03
Dibenz(a,h)anthracene	-	3.80E-06	1.30E-05	1.50E-05	3.80E-06
Fluoranthene	-	0.056	0.022	0.025	2.60E-03
Fluorene	-	0.41	0.11	0.12	0.033
Indeno(1,2,3-cd)pyrene	-	6.20E-06	1.20E-05	1.40E-05	3.50E-06
Naphthalene	-	1.3	0.28	0.28	0.089
Phenanthrene	-	0.99	0.068	0.075	0.02
Pyrene	-	0.25	0.023	0.025	4.00E-03
Total PAHs	4	3.5	1.2	1.2	0.35
Aroclor 1268 PCBs (Average)	2.0-4.0	0	0	0	0
Aroclor 1268 PCBs (Maximum)	6.0-16	0	0	0	0
Lead	90-177	0	0	0	0
Mercury (Average)	1.0-2.0	0	0	0	0
Mercury (Maximum)	4.0-11	0	0	0	0

mg/kg: milligrams per kilogram

FIGURES



NOTES:
Aerial image provided by ESRI basemaps.

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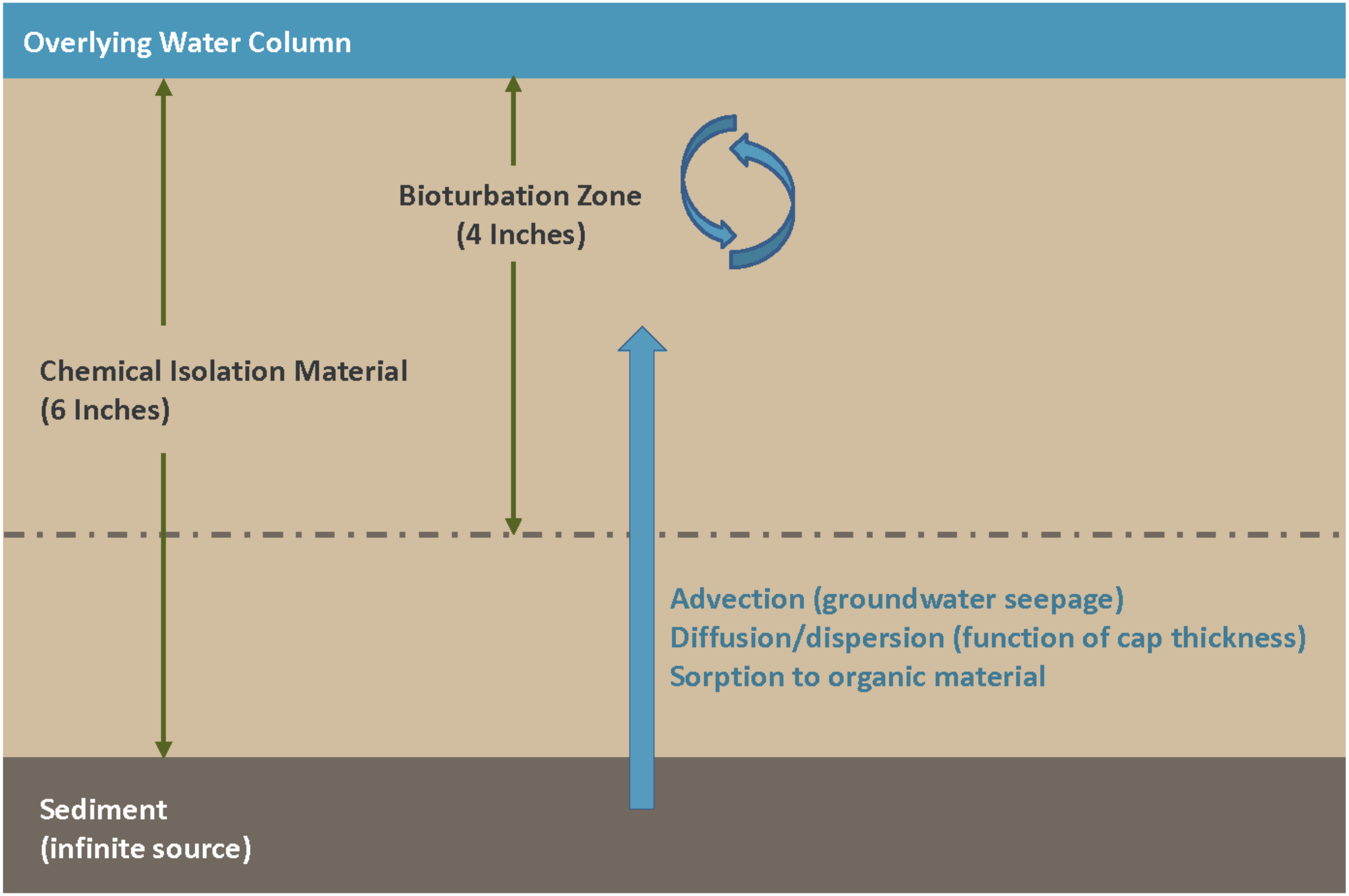
Capping Areas Evaluated with the Model
Appendix H – Preliminary Chemical Isolation Cap Modeling
LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

DRAFT

Figure

H1



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Model Domain and Cap Profile

Appendix H – Preliminary Chemical Isolation Cap Modeling

LCP CHEMICAL SITE
BRUNSWICK, GEORGIA

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Figure

H2